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EU Policy-Based Assessment of the Capacity of Marine Ecosystems to Supply Ecosystem Services

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Contents

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Executive Summary

Our seas and oceans cover more than 70 % of the Earth's surface and support around 30 % of the global Gross Domestic Product (Costanza et al. 2014). They provide over 50 % of the oxygen we breathe, around 17 % of the animal protein we consume annually, and have absorbed about 30 % of the CO_2 emitted from the burning of fossil fuels and other human activities (Lalli & Parsons, 1993; Nadis, 2003; FAO, 2014; IPCC, 2013; EEA, 2014). They also treat our organic wastes, dilute and disperse our inorganic toxic wastes, underpin and/or enhance our recreation and cultural activities, limit the erosion of our coasts, and provide us with energy and building materials – amongst many other outputs. The marine natural resources, living organisms and the physical, chemical, biological and ecological pathways that give rise to these outputs are a massive asset and represent the 'natural capital' of the seas and oceans. This natural capital consists of: 1) the marine living assets in their surrounding environment, i.e. marine ecosystem capital, which includes marine ecosystem services; and 2) the marine non-living assets, i.e. marine abiotic natural capital (e.g. sand and gravel deposits) (cf. Maes et al, 2013; EEA, 2018). Almost 50 % of the area under the jurisdiction of the European Union consists of seas and oceans. The EU Water Framework Directive (EC, 2000), the Marine Strategy Framework Directive (EC, 2008), the EU Biodiversity Strategy to 2020 (EC, 2011) and the 7th Environment Action Programme (EC, 2013), amongst other policy instruments, all recognise the importance of the marine ecosystem capital of Europe's seas and provide policy drivers for its protection.

In recent years, the realisation of the diversity of direct outputs the marine ecosystem delivers to people (i.e. marine ecosystem services), and the fragility of most of these to human pressures, has led to the development of the 'ecosystem approach' as a more holistic way to manage human activities. The ecosystem approach considers all aspects of the system including sustainable human use, multiple sectors, multiple biological aspects, ecosystem services and the interaction between these parts (Crain et al., 2009). Further, multiple management objectives and trade-offs which may occur between ecological, social and economic factors are also considered (Knights et al., 2014). This approach is increasingly accepted as the solution to managing ever-greater human activity in the marine environment and the resulting complex interaction of multiple impacts between system components (e.g. Crain et al., 2009; Tallis et al., 2010, Halpern et al., 2012). Ecosystem-based management is firmly embedded in the environmental policies of the EU and the marine centred policies of the Integrated Maritime Policy (EC, 2007), in particular in its 'environmental pillar': The Marine Strategy Framework Directive.

A framework that can link marine ecosystem components with all the marine ecosystems services they have the potential to supply is essential in progressing towards an ecosystem approach to management. Thus, the aim of this Report is to provide an EU-level marine ecosystem-based assessment approach (i.e. a concept, framework and method) that considers how ecosystem state affects its capacity for the supply of ecosystem services. The outcomes of this assessment can indicate whether marine, and other[1], natural capital is being managed sustainably, and so whether marine ecosystem capital (its biotic component) is being renewed as needed to ensure the continued supply of these services to, and their associated benefits for, people. The approach here is framed by and based on certain EU policy instruments so that the outcomes of the assessment can serve to support their implementation.

This Report describes an approach for a Marine Ecosystem Capacity for Service supply Assessment (MECSA) following on from preliminary work by the European Environment Agency and its European Topic Centre on Inland, Coastal and Marine Waters. It first describes the key elements considered to be a prerequisite for such an assessment, it then explains how these elements led to the development of an assessment method and, finally, it describes and tests the assessment method itself. The approach starts from the perspective that the state of marine ecosystem components can inform us on

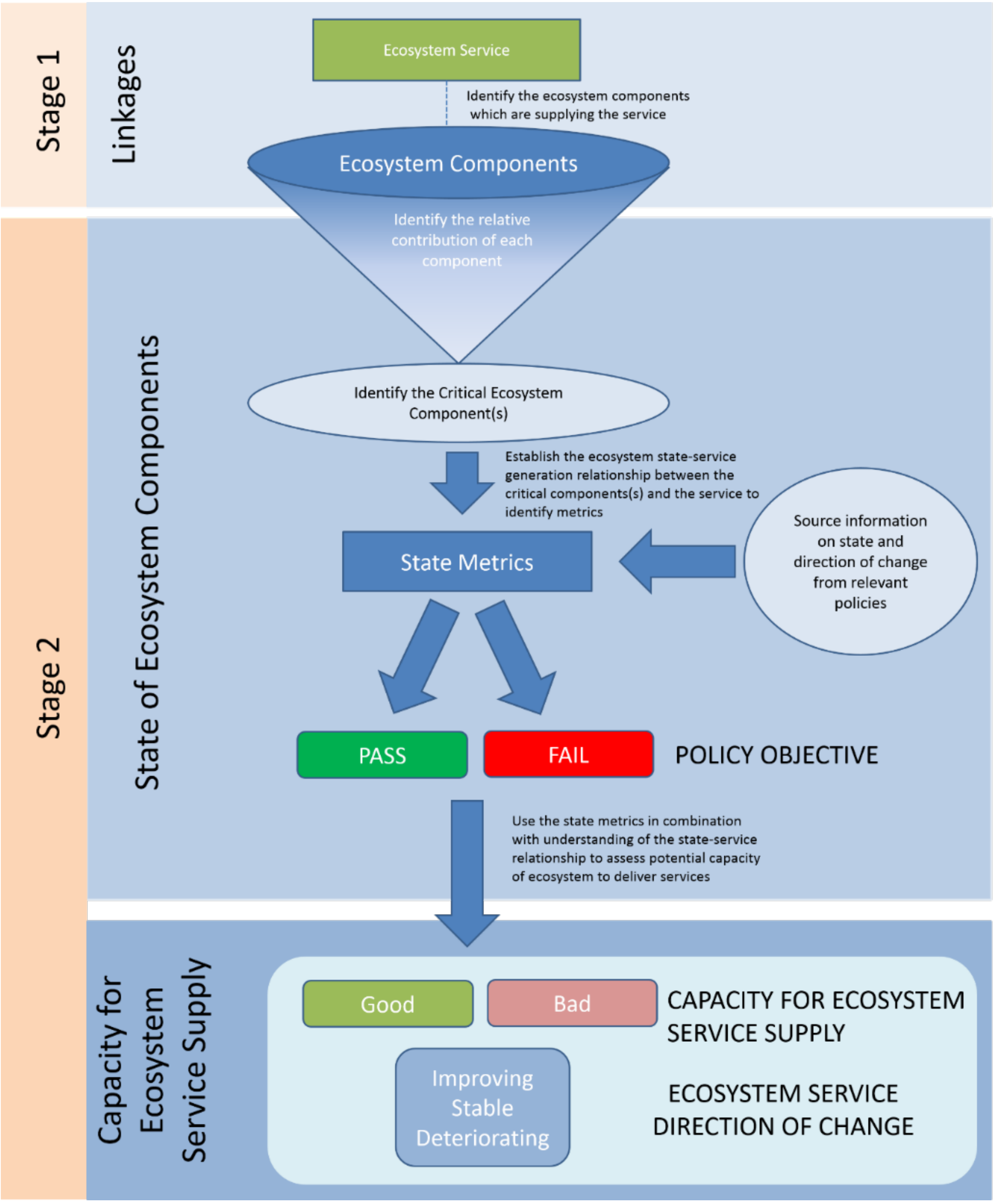
[1] Other natural capital means non-marine natural resources and processes (e.g. terrestrial), and is referred to here as its use can also impact marine ecosystems

the state of marine ecosystem services (specifically on the sustainability of marine ecosystem service supply) through indicating the capacity of marine ecosystems to supply these services (*supply-side* assessment approach). In designing this approach, we set out to present a flexible method that could capture the complexity of the system, but would not be reliant on data-driven or spatially resolved information.

The first prerequisite for the MECSA was a customisation of version 4.3 of the Common International Classification of Ecosystem Services to aid appropriate use of this typology for the assessment of marine ecosystems and their services (Section 2). The second prerequisite for the MECSA was the development of an EU-policy relevant typology of marine ecosystem components as the units holding the ecosystem capacity to supply the marine ecosystem services used in EU marine regions (Section 3).

The MECSA method is broken into two stages (see Figure 0.1 below). Stage 1 of the assessment establishes the linkages between marine ecosystems components and the marine ecosystem services they can supply (Section 4) by considering all possible interactions (in an EU context) between components and services in a qualitative way. A definition of each service is given, followed by a description of which marine ecosystem components can contribute to, or solely hold, the ecosystem capacity to supply that service. Stage 2 of the approach describes the operational steps that link the state of marine ecosystem components to the capacity of the ecosystem to supply marine ecosystem services (Section 5). These operational steps use the Stage 1 outcomes as a starting point and apply a focused approach, using a semi-quantitative critical path analysis to identify the critical ecosystem component(s) contributing to the supply of a given service. Having identified these, the (ecosystem) state-service (generation) relationship is then established, which also serves to identify other parts of the ecosystem that are key for service generation. Policy-relevant information is then utilised to assess the current and, if information is available, the future state as well as the current and future direction of change in the state of all these elements. These assessments are, in turn, interpreted in terms of the (ecosystem) state-service (generation) relationship to determine the current and, where possible, the future state of as well as the current and future direction of change in the capacity of the ecosystem to supply the service (Figure 0.2).

Figure 0.1: The two stages of the assessment of the capacity of marine ecosystems to supply eco-system services described in this Report (see Figure 5.1 main text)



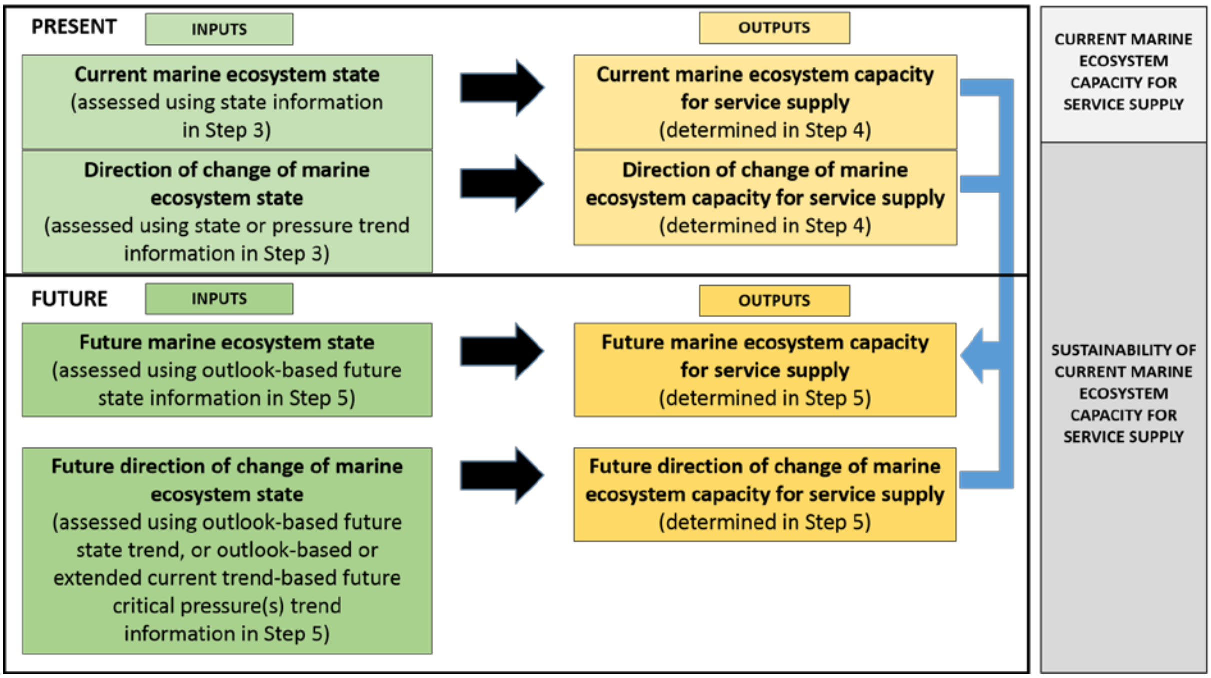
The MECSA approach is built on the following key premises, assumptions or limitations (see Section 6 for full details):

1. The (ecosystem) state-service (generation) relationship is the backbone of the assessment. This relationship aims at reflecting how the state of marine biota, which is dependent on the state of other parts of the ecosystem, including the supporting habitat, leads to the generation and, thus, supply of marine ecosystem services. It, therefore, provides a way to translate marine ecosystem state into marine ecosystem capacity for service supply.
2. Whilst one would ideally always assess the ecosystem capacity for service supply based on the state of marine biota in each specific habitat where they occur, this was not possible due to the resolution of the underlying assessment information. Thus, the assessment method and case studies explored were based on the assessment of the state of marine biota across all relevant habitats within an EU marine region; where the state of other parts of the marine ecosystem (e.g. physico-chemical aspects) was also directly assessed where relevant.
3. ‘Good’ state of marine biota (and of other parts of the ecosystem where relevant) generally means ‘good’ ecosystem capacity for service supply. However, we acknowledge that this is not always the case and that the relationship between ecosystem state and service supply capacity will not always be positive or linear. Thus, the assessment captures the specific (ecosystem) state-service (generation) relationship per service as this would differ for different services.
4. The assessment of the state of marine biota (and of other parts of the ecosystem where relevant) uses existing marine assessment products available at the EU level generated by the implementation of relevant EU, and other, policy, i.e. it is an EU-level assessment based on existing EU-level assessment information.
5. EU-level marine assessment products generated by different pieces of relevant EU, and other, policy are used together to assess the state of marine biota (and of other parts of the ecosystem where relevant).
6. Marine ecosystem capacity for service supply is assessed on a service-by-service basis, i.e. each service is assessed individually.
7. The service supply capacity assessment is carried out at the level of EU marine regions but its outcomes are not bio-physically mapped within a region.

Despite these assumptions and limitations, this Report demonstrates that the MECSA approach can be used to assess the current state, and sustainability, of the capacity of marine ecosystems to supply marine ecosystem services. Furthermore, in being framed by and based on EU policy instruments, the MECSA approach: (1) makes use of the marine ecosystem structures (i.e. species/species groups and habitats) under the scope of existing EU (and other) legislation/policy as well as information on marine ecosystem state generated by these policy instruments (e.g., the Marine Strategy Framework Directive and the Habitats Directive); (2) uses existing knowledge of marine ecosystem functioning to understand how ecosystem state relates to its capacity for service supply; and (3) is applicable at an EU marine regional scale. The three worked examples, in the form of test case assessments, demonstrated that the state of the critical ecosystem components for the supply of those services, combined with our knowledge of how the ecosystem can generate them (including the role of other parts of the ecosystem) could tell us how the capacity for service supply was affected.

The MECSA approach presented in this Report can, therefore, facilitate measuring the effectiveness of policy interventions in achieving *sustainability* of marine ecosystem capacity for service supply at the EU scale by, firstly, establishing a baseline assessment, i.e. the current state of and the direction of change in this capacity; and, secondly, by establishing the future state of and direction of change in this capacity (Figure 0.2).

Figure 0.2: Inputs into and outputs from the assessment of the capacity of marine ecosystems to supply ecosystem services described in this Report (see Figure 5.2 main text)



Notes: Black arrows represent an understanding of the (ecosystem) state-service (generation) relationship. The blue arrow indicates an alternative route to assessing the future ecosystem capacity for service supply, based on first assessing the other three outputs, and then using these to do so.

A key way that this approach can capture the sustainability of marine ecosystem capacity for service supply is through strongly retaining the connection between the state of the marine ecosystem and the supply of marine ecosystem services. Thus, this connection captures the self-regulating/renewing aspects of the ecosystem and ensures that the services which are assessed best reflect those which are likely to change as a result of changes in ecosystem state due to policy interventions (given the above-mentioned use of policy-generated information to assess ecosystem state). A high-level assessment such as this can show where improvements towards the sustained supply of ecosystem services are being made and where efforts are paying off, as well as where further effort is required.

The Report identifies possible areas of future work, including the updating of some of the 'structural elements' of the MECSA approach, e.g., the characterisation and/or classification of marine ecosystem components and marine ecosystem services, for the approach to keep on being one-to-one EU policy-relevant. This is because there have been recent advances in and updates to the relevant EU legislation/policy on which the MECSA approach is based since its development was completed over 2014–2018. Future work also includes exploring risks to service supply capacity and assessing multiple services to better understand the likely co-benefits and/or trade-offs in trying to maintain and/or restore marine ecosystems and, thus, achieve a continued supply of *all* marine ecosystem services. Lastly, this Report puts forward 11 recommendations for future assessments of marine ecosystem capacity for service supply, which focus on the information and knowledge required for such assessments, as well as the scope of the assessments (Section 7).

1 Introduction

1.1 Assessing the state of marine ecosystems in terms of their capacity to supply ecosystem services

Modern societies are increasingly concerned with information and the holding of politicians, leaders of industry and commerce, and others to account on a myriad of topics of relevance to our daily lives. There has therefore been a phenomenal growth in the provision of data, driven in part by technological advances and automated systems, and the presentation of information in accessible formats through the World Wide Web and social media platforms, as well as more traditional publications. While the amount of information and data has increased, technical, scientific data is not always easy to interpret and so there have been initiatives to develop simple descriptors or league tables of evidence/performance. These range from the quality of schools, to the waiting times for a new passport. In the marine environmental sphere these accessible and readable accounts of the state of the environment can be traced back to the North Sea Quality Status reports of the 1980s. The number of such assessment tools and reports has increased since, covering more EU marine regions, particular water bodies and specific groups of marine organisms. However, the number of assessments describing how the state of the marine ecosystem (Box 1.1) is affecting its ability to support human wellbeing, by looking at its capacity to supply ecosystem services, are few; this is more so when considering assessments applied at the EU level.

Box 1.1 Defining marine ecosystem state

Here we use ecosystem **state** as defined by Maes et al. (2013), "the physical, chemical and biological condition of an ecosystem at a particular point in time". This differs to ecosystem **status**, which they define as "a classification of state among several well-defined categories; it is usually measured against time and compared to an agreed target [in relevant EU environmental directives (e.g. HD, WFD, MSFD)]". We refer to 'state' throughout this study, but acknowledge that the term 'condition' can be considered equivalent (*sensu* Maes et al., 2013, 2014). We consider that when thinking about how the state of marine ecosystems affects the capacity of ecosystem components to supply ecosystem services, relevant metrics or indicators of ecosystem state can include (but are not exclusive to) one or more of the following:

- Presence/absence, abundance, distribution, age/size structure, species composition etc. for mobile biotic groups in their habitats, and
- The same, but also including extent (area covered), for sessile species groups (e.g. habitat structuring species) in their habitats.

These metrics/indicators are largely in line with the criteria deemed appropriate to assess marine species groups under the EU Marine Strategy Framework Directive's (MSFD) (EC, 2008) Descriptor 1 (Biodiversity) objective (see part B of Annex in EC, 2010[2]). The MSFD's assessment of the state of species groups based on such criteria leads to a status classification *sensu* 'good environmental status'. In addition, metrics/indicators on the physical and chemical state of marine ecosystems would also be relevant to assess the state of species groups (e.g. nutrient or oxygen concentrations). The same would apply to certain pressure metrics/indicators (e.g. fishing mortality).

We have used these types of metrics/indicators to assess ecosystem state as shown under the description of the assessment method in Section 5.

To add further complexity, much of the reported information we set out to use in applying the assessment method (see 1.1.2 (i) and 1.4.4 below) actually comes from status assessments. Status assessments already interpret the state of such ecosystem metrics/indicators against reference or target conditions, providing a classification that is often interpreted to be equivalent to an assessment of the 'health' of the ecosystem, with good status equating to a 'healthy' ecosystem (see 1.4.4 below). In applying our assessment approach we thus also go on to consider how status assessment information can be interpreted in terms of telling us something about the state of the ecosystem and its capacity to supply ecosystem services.

[2] Note that a revision of the MSFD criteria and methodological standards on 'good environmental status' took place over 2014–2017 through EC (2017)

1.1.1 Aim of this Report

The purpose of this Report is to provide an EU-level marine ecosystem-based assessment approach (i.e. a concept, framework and method) that considers how ecosystem state affects its capacity for the supply of ecosystem services. The outcomes of this assessment can indicate whether marine, and other[3], natural capital is being managed sustainably, and so whether marine ecosystem capital (its biotic component) is being renewed as needed to ensure the continued supply of these services to, and their associated benefits for, people. The approach here is framed by and based on certain EU policy instruments so that the outcomes of the assessment can serve to support their implementation. EU legislation and policy implementation support is one of the roles of the European Environment Agency (EEA), which commissioned and has supported the development of this work[4]. Relevant EU policy drivers include the EU Biodiversity Strategy to 2020 (EC, 2011a) and the 7th Environmental Action Programme (EC, 2013), which include objectives related to the sustainable use of natural capital and/or the protection of ecosystem capital and ecosystem services in the EU to be achieved by 2020 and/or 2050[5].

This Report describes an approach for a Marine Ecosystem Capacity for Service supply Assessment (MECSA) following on from preliminary work by the European Environment Agency and its European Topic Centre on Inland, Coastal and Marine Waters. It first describes the key elements considered to be a prerequisite for such an assessment, it then explains how these elements led to the development of an assessment method and, finally, it describes and tests the assessment method itself. Thus, worked examples in the form of test case assessments are included in Annexes II, III and IV. Parts of the approach have already been published in EEA reports, e.g., EEA (2015) and EEA (2016a).

1.1.2 Key aspects to the scope of the assessment approach in this Report

In order to assess the state of marine ecosystems in terms of their capacity to supply services across the EU, there needs to be a common framework to describe the marine ecosystem and some common definitions for ecosystem services. As the assessment approach designed here is required to be framed by and based on EU policy (one-to-one policy relevant), we work from the EU reference frameworks for the characterisation and classification of both ecosystem services, as provided by CICES (the Common International Classification of Ecosystem Services) (Haines-Young & Potschin, 2013), and ecosystem components, which is the MAES (Mapping and Assessment of Ecosystems and their Services[6])

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[3] Other natural capital means non-marine natural resources and processes (e.g. terrestrial), and is referred to here because its use can also impact marine ecosystems

[4] The majority of the work described in this Report, including its Annexes with the test case assessments, was carried out and completed in 2014 as Culhane et al. (unpublished), with a small refinement of the original Report, but not of the test case assessment Annexes, in 2016 and a more substantial one in 2017 and into 2018 leading to this updated version. These refinements have been limited to specific issues around the 'structural elements' of the assessment approach, such as the characterisation and classification of marine ecosystems and ecosystem services. To note that ongoing reviews of key EU legislation and policy, including associated classifications, over 2016-2018 mean that, in order to keep the approach one-to-one EU policy-relevant, elements of our assessment approach (including some of those 'structural elements' and the information used to test the approach) will need to be updated when used for future/other work. A more detailed discussion on this is given in Section 7.

[5] To note that, at times, high level EU policy, global policy and related initiatives and assessments concerned with natural capital, e.g., the 7th EAP, use a different terminology than done here; where the term 'natural capital' is taken as a synonym of 'ecosystem capital'. In contrast, here, we follow EU-level guidance for the implementation of the EU Biodiversity Strategy (Maes et al., 2013), which includes the stocks and flows of abiotic natural assets (i.e. abiotic natural capital) in the definition of natural capital to illustrate that, even if still 'natural', their use can damage ecosystems indirectly.

[6] Working Group (WG) MAES leads the EU-level process supporting the implementation of Target 2/Action 5 of the EU Biodiversity Strategy to 2020 within the Strategy's Common Implementing Framework.

marine ecosystem typology. The MAES marine ecosystem types are an aggregation of a series of marine habitat types, which are ultimately derived from the MSFD predominant habitat types (Maes et al., 2013). From these frameworks, this study considers the linking of ecosystem components with the ecosystem services they provide.

The CICES typology of ecosystem services is not marine specific, and the MAES marine ecosystem types are broad. As a consequence, a pilot study undertaken in order to test the application of the MAES EU-level conceptual framework for services assessments in a marine context, considered how the MAES marine ecosystem types linked to the CICES typology of services (Maes et al., 2014 using CICES version 4.3). The pilot study produced results that suggested that further work was required to advance the development of both the MAES marine ecosystem typology (Maes et al., 2013 and 2014) and the CICES typology, the ultimate aim being improving the application of these typologies for marine ecosystems (MAES et al., 2014). We build on this initial review work in the typologies taken forward here.

Other key aspects to the scope of the assessment approach designed here are that:

(i) The EU Biodiversity Strategy aims to halt the loss of biodiversity and the degradation of ecosystem services in the EU by 2020, restoring them in so far as feasible, while stepping up the EU contribution to averting global biodiversity loss (EC, 2011a). Action 5 under Target 2 of the Strategy envisages that Members States, with the assistance of the Commission, will carry out ecosystem and ecosystem services assessments (by 2014, although this is ongoing), and that the value of the latter will be integrated into current EU accounting and reporting systems (by 2020). The Biodiversity Strategy also envisages that Target 2, in particular its Action 5, will be fulfilled by using the information available through the implementation of EU environmental directives and relevant EU policy. Thus, in order to support assessments under Target 2/Action 5 of the Strategy and/or its post-2020 follow-up, the assessment approach developed here sets out to use information on marine ecosystem state reported at the EU level. This information is often actually reported as status (as defined by Maes et al., 2013; see further elaboration on this under Sections 1.4.3 and 1.4.4) as part of the implementation of EU water, marine and nature legislation and related EU policy, following a 'top-down' approach[7]. Doing this would also facilitate the integration of ecosystem services assessment reporting into existing systems, as well as serve to identify potential gaps in those systems. It is also consistent with the 'collect once, use many' SEIS[8] principle of data collection, whereby greater worth can be achieved from information already available.

(ii) The geographical scope of the assessment method developed in this study is based on the four (large) marine ecosystems of Europe: the Mediterranean Sea, the Baltic Sea, the Black Sea and the North-East Atlantic Ocean, i.e. the four EU marine regions listed in Article 4 of the MSFD[9], which are delineated in the map on the 'Marine regions and sub-regions of MSFD'

[7] A 'top down' assessment approach directly uses Member State reported information on all the EU (and other) policy assessments relevant to a particular marine ecosystem (e.g. an EU marine region) on the state (or status) of ecosystem components available at the EU level to generate an overall assessment of the capacity of marine ecosystems to supply services. A 'bottom up' approach would instead aggregate the results from each individual Member State assessment of marine ecosystem service supply capacity to provide an overall EU-level assessment.

[8] SEIS: Shared Environmental Information System http://ec.europa.eu/environment/archives/seis/

[9] http://eea.maps.arcgis.com/apps/MapSeries/index.html?appid=e11c991280f54d3b839d9b8cc695b168
Note, however, that – while the seas covered in this assessment are, geographically, those outlined as the EU marine regions in the MSFD – the nature of these seas, in terms of their coverage of marine zones and the physical features they include, differs from those in the MSFD's. These differences are described in Section 3 of the report. The geographical scope of this assessment does not extend to the Arctic, which is also the case for the MSFD.

(iii) The broader MECSA framework and method developed in this study is described in section 5 of this Report. The approach was designed to deliver a 'one-to-one' policy-relevant assessment; whereby we have used both the 'assessment structures' (e.g. biotic groups, habitats) included in policy, as well as the 'assessment information' (e.g. reported status of biotic groups and habitats) coming from policy implementation and reported at the EU-level directly to develop and 'feed' our assessment framework and method respectively. Thus, following from point (i), it is useful if, ultimately, the classifications of marine ecosystems used here can be linked to classifications used in assessment, reporting and mapping under relevant EU environmental directives, and the assessment outcomes from operationalising our framework can be linked to progress with meeting their objectives.

(iv) At the same time, we set out to structure our MECSA framework (ecosystem and services typologies and linkages between these, see Sections 2 to 4) in a way that is as inclusive as possible of the full capacity of marine ecosystems to supply marine ecosystem services. This meant that we did not constrain: (a) our marine ecosystem services typology to those services that can be easily valued in monetary terms; or (b) our marine ecosystem components to those components that can be assessed using *existing* information from EU (and other) legislation/policy. We felt that this was an essential standpoint to take because it would reveal what we need to know to have a full picture of the state of marine ecosystems to sustainably support all aspects of human wellbeing delivered from the seas, and highlight gaps where data or method currently preclude full coverage of this. What we have learnt from doing so is described under Section 7. We also discuss the ongoing reviews of key EU legislation and policy, including associated classifications in that section, as these would require an updating of the classifications and broader aspects of the approach developed herein for application in the future or in other work.

(v) The MECSA approach designed here aims at assessing the capacity of the ecosystem to supply services now and in the future, informed by its current and future state and their direction of change (*supply-side* assessment approach). Only the capacity of the ecosystem to supply services (based on the state of the relevant ecosystem components) is assessed, because:

1. The assessment is carried out at an EU scale (i.e. covering the four EU marine regions). While assessments made at 'lower' (e.g. national, local) scales would be able to account for the specific use of a service in a particular habitat or sub-unit (in relation to human demand, *demand-side* assessment approach, which also includes estimating the services used and valuing the benefits from such use), this is currently not possible at a European scale. Thus, EU-level policy generated information characterising and assessing marine ecosystem services 'end-to-end', i.e. from the capacity of the ecosystem to generate services, to the use of a service and then to the (economic) value of the benefits from using that service, is not available at that level (with extremely few exceptions, e.g. for wild seafood provisioning).
2. Focussing the services assessment on the 'supply' side', and thus assessing the capacity of the ecosystem to deliver services based on its state, retains greater links with an ecosystem assessment, which is the aim of this work (rather than an economic assessment) Thus, its focus is to indicate whether marine ecosystems can self-renew.

1.1.3 General structure of the Report

This Report is divided into sections, each of which is briefly described in Table 1.1 and illustrated in Figure 1.1. Section 1 describes key concepts fundamental to the scope of the assessment, with sections 2 and 3 outlining key 'structural elements' of the assessment (i.e. customised typologies of ecosystem services and of ecosystem components[10]). Section 4 establishes how these key elements link to each other, and Annex I details all of the linkages found between ecosystem services and biotic groups, organised by habitats. Section 5 uses the information laid out in Sections 1–4 and outlines the operational steps (method of the MECSA) to assess the current state, and sustainability, of the capacity of marine ecosystems to supply marine ecosystem services; and Annexes II–IV demonstrate the application of the method with test case assessments. Section 6 draws together the assumptions and limitations of the approach, which are highlighted throughout all other sections. Section 7 describes the lessons learnt and the way forward. Annex V estimates the confidence in the MECSA method. Annex VI concerns the application of the new (from January 2018) CICES version 5.1 to marine ecosystems, including its implications for some key outputs of this Report. All Annexes (I-VI) are included in a separate document to the main Report here.

Table 1.1 Description of the sections of this Report

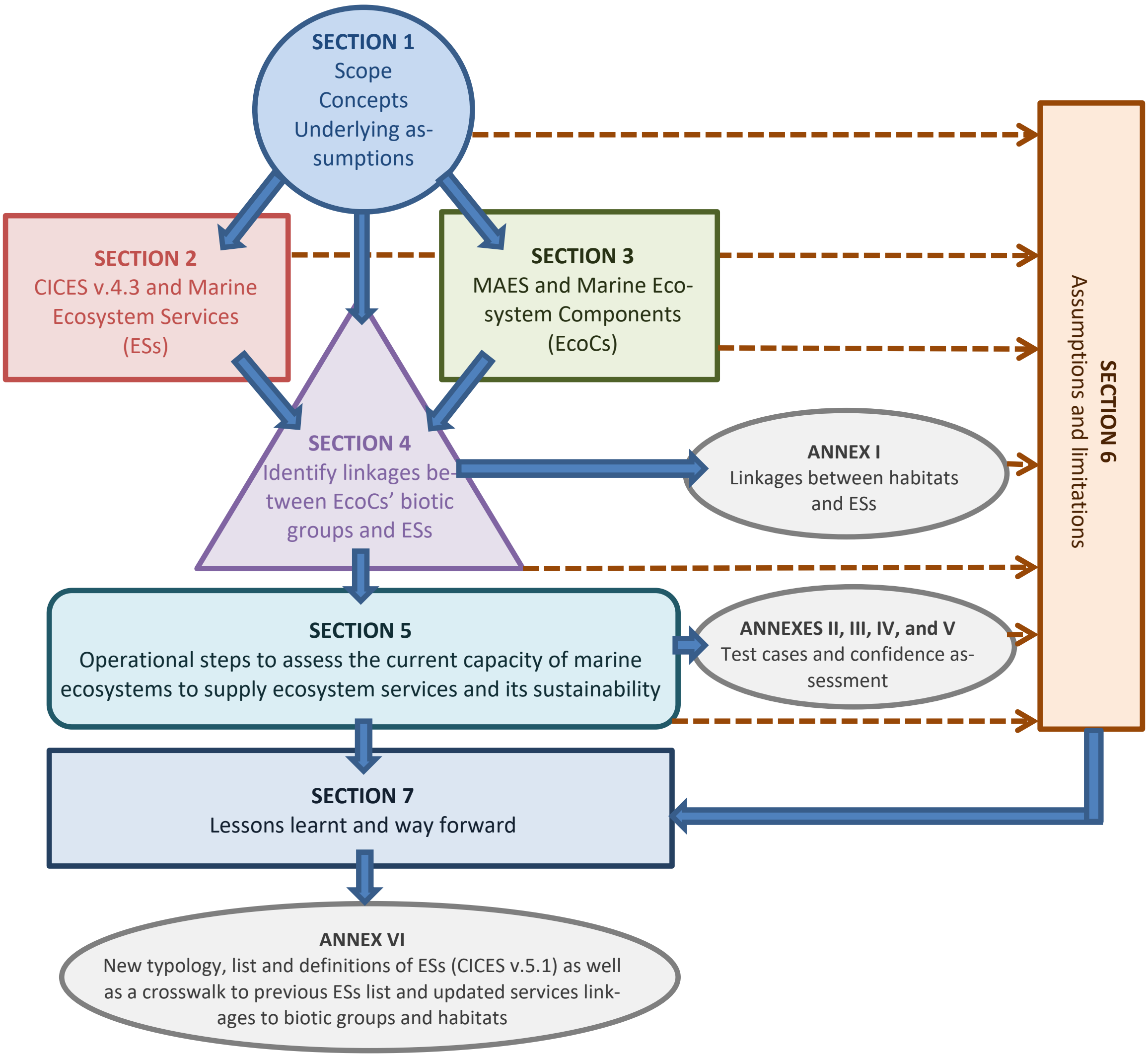
Section 1	Section 1 contains the introduction and outlines key concepts and assumptions relevant to the assessment approach developed here.
Section 2	The Common International Classification of Ecosystem Services (CICES) provides the framework for the characterisation of ecosystem services as well as a services typology. Section 2 describes the criteria used to customise the CICES typology (version 4.3) for its (improved) application to marine ecosystems, as well as provides the list of marine ecosystem services used in the MECSA approach.
Section 3	The MAES (Mapping and Assessment of Ecosystems and their Services) marine ecosystem types provide the framework for the characterisation of the ecosystem components developed here. Section 3 presents the rationale for an adaptation of the MAES characterisation of marine ecosystems in order to develop ecosystem components, and explains why these components are needed to link to ecosystem services.
Section 4	The assessment proper is broken into two stages. Section 4 presents Stage 1 of the assessment, the aim of which is to establish the linkages between marine ecosystem components and the marine ecosystem services they can supply. Stage 1 is holistic as it considers all possible interactions (in an EU context) between components and services in a qualitative way. A definition of each service is given, followed by a description of which biotic groups can contribute to, or solely hold, the ecosystem capacity to supply that service, where we assume this is within all habitats that each biotic group occupies (see Section 3) unless otherwise stated. The concept behind this identification is explained in this section, which also provides the full services linkages per biotic group; while the full services linkages per habitat are presented in Annex I.

[10] It is important to note that the definition of marine 'ecosystem components' (EcoCs) used in this Report (where an EcoC consists of a biotic group (e.g. fish) within a given habitat type (e.g. fish in oceanic waters)), differs to that used in some related policies and assessments, where marine ecosystem components may be used to describe one or more of the following: 'species groups', 'functional groups', 'habitats' or 'ecosystems' (e.g. the MSFD (EC, 2011b); the EEA 'State of Europe's Seas' Report (EEA, 2015); and the revised EC Decision on the criteria and methodological standards for 'good environmental status' (EC, 2017)).

Table 1.1 Cont.

Section 5	Section 5 presents the operational steps of the MECSA analytical framework (Stage 2 of the assessment approach), which make up the MECSA method linking the state of marine ecosystem components to the capacity of the ecosystem to supply marine ecosystem services. Detail is given on Stage 2, which employs the Stage 1 outcomes as a starting point and applies a focused approach, using a semi-quantitative critical path analysis to identify the major (critical) ecosystem component(s) contributing to the supply of a given service. Having identified these, the (ecosystem) state-service (generation) relationship is then established, which also serves to identify other parts of the ecosystem that are key for service generation. Policy-relevant information is then utilised to assess the current and, if information is available, the future state as well as the current and future direction of change in the state of all these elements. These assessments are, in turn, interpreted in terms of the (ecosystem) state-service (generation) relationship to determine the current and, where possible, the future state of as well as the current and future direction of change in the capacity of the ecosystem to supply the service.
Section 6	Section 6 presents a summary of the assumptions and limitations made throughout the development of the assessment approach and discusses the implications of these.
Section 7	Section 7 discusses lessons learnt and likely future updates and improvements that could be made to the assessment approach, making some clear recommendations.
Annex I	Annex I presents the full linkage matrices of ecosystem components to services displayed as one table per habitat, where the habitats are based on the MSFD predominant habitat types.
Annex II	Annex II presents a test case assessment for a cultural service (*Recreation and leisure* (from whale watching))
Annex III	Annex III presents a test case assessment for a regulation and maintenance service (*Waste and toxicant removal and storage* (of nutrients))
Annex IV	Annex IV presents a test case assessment for a provisioning service (*Seafood from wild animals* (commercial fish and shellfish))
Annex V	Annex V describes the method to assess and the assessment of the confidence of each of the operational steps in Section 5 based on the test case assessments in Annexes II–IV.
Annex VI	Annex VI is a separate MS Excel file presenting a customisation of the new (from January 2018) CICES version 5.1 for its (improved) application to marine ecosystems, which is to be used in future work rather than the typology and list of marine ecosystem services used by the MECSA approach (as that is based on CICES version 4.3). The Annex includes an updated list of marine ecosystem services based on CICES v.5.1 (building on Table 2.2 in Section 2 of this Report) and a short description of each of the new services (building on those provided in Section 4 of this Report). It also includes a cross-walk between the MECSA marine ecosystem services list based on CICES v.4.3 and this updated list based on CICES v.5.1, as well as an in-depth comparison between them. It further includes updated linkages matrices between biotic groups and the updated list of services based on CICES v.5.1 (building on that provided in Section 4 of this Report), and between these services and habitats (building on that provided in Annex I of this Report), where the habitats are based on the (new) MSFD broad habitat types. This annex was developed following the completion of Sections 1–7 and Annexes I–V of the Report.

Figure 1.1: The structure of this Report and the inter-relations between major elements



1.2 Understanding the seas and oceans and their link to human well-being

The seas and oceans cover around 70 % of the Earth's surface and support around 30 % of the global Gross Domestic Product (Costanza et al., 2014). Almost 50 % of the area under the jurisdiction[11] of the European Union consists of seas and oceans. Humans have gained benefits from the seas since prehistoric times. Initially gathering food from the shores, then as communities became established placing waste into the sea (including via rivers and estuaries), as a means of transport, as a place of business (the first international markets were merchants selling from vessels dried out on the sands) and the development of ports. Archaeological evidence shows us that even ancient peoples were overex-

[11] This is a very rough calculation using a GIS shape-file downloaded from http://www.marineregions.org/eezmethodology.php, areas for EU Member State Exclusive Economic Zones were calculated in ArcGIS 10.1. Areas of EU Member State countries were obtained using data from http://en.wikipedia.org/wiki/List_of_European_countries_by_area, the proportion of the EU under water was then calculated from the two values. Note that this area is smaller than the full area considered in this assessment and corresponding to the geographical scope of the EU marine regions listed in the MSFD and delimited in 'Marine regions and sub-regions of MSFD' http://eea.maps.arcgis.com/apps/MapSeries/index.html?appid=e11c991280f54d3b839d9b8cc695b168

ploiting shellfish resources in the Mediterranean Sea and so influencing ecosystem dynamics. Additionally, the ancient Egyptians, Greeks and Romans all undertook extensive coastal developments including land claims. Since the industrial revolution, these activities have intensified and disposal of human, agricultural and industrial wastes, and land claim and coastal development have accelerated. In recent decades growth in leisure time has led to increasing use of the seas and coasts for recreation, while we now recognise the health benefits not only of eating seafood but also of being by the sea.

While many of these uses depend on the physical environment – shipping transport, walking at the coast – most are dependent on, or benefit from, the activities of marine organisms and the functioning of marine ecosystems. Food consumed from the sea clearly provides a direct human benefit: nutrition, which is tightly linked to the state of the biota that provide that food, but our enjoyment of swimming in the sea is enhanced when the sea water and beach environment are free of organic waste – a process mediated by living organisms. It is also clear that many of these uses impact on the ecosystem, and so potentially can undermine the system's ability to continue to support that or other uses, thereby creating conflicts between users.

It is heartening the extent to which TV documentaries have raised environmental awareness to the point that many citizens of Europe are aware of the diversity of life on Earth, appreciate some of the threats to wildlife and understand some ecological concepts, for example the nature of a food chain. This understanding, however, tends to be biased towards charismatic marine mega-fauna (e.g. birds, sharks) and terrestrial systems. Unfortunately, terrestrial and marine ecosystems function rather differently and so there is less societal understanding and valuing of marine ecosystems and their role in supporting human well-being.

Marine ecosystems differ from their terrestrial counterparts in two major ways. Firstly, they differ in their scale and dimensionality. The sea and oceans cover over 335 million square kilometres of the Earths' surface with an **average** depth of almost 3.7 km; this is a vast environment (over 1.3 trillion km^3) and life and living processes occur throughout this volume. While birds, bats and insects may exploit the air above, really this is mainly as a means of moving around, and ecological processes are tightly linked to the Earth's surface (or rather a narrow band below it – the soil and above it – the vegetation's canopy). Secondly, almost all terrestrial environments have *in situ* primary production, that is, they convert the energy from the sun into vegetation, while, in most of the seas and oceans, the food chain is based on scavenging and detritus as there is no primary production there.

Seafloor environments away from the coast tend to be sedimentary and are dominated by a range of organisms living in such sediment (infauna) and roaming over its surface (epifauna). Some infauna exploit food particles from the overlying water but many consume bacteria, micro-organisms and detrital particles from within the sediment. The activities of these burrowers oxygenate the sediment and so promote the bacterial breakdown of waste and detritus and the release of nutrients back into the water, where they are available to plants living in the illuminated near surface waters (and where primary production does take place). The ecology of the sea floor varies depending on the physical nature of the habitat (rock, shell, gravel, sand, mud etc.) and the nature of the available food supply.

The ecology of the water column and shallow photic seabed habitats is driven by the availability (or not) of light in sufficient quantity to allow (microscopic) plant growth and availability of nutrients to support this growth. In near shore areas, nutrients may be supplied by estuaries or run off from the land, but in offshore areas the processes that mix nutrients regenerated at the sea floor back into the surface waters are key. Seasonal warming may create a warm surface layer separated from the deep waters by a thermocline layer. Over deep water a permanent thermocline may exist. These create two distinct ecological zones.

The ecological processes in the water column and the sea floor are linked – primarily through the settlement of organic material and the feeding of activities of filter feeding bottom dwellers, through the export of food organisms from the sea floor by mobile bottom feeding predators, and through the export of nutrients in waters that percolate through the seafloor.

Ecologically, micro-organisms are much more critical to the functioning of marine ecosystems than in terrestrial systems and, in turn, the larger organisms promote microbial activity. The ecology of the microbial part of the marine ecosystem is extremely poorly understood, while we are only beginning to understand the links between macroscopic organisms and the delivery of ecological processes. For example, to what extent do all the hundreds of species of worm living under a square metre of the seafloor fulfil the same ecological role? We do not know, and so the management of human activities in the marine environment should follow a precautionary approach and should lead to the protection of natural biological assemblages. It must also recognise that it is likely that (i) all human activities have the capability to impair ecosystem functioning, and (ii) links between different organisms or groups of organism, ecological processes and ultimately ecosystem services that support human well-being are likely to be complex.

Management measures for human activities in the marine environment need to proceed based on the best available evidence but be prepared to adapt as issues emerge and new insights are gained. For a fuller account of the ecology of marine ecosystems, the reader is directed to Dobson & Frid (2009) and for an overview of impacts on aquatic ecosystems and their management to Frid & Dobson (2013).

1.3 Protecting the value of marine ecosystems

Globally, the seas and oceans provide over 50 % of the oxygen we breathe, around 17 % of the animal protein we consume annually, and have absorbed about 30 % of the CO_2 emitted from the burning of fossil fuels and other human activities, and so have helped to mitigate the effects of anthropogenic global warming (Lalli & Parsons, 1993; Nadis, 2003; FAO, 2014; IPCC, 2013; EEA, 2014). They also treat our organic wastes, dilute and disperse our inorganic toxic wastes, underpin and/or enhance our recreation and cultural activities, limit the erosion of our coasts, and provide us with energy and building materials – amongst many other outputs. The marine natural resources, living organisms and the physical, chemical, biological and ecological pathways that give rise to these outputs are a massive asset and represent the 'natural capital' of the seas and oceans. This natural capital consists of: 1) the marine living assets in their surrounding environment, i.e. marine ecosystem capital (also known as marine biotic natural capital), which includes marine ecosystem services; and 2) the non-living marine assets, i.e. marine abiotic natural capital (e.g. sand and gravel deposits) (cf. Maes et al, 2013; EEA, 2018).

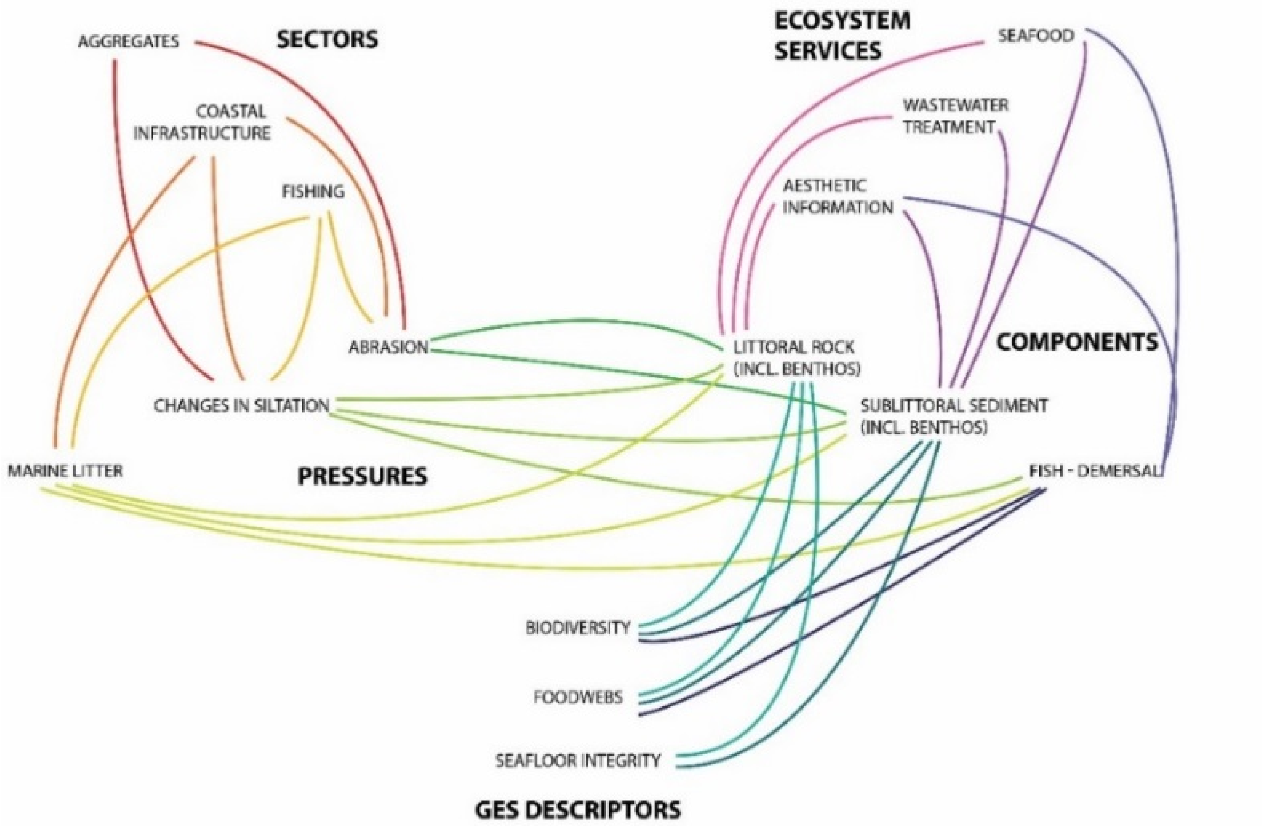
We have attempted to provide scientific management of our use of the seas as a food resource for over 100 years, while we have sought to limit waste and, in particular, oxygen demanding wastes and nutrients, entering the seas for 150 years. In more recent years, the realisation of the diversity of direct outputs the marine ecosystem delivers to people, i.e. marine ecosystem services, and the fragility of most of these to human pressures, has led to more holistic approaches to managing human activities. In the EU, the Water Framework Directive (EC, 2000), the Marine Strategy Framework Directive (EC, 2008), the EU Biodiversity Strategy to 2020 (EC, 2011) and the 7th Environment Action Programme (EC, 2013), amongst other policy instruments, whilst globally, the Convention on Biological Diversity (UN, 1992) and the 2030 Agenda for Sustainable Development (UN, 2015), all recognise the importance of functioning ecosystems and provide policy drivers for their protection.

Within a functioning marine ecosystem, the ecological processes should allow the breakdown of wastes, production of food, and absorption of CO_2 etc., and hence the continued availability of these ecosystem services to society. One of the challenges faced by managers is that many processes contribute to a given service and many processes underpin more than one service. So, for example, the service of wild seafood provisioning is drawn from a wide number of species; some of these require other species to feed on; many require different habitats as adults and as juveniles/larvae. Similarly, the biological production of organisms living in the sea floor may, depending on location, use up waste organic matter, sequester carbon in shells, promote oxygenation of the sediment (and hence nutrient regeneration and supply for marine plants), supply food to fish (which in turn support the human food supply), contribute directly to human food, and provide food for birds that are important for recreational activities. Therefore, management actions that focus on either one component of the ecosystem, or only one these services, risk compromising multiple services, and so management needs to be mindful of the trade-offs and interconnections within both the ecological and economic systems. A framework that can link ecosystem components (representing the biotic natural capital) with all services they have the potential to supply is essential in progressing towards management that can achieve this (see Section 4).

The consideration of ecosystem services in policy and management has arisen from the shift in emphasis of management from the traditional narrow focus on single sectors, pressures or biological entities to the 'ecosystem approach' (to the management of human activities in the marine environment). The ecosystem approach considers all aspects of the system including sustainable human use, multiple sectors, multiple biological aspects, ecosystem services and the interaction between these parts (Crain et al., 2009). Further, multiple management objectives and trade-offs which may occur between ecological, social and economic factors are also considered (Knights et al., 2014). This approach is increasingly accepted as the solution to managing ever greater human activity in the marine environment and the resulting complex interaction of multiple impacts between system components (e.g. Crain et al., 2009; Tallis et al., 2010, Halpern et al., 2012). It is firmly embedded in the environmental policies of the EU and the marine centred policies of the Integrated Maritime Policy (EC, 2007), where the ideas of sustainability and the integration of society as part of the ecosystem are stressed, in particular in its 'environmental pillar': The Marine Strategy Framework Directive (MSFD) (EC, 2008).

Making this approach operational requires a structure which can allow all the linkages of the whole system to be assessed through to the eventual consideration of management options. However, the complexity of the system requires a structure that can weight and rationalise what is important and what management should focus on. A number of frameworks have been developed in order to support implementation of ecosystem-based management. These frameworks include the DPSIR approach (Drivers, Pressures, State, Impact, Response) (EEA, 1998). The DPSIR approach has underpinned many recent developments in frameworks for applying the ecosystem approach. For example, the EU FP7 ODEMM project (Options for Delivering Ecosystem-based Marine Management) used the DPSIR framework as a starting point for a linkage framework that systematically organises ecosystem information and identifies all relevant interactions between key ecosystem components – human activities or sectors, their pressures, ecological components and ecosystem services, and the relevant policy objectives, for use in the assessment of management options on the state of the marine environment (Figure 1.2) (Robinson et al., 2014).

Figure 1.2: An illustration of the full EU FP7 ODEMM project linkage framework but only showing the linkages between a subset of elements of the ecosystem



Notes: ODEMM is 'Options for Delivering Ecosystem-based Marine Management'. From White et al. (2013) and Robinson et al (2014) (https://odemm.com/content/linkage-framework)

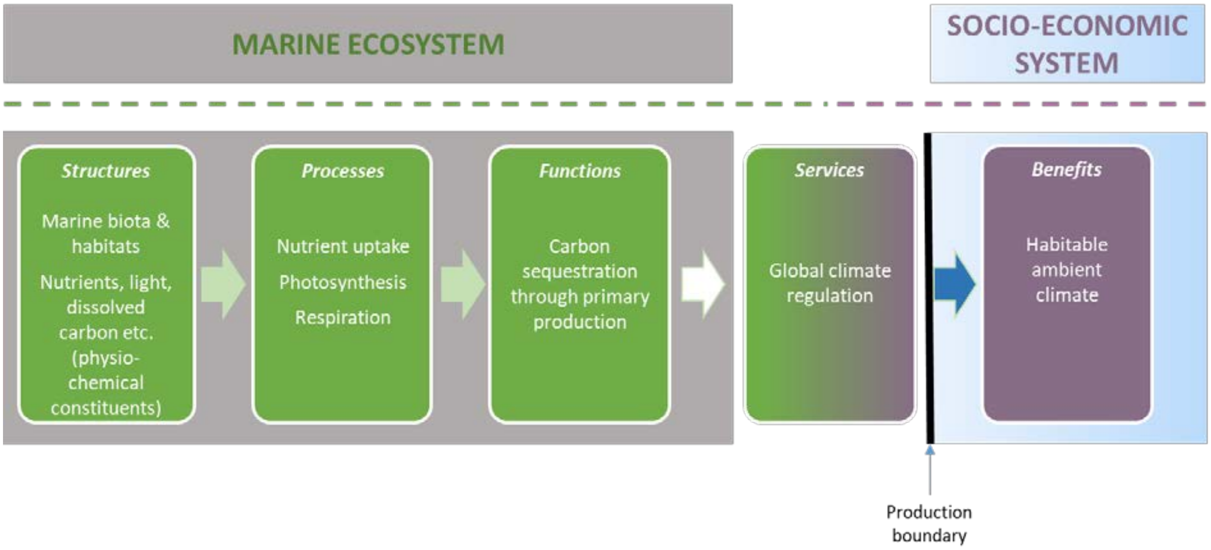
1.4 Assessing the capacity of Europe's marine ecosystems to supply ecosystem services: Key concepts for a Marine Ecosystem Capacity for Service supply Assessment (MECSA) approach

1.4.1 General definition and typologies of ecosystem services

In order to ensure the sustained delivery of ecosystem services, it is necessary to recognise which parts of the ecosystem (i.e. which groups of organisms, what ecological interactions and processes?) determine the supply of ecosystem services and are, thus, the basis/core of any linkages between ecosystem components and ecosystem services. It is essential, therefore, to have a clear understanding of both what is meant by ecosystem services and how these link to the ecosystem through an overall cascade of interactions.

Since the concept of "ecosystem services" was defined in the Millennium Ecosystem Assessment (MA) as "*the benefits people obtain from ecosystems"* (MA, 2005), there has been confusion in terms of whether ecosystem services are the actual ecosystem structures, functions or processes; the use of those structures, functions or processes (as services); or the benefits that arise from this use. It has, therefore, been recommended to follow the ecosystem services 'cascade' model (Potschin & Haines-Young, 2011), which has been adopted in several ecosystem service assessment frameworks (e.g. Liquete et al., 2013a), and to keep each part of this cascade clearly defined and segregated (Böhnke-Henrichs et al., 2013) (see Figure 1.3).

Figure 1.3: *Partial* marine 'cascade' model, adapted from Potschin & Haines-Young (2011), for the *photosynthetic part of* the generation of the *Global climate regulation* service only



Notes: Model demonstrates the links between ecosystem structures, processes and functions via the flow of ecosystem services to final beneficiaries. Ecosystem 'services' are the link between the ecosystem and the socio-economic system; 'benefits' to society (habitable (sensu McKay et al., (1991) ambient climate in this case) and the 'value(s)' that are placed upon them are outside of the 'production boundary' that separates ecosystem constituents (green boxes) and ecosystem services from the socio-economic system (purple box) within the cascade (i.e. separating the environment from the economy). 'Value' is not shown here although it is captured explicitly in the original 'cascade' model and other versions of it (e.g. Böhnke-Henrichs et al., 2013).

Following the rationale of the ecosystem services 'cascade' model, we use the following definition of ecosystem services in our work going forward:

'Ecosystem services represent the flow of ecosystem capital that is realised because of a human active or passive demand (modified from EEA, 2015). They are thus the final outputs from ecosystems that are directly consumed, used (actively or passively) or enjoyed by people (Fischer et al., 2009; Haines-Young & Potschin, 2013; Maes et al., 2013).'

We get many benefits from these services such as nutrition, habitable ambient climate, and enhanced physical or mental health (e.g. Sandifer et al., 2015), and we also recognise that obtaining these benefits requires human inputs such as labour, capital, or energy investments (Maes et al., 2013), which helps to further characterise the difference between ecosystem services and benefits. However, there are some services for which there is a passive human demand (e.g. regulation and maintenance services, such as carbon sequestration, and cultural services such as some aesthetic interactions) and for which the benefits are, in principle, free flowing without requiring human input, but in economic terms there are at least opportunity costs or costs of degradation involved (HM Government, 2012; Maes at al., 2013). For example, the marine ecosystem capacity for 'Bio-remediation by micro-organisms, algae, plants, and animals' to treat some wastes, such as raw or partially treated sewage, can be overcome rather fast leading to eutrophication and other negative impacts on the ecosystem and/or people. It is important to note that the concept of ecosystem services is anthropocentric in nature, given that ecosystems have the capacity to provide ecosystem services, regardless of whether those services are utilised (active or passively) by people or not.

Ecosystem services can be classified into different typologies; where the original globally accepted classifications from the Millennium Ecosystem Assessment (MA, 2005) and The Economics of Ecosystems and Biodiversity initiative (TEEB, 2010) both classified services under four broad categories: provisioning services (such as food from fish); regulation and maintenance services (such as waste regulation); supporting services (such as primary production in the MA, and habitat services in TEEB); and cultural (or cultural and amenity in TEEB) services (such as the availability of charismatic marine species to observe or to research). Following these international initiatives, ecosystem services typologies have been further developed and/or adapted for the marine environment (e.g. Liquete et al., 2013a; TEEB adapted for the marine environment by Böhnke-Henrichs et al., 2013; Beaumont et al., 2007; MA typology adapted for the marine environment by Austen et al., 2011 and Potts et al., 2014). These typologies cover the broad categories of services that are recognised as being delivered by marine ecosystems.

As described in Section 1.1, in order to base the approach here on EU policy, we use CICES, which is the Common International Classification of Ecosystem Services (Haines-Young & Potschin, 2013[12]), as the reference typology for this assessment. CICES differs from the MA and TEEB services classifications in that it recognises only three categories (called 'sections') of 'final' ecosystem services: provisioning services, regulation and maintenance services, and cultural services. CICES does not include 'supporting' services because it considers that these are part of the processes and functions that characterise ecosystems and, thus, that they may simultaneously facilitate many 'final' ecosystem services. These 'supporting' (or 'intermediate') services are therefore only consumed or used by people indirectly rather than directly, which is the CICES criterion for defining services (for a comparison of the MA, TEEB and CICES service typologies see Maes et al., 2013).

CICES was developed primarily for the terrestrial system but is widely used, including being the EU ecosystem services 'reference' typology as adopted by Working Group (WG) MAES (Maes et al., 2013). It is, therefore, used as the basis for a typology of marine ecosystem services here (building on the WG MAES adaptation of CICES for the marine environment (Maes at al., 2014) mentioned in Section 1.1), where the customisation required to apply it for the MECSA framework developed herein is described in Section 2 of this Report. However, there is one further clarification in meaning required for a complete understanding of the broad concept of how ecosystem services are defined, and this is discussed in Section 1.4.2 below.

1.4.2 Final' versus 'Intermediate' services

An increasing number of authors (e.g. Haines-Young & Potschin, 2013; Mace et al., 2011; Potts et al., 2014) have followed Fisher et al. (2008), who nest '*final'* and '*intermediate'* services within the broad definition of ecosystem services. In terms of distinguishing the difference between these, final services should be confined to the ecosystem outputs *directly* consumed, used (active or passively) or enjoyed by a beneficiary; whereas intermediate services are only *indirectly* consumed/ used/enjoyed by people, and can themselves support many other ecosystem services.

The rationale for the division and compartmentalising of ecosystem services into either final or intermediate services is to avoid the 'double assessment' of (final and intermediate) services in a services assessment, or the 'double counting' of the benefits from (final and intermediate) services in the economic valuation of service benefits[13] and/or in the monetary accounting of ecosystem services (i.e. in a *demand-side* assessment, see Section 1.4.4). However, there are different interpretations of what should be included under *'final'* services, where the concept of ecosystem service classification is still evolving in both terrestrial and marine realms.

[12] The CICES typology referred to here is version 4.3 (see Haines-Young & Potschin, 2013), and underwent a review during 2016/2018 resulting in CICES version 5.1 (see Haines-Young & Potschin, 2018). See Section 7 and Annex VI.

[13] Where the economic value of the benefits from each of the ecosystem services assessed is added up *sensu* Total Economic Value.

Thus, some of the services included in the MA (2005) and TEEB (2010) classifications would always be considered to be 'intermediate' services if differentiated in this way (Mace et al., 2011). The CICES classification system states that all services included are final; whilst also recognising that whether certain services are actually 'final' can only be determined in a given context (Haines-Young & Potschin, 2013). This context-dependency can explain why *pollination and seed dispersal* is included as a 'final' ecosystem service by CICES, but considered 'intermediate' in Mace et al. (2011). The same can be claimed for services related to biological control and biologically mediated habitats, which are considered 'intermediate' in Potts et al. (2014). It is indeed argued that these different interpretations may be required for assessments made under different contexts (Hattam et al., 2015).

In addition, even where there is agreement that a service can be defined as 'final', with a clear example that it can provide benefits to people in its own right, there can be cases where that service can feed back into the ecosystem, acting as an 'intermediate' service and supporting the generation of another service. This could also lead to 'double counting' at the service benefit valuation stage or in service monetary accounting. This issue was identified in the context of one of the MAES pilot exercises in relation to the input of capital into agricultural output and for livestock, where it was noted that these services also depend on using other (final) ecosystem services from inside or outside the EU (Maes et al., 2014). A good example from the marine environment of where an ecosystem service could conceivably be defined as both '*final'* and '*intermediate'* is the provision if fishmeal, which is a product made from fish and the bones and offal from processed fish. This is s service (class) type under the CICES *Materials from plants, algae and animals for agricultural*[14] *use* provisioning service (falling itself under the CICES 'Materials' division and 'Biomass' group, see Table 2.1). Fishmeal provision from marine ecosystems is a 'final' service to the person who collects the raw material, and produces and sells the fishmeal. But, it can also be an 'intermediate' service in providing nutrition for finfish farms, where the farmed animals are then themselves – through the seafood provided by their biomass – defined as the 'final' service (see Section 4).

As previously described, the assessment undertaken here is based on the CICES general ecosystem services definition and services typology, and CICES considers all services included to be 'final services'. We note, however, that a service *currently* considered 'final' in CICES could justifiably be considered to be an 'intermediate' service in other work. We also note that the version of the CICES typology used here (version 4.3, Haines-Young & Potschin, 2013) was reviewed when the bulk of this Report/study had just been completed[15].

The customisation of the CICES (version 4.3) typology for marine ecosystems described in Section 2 here has identified a number of services that could be interpreted as both '*intermediate'* or '*final'* dependent on the context in which they are assessed (see further detail in Section 4 of this Report). CICES could, thus, be considered to be about 'potential final services' as its authors recognise that the 'final' attribution would be contextual (Haines-Young & Potschin, 2016). We consider that all services included for the assessment here do have a direct (active or passive) human use, including through the avoidance (or limiting) of a human intervention and related societal costs by using the service. This is regardless of whether the specific examples included elsewhere in this Report express them in terms of an 'intermediate' or 'final' use. At the same time, the MECSA approach designed herein should capture how the state of the ecosystem is affecting its capacity to supply services, with the ultimate aim of providing knowledge on how well (or not) ecosystems are being managed to maintain capacity of ecosystem service supply into the future (sustainable use). It is, therefore, important that any ecosystem service typology used here should be inclusive of all potential *direct* ecosystem outputs, as far as possible and relevant, regardless of the level of current use. In Section 2, we describe the customisation of the CICES typology used for the purposes of this assessment going forward.

[14] Including aquaculture

[15] The CICES typology referred to here is version 4.3 (see Haines-Young & Potschin, 2013), and underwent a review during 2016/2018 resulting inCICES version 5.1 (see Haines-Young & Potschin, 2018). See Section 7 and Annex VI.

1.4.3 Linking to the state of the ecosystem – the ecological underpinning of ecosystem services

As stated under Section 1.4.1, it is necessary to recognise which parts of the ecosystem hold the capacity to generate ecosystem services in order to ensure the renewal of ecosystem capital and, thus, the sustainable supply of ecosystem services. So how should we describe and classify the parts of the ecosystem that generate ecosystem services? It may be convenient to try to map the spatial capacity of the ecosystem to generate ecosystem services, by linking services to different supporting habitats directly (e.g. see Galparsoro et al., 2014), but ultimately it is the individual biota (marine organisms) within these habitats that are responsible for the structures, processes and functions that underpin services (see Figure 1.3 and examples in Sections 1.2 and 1.3).

At the same time, as described under Section 1.1 of this Report, a key requirement for the assessment approach developed here is that marine ecosystem services are linked directly back to EU policy assessments (and other, e.g. regional assessments) of the state of the marine ecosystem. These 'status' assessments (e.g. those conducted under the MSFD, the Water Framework Directive or the Habitats Directive) tell us something about the 'health' of the ecosystem (whether or not the ecosystem is fully functioning, i.e. possesses the full array of ecosystem functions (see Borja et al., 2013; Maes et al., 2013)), and this is directly related to whether or not the full range of ecosystem services is supported in a sustainable way. These 'status' assessments are conducted at the level of species and/or habitats, sometimes also including information on abiotic elements and pressures acting on the relevant biota and/or habitats, which illustrates the importance of being able to link capacity for service supply back to *both* habitats and biotic groups. Considering the 'cascade' model covered in Figure 1.3, this means that the input information used for the ecosystem services assessment being developed herein is (for the most part) at the level of 'Structures'.

Whilst services are generated from biotic groups, the capacity to supply services should always be considered in the context of the environment (habitat) that the organisms reside in, and this is influenced by biotic (other individuals and species) and abiotic elements (e.g. light, temperature) (see examples in Box 1.2). Thus, in this assessment approach, marine *ecosystem components*[16], from which marine ecosystem services can be supplied, are defined as including the biotic elements and their interactions with other biotic and abiotic elements contained within a given habitat type (see Section 3). The biotic group may be embedded in its associated habitat, e.g. seaweed in coarse shallow sublittoral sediment, or the biotic group may use its associated habitat periodically for feeding, e.g. turtles feeding in shallow sublittoral sand habitat. The link between ecosystem components and the ecosystem services they can supply (Section 4) *implicitly* covers any relevant structures, processes and functions (i.e. all relevant interactions) that are required to generate the service, and this is described in terms of the (ecosystem) state-service (generation) relationship (see Section 5).

[16] It is important to note that the definition of marine 'ecosystem components' (EcoCs) used in this report (where an EcoC consists of a biotic group (e.g. fish) within a given habitat type (e.g. fish in oceanic waters)), differs to that used in some related policies and reports, where marine ecosystem components may be used to describe one or more of the following: 'species groups', 'functional groups', 'habitats' or 'ecosystems' (e.g. the MSFD (EC, 2011b); the EEA 'State of Europe's Seas' Report (EEA, 2015); and the revised EC Decision on the criteria and methodological standards for 'good environmental status' (EC, 2017)).

Box 1.2 Examples of how marine ecosystem services are underpinned by key marine biotic groups, the state of which is dependent on other biotic and on abiotic elements of the supporting marine ecosystem

Example 1: The provision of seafood from wild fish, through commercial fishing of species such as cod or mackerel, is dependent on the state of fish themselves (biotic element), but the state of the fish populations will also be dependent on the state of the habitat of the fish (on biotic, e.g. prey and predators, and abiotic/environmental, e.g. nutrients and pollution, elements).

Example 2: The availability of whales for whale watching is underpinned by the state (population size and distribution) of whales, but the state of whale populations also depends on the state of the habitat (on biotic, e.g. prey availability, and abiotic, e.g. temperature, elements).

Example 3: Kelp can contribute to erosion prevention but this contribution requires interaction with the other biotic (e.g. bacteria for nutrition and herbivore densities) and abiotic elements (e.g. light and nutrients for growth) in their habitat.

Example 4: The capacity of phytoplankton to produce oxygen relies on abiotic conditions (e.g. light, nutrients, water quality), but also biotic interactions (e.g. with competitors and predators) in their habitat.

1.4.4 A 'supply-side' assessment based on ecosystem capacity

For the purposes of this study, the capacity of the ecosystem to supply services is assessed based on its state, i.e. taking into account whether the ecosystem is 'healthy' or degraded. This is so we can infer something on the sustainability of marine ecosystem capacity for service supply (Maes et al., 2013, 2014; EEA, 2015). We, thus, define marine ecosystem capacity for service supply here as:

'*the effective capacity (potential) of an ecosystem to supply services, which is that based on its state and so linked to its functioning (rather than pure or total capacity, sensu MA (2005), which is linked to just its extent).'*

Additionally, only the capacity of marine ecosystems to supply services is assessed because, as noted already, it is currently not possible to quantify the specific use of a service from a particular unit of a habitat at the EU scale (i.e. when considering the four EU marine regions) on the basis of the information that is reported at the EU level from the implementation of EU legislation and policy. Nevertheless, assessing the capacity of the ecosystem to supply services retains greater links with an ecosystem assessment. This is, in particular, of an assessment aimed at providing evidence on whether the use of marine, and other, natural capital is sustainable and allows the maintenance of marine ecosystem capital, such as the one here (see further explanation under Sections 1.1. and 1.3).

Overall, the assessment of marine ecosystem capacity for service supply requires consideration of both:

- the capacity of the ecosystem to supply a service on the basis of its state, and
- the possibility for this capacity to be realised, i.e. whether an actual service could be delivered through a direct (active or passive) human use

One can say, therefore, that a 'supply side' assessment based on ecosystem capacity considers how the state of the ecosystem is affecting the generation of the *actually used* services (Burkhard et al., 2012). In the MECSA approach developed here, however, we focus more on assessing the capacity of the ecosystem to supply a service on the basis of its state (see Section 5); only considering the (likelihood of) use of the services (by society) in order to identify *which* links from the ecosystem to the services are relevant in an EU context (see Section 4). For example, we do not include whales as capacity for provision of seafood for nutrition because it is illegal to hunt and consume whale meat in the EU Member States bordering the EU marine regions. We also exclude links between ecosystem components and services where there is currently no practical way of accessing the service (e.g. fish found in the abyssal zone of the deep sea may never be considered to have the capacity to provide seafood for nutrition since they are located outside of where they can be accessed with current fishing technologies) (see further explanations under Section 4).

Quantifying the amount of services used only used becomes relevant when assessing ecosystem services following the ’demand-side' approach, which also considers the valuation of the benefits from this use (see Figure 1.3). As described, under Section 1.4.1, obtaining the benefits from ecosystem services normally requires human inputs such as labour, capital, or energy investments, and these benefits are realised where there is both the capacity in the ecosystem *and* such a human input, or a passive human demand (Haines-Young & Postchin, 2013; Maes et al., 2013). To give an example, the capacity of the ecosystem to supply (wild) animal seafood would be based on the status of all fish and invertebrate species that can potentially be used for nutrition, but the (wild) animal seafood service is only based on the individuals that are actually taken following human input (i.e. the catch), which also provides economic benefits to the fishermen when the fish is sold. In an alternative example, all soft sediments have the capacity for anthropogenic waste treatment due to the functioning of the biota living therein, but not all soft sediment habitats in the whole of an EU marine region may be supplying this service at any point in time. Thus, the supply of this service and the reaping of its associated benefits will depend on the passive human demand for it, which is dictated by where and how much anthropogenic waste is deposited and how it is transported in the ecosystem.

The assessment approach described in this Report facilitates the consideration of the types of interactions between changes in an ecosystem's state and service generation that are needed to assess its capacity for service supply. It is assumed that the state of ecosystem components, would, generally speaking, need to be 'good' (*sensu* status) for marine ecosystems to be able to sustain the supply of ecosystem services. However, we acknowledge that the relationship between ecosystem state and service supply capacity will not be linear (see the concept of the (ecosystem) state-service (generation) relationship in Section 5). Thus, in some cases, a change in the state of an ecosystem component may not be positively linked to a change in the capacity to supply an ecosystem service. For example, within the CICES *Wild animals and their outputs* provisioning service, a 'healthy' benthic habitat (in 'good' status) may improve the supply of some commercial fish species such as cod, while having a negative impact on fish species such as plaice, which thrive in slightly disturbed conditions (Rijnsdorp & Vingerhoed, 2001; Link et al., 2002; Hiddink et al., 2008). Thus, the assessment needs to capture the specific (ecosystem) state-service (generation) relationship, which can differ for different services. At the same time, different service categories depend in different ways on the state of ecosystem components. Thus, the supply of (wild) animal seafood is an example of tight coupling, where the service is directly dependent on the state (e.g. population size, age structure, spatial distribution) of the relevant fish and invertebrate species. In contrast, the supply of a cultural heritage service may be completely decoupled from the current state of the relevant ecosystem components, where the service is supplied, for example, through the existence of historic records of a maritime activity (i.e. whaling).

In conclusion, the state of the ecosystem can inform us about the state of its capacity to supply ecosystem services, in particular whether this capacity can be sustained (*supply-side* assessment approach). That is the focus of the assessment approach designed herein and described under Section 5. Where the 'state' of a service is referred to (rather than the state of the ecosystem, see Box 1.1.), this is the 'state' of the capacity of the ecosystem to supply a service (i.e. whether that is 'good' or 'bad').

1.4.5 An operational, 'one-to-one' EU policy-based assessment approach

Available assessments of marine ecosystem services range from identifying linkages between EU-policy relevant ecosystem components and ecosystem services, with an indication of the relative contribution of components to services (e.g. EUNIS habitats in Potts et al., 2014); to detailed mapping of the factors associated with the components that supply services (e.g. Dickie et al., 2014); to attempts to value costs associated with degradation of services related to the ability or not to achieve relevant policy objectives (e.g. HM Government, 2012; see explanation in Box 7.5 of EEA, 2015). Policy relevance is considered in approaches such as: (1) Potts et al. (2014), which makes an explicit link between ecosystem services with EU-policy relevant habitats and species, and (2) the WG MAES (Mapping and Assessment of Ecosystems and their Services, see Section 1.1) assessment approach, which relies on the information/data collected from EU environmental legislation and related EU policy obligations (Maes et al., 2013, 2014). Information/data availability is a factor in the difference between approaches. For example, an assessment for a country's marine waters, such as the UK (e.g. Dickie et al., 2014, Alexander et al. 2016), can make use of extensive availability of spatial data (mapping); while studies which need to be applicable to the four EU marine regions in geographical scope, such as the MAES approach, must account for regions where little or no spatial data are available. The MAES approach attempts to account for different levels of data availability in different regions by having a three-tiered approach: a first tier linked to the level of least data availability, through simply using any available indicators of ecosystem state; a second tier, which involves semi-quantitative mapping and inferences based on available data and expert knowledge; and a third tier, which involves biophysical modelling of the ecosystem processes that lead to the supply of ecosystem services (Maes et al., 2014).

The approach developed here aims at carrying out an assessment of the capacity of marine ecosystems to supply ecosystem services based on their state, while being pragmatic (i.e. making the best use of available information at the EU level) and applicable (to, e.g., support implementation of EU legislation and policy). The approach starts from the perspective that the state of ecosystem components can inform us on the state of ecosystem services (specifically on the sustainability of service supply) through indicating the capacity of the ecosystem to supply them (*supply-side* assessment approach). Such an approach is based on EU environmental legislation and related EU policy through the use of ecosystem components (supplying the services) that are specified in EU environmental water, marine and nature directives (explicitly or via proxy), and through its operationalisation via the direct use of EU reported information on their state, which then makes assessment outcomes 'one-to-one' relevant to support the implementation of EU legislation and policy objectives. However, as described under Section 1.1 (see 1.1.2 (iv)) the MECSA approach is not completely constrained by the structures set out under relevant EU legislation and policies and neither by available reported information on their state (e.g. global and regional assessments can be used when EU assessments are insufficient).

In designing this approach, we also *set out* to present a flexible method that could be applied in a best case scenario (e.g. spatial data available); in a moderate case (semi-quantitative); or in data poor situations. The MECSA framework and method herein, was, therefore, designed so that it could capture the complexity of the system, but would not be reliant on data-driven or spatially resolved information. However, we know that there is currently poor marine environmental information/data availability in many regions (particularly for marine habitats – see Kaiser et al., 2015), judging by what is reported at the EU level from the implementation of the relevant environmental legislation (ETC/ICM, 2014; EEA, 2015) and, thus, available for this assessment; we also know that existing data at the EU level tends not to be spatially explicit (including because what is reported from the legislation is not actual, georeferenced datasets but assessment products, i.e. information rather than data) (ETC/ICM, 2014). Further, EU-level consistent mapping approaches for European seas are incomplete (e.g. no consistent layers for pelagic habitats) (EEA, 2015), or mapping is of a resolution that is not comprehensive of all the contributing factors for ecosystem service generation and, thus, for a complete services capacity assessment (EEA, 2016).

The above means that, in the three test case assessments resulting from the application of the MECSA method developed herein (Annexes II–IV and summarised in Section 5), we were only able to work in information/data poor or moderate (semi-quantitative) situations, and that the results could not be presented in a spatially explicit format (although they were linked to the EU marine regions, see Section 3 for more detail on this). This is equivalent to a MAES Tier 1 type approach, where a qualitative assessment of relevant state information is used to assess the current and future state of the capacity of the ecosystem to supply services, and their direction of change, and this is not spatially supported (mapped). Few MECSA applications will be readily 'mappable' at the EU marine regional scale, and in Section 7 we explore this issue further in terms of the implications for the future development of assessment frameworks and methodologies in the MECSA domain.

2 Marine Ecosystem Services for the MECSA approach

2.1 Ecosystem Services typology – the Common International Classification of Ecosystem Services (CICES version 4.3) in a marine context

As described under Section 1, the Common International Classification of Ecosystem Services (CICES) approach for the classification of ecosystem services[17] was developed primarily for the terrestrial system but is widely used, including being the EU services 'reference' typology for ecosystem services as adopted by Working Group (WG) MAES (Maes et al., 2013). It is, therefore, used as *the basis* for a typology of marine ecosystem services here and this is, specifically, version 4.3[18] of CICES (CICES, 2013, see Haines-Young & Potschin, 2013). CICES is composed of a hierarchical table of services, starting from the 'section' (e.g. Provisioning) and subdivided through 'division' (e.g. Nutrition), 'group' (e.g. Biomass) and 'class' (e.g. *Wild animals and their outputs*). 'Class' can be further subdivided into 'types' of services (see summary in Box 2.1 and full coverage in Table 2.1).

Being the WG MAES reference typology implies that the CICES classification is multi-purpose in nature, in that it can be used for mapping and assessment of ecosystem capacity for service supply (*supply-side* approach, see Section 1.4.4), as well as for service benefit valuation and ecosystem monetary accounting purposes (*demand-side* approach, see Sections 1.4.2. and 1.4.4.). For use in an approach that is designed to assess the overall state of the capacity of the ecosystem to supply services (see Section 1.4.4), it is important that an extensive catalogue of possible ecosystem services is considered, regardless of whether these can be valued or accounted, in particular in monetary terms. Thus, in the process of customising the CICES typology to be relevant for the marine ecosystem capacity for service supply assessment (MECSA) under consideration here, we have:

- Identified the 'sections' and 'divisions' relevant in a marine context (Box 2.1)
- *Mostly* limited ourselves to excluding services ('classes' and 'groups') that are not applicable in a marine context (see Tables 2.1 and 2.2).

The CICES classification is designed to cover only 'final' services (those final outputs or products from ecosystems for which there is a direct active or passive human demand, see Section 1.4.1) but, as described in Section 1.4.2, there is some debate as to whether all the services covered in CICES can all be unequivocally considered as final. As such, it would be best to consider them as 'potential final services' (Haines-Young & Potschin, 2016). Under Section 4 (where we define each of the marine ecosystem services that we have included in our assessment approach), we give examples of where some of the services that may not be immediately perceived as being 'final', can indeed be interpreted as a final ecosystem output with a direct human (active or passive) use (and benefit).

[17] Following the CICES version 4.3 approach (see https://cices.eu/resources/) , we do not consider abiotic outputs (abiotic natural capital stocks or flows, e.g. sand, salt, oil, etc., cf. Table 7.2 in EEA, 2015, and Haines-Young & Potschin, 2013) as ecosystem services in the typology here. This is because the state of these is not tightly linked to the state of the ecosystem, which is a fundamental requirement for our assessment approach.

[18] CICES version 4.3 underwent a review during 2016/2018 resulting in CICES version 5.1 (see Haines-Young & Potschin, 2018). See Section 7 and Annex VI.

Box 2.1 Marine interpretation of part of the CICES version 4.3 ecosystem services hierarchy

CICES Section	CICES Division	CICES Group (Class example)
Provisioning services All materials and biota constituting tangible outputs from marine ecosystems. They can be exchanged or traded as well as consumed or used by people (in, e.g., manufacturing)	*Nutrition* – All marine ecosystem outputs that are used as foodstuffs (seafood). *Materials* – Marine biotic materials that are used directly or in the manufacture of goods. *Energy* – Marine biotic materials that are used in the production of energy	• Biomass (seafood from wild or in situ cultured plants, algae and animals as well as from their wild outputs) • Biomass (fibres and other raw biotic materials including genetic material) • Biomass-based energy sources
Regulation and maintenance services All the ways in which marine biota and ecosystems control or modify the biotic and abiotic parameters defining the environment of people (i.e. all aspects of the 'ambient' environment). These marine ecosystem outputs are not consumed, but they affect the performance of individuals, communities and populations.	*Mediation of waste, toxicants and other nuisances* – Marine biota or ecosystems can mediate (neutralise or remove) waste and toxic substances that result from human activities. This mediation has the effect of detoxifying the marine environment. *Mediation of flows* – Marine biota/ecosystem contribution to maintaining coastal landmasses and currents, reducing the intensity of floods, and keeping a favourable ambient climate. *Maintenance of physical, chemical and biological conditions* – Marine biota/ecosystem contribution to the provision of sustainable human living conditions.	• Mediation by biota • Mediation by ecosystems • Mass flows • Liquid flows • Gaseous / air flows • Lifecycle maintenance, habitat and gene pool protection • Pest and disease control • Soil formation and composition • Water conditions • Atmospheric composition and climate regulation
Cultural services Includes all non-material marine ecosystem outputs that have physical, experiential, intellectual, representational, spiritual, emblematic, or other cultural significance.	*Physical and intellectual interactions with marine plants, algae, animals, ecosystems, and land-/seascapes [environmental settings]* – Marine biota/ecosystems underpin or enhance recreation and leisure, as well as underpin intellectual, cultural, emotional, and artistic development that can depend on a particular state of marine/coastal ecosystems (or where this can enhance it). *Spiritual, symbolic and other interactions with marine plants, algae, animals, ecosystems, and land-/seascapes [environmental settings]* – Marine biota/ecosystems underpin spiritual development and aspects of legacy, as well as act as cultural or other symbols and have an intrinsic significance to people that can depend on a particular state of marine/coastal ecosystems (or where this can enhance it).	• Physical and experiential interactions • Intellectual and representative interactions • Spiritual and/or emblematic interactions • Other cultural outputs

Notes: Marine interpretation is with regards to CICES v3.4 'sections' and 'divisions' as well as a list of the relevant marine ecosystem services 'groups' and a few examples of marine ecosystem services 'classes' (in brackets, see them all in Table 2.1). Adapted from EEA, 2015; Maes *et al,* 2013; and CICES v4.3.

Thus, going forward here, version 4.3 of the CICES typology of ecosystem services (Table 2.1) was reviewed, building on the review by Maes et al. (2014), and this led to services either being taken forward or not, as necessary to adequately characterise those supplied by marine ecosystems, including when comparing the capacity of marine ecosystems with that of other ecosystems. Services that were not taken forward from the CICES typology into our assessment approach were excluded on the basis of the following criteria:

A. **Not relevant in a marine context**
   e.g. *Animal-based mechanical energy,* such as horse power, has no known equivalent marine example, or
B. **Contribution from marine ecosystems is marginal compared to terrestrial and/or freshwater ecosystems**
   e.g. *Micro and regional climate regulation* – this service is the biotically mediated small-scale changes in temperature, humidity, wind patterns and precipitation that can be caused by forests, etc. However, the contribution from marine ecosystems to this service, i.e. from salt marsh plants, occurs on a much smaller scale, **or**
C. **The marine biotic contribution is negligible in comparison with the role played by the marine abiotic environment**
   e.g. *Dilution by marine ecosystems* – although bioturbators and filter feeders may facilitate dilution of substances/particles, this is on a significantly smaller scale compared to the (abiotically mediated) physical processes driving dilution within the water column, i.e. wind driven mixing, global flows/currents and tidal movement, and which also depends on the actual (abiotically mediated) volume of seawater.

Nevertheless, for both, categories **B and C**, if it is known that the marine biotic contribution to the service can be considerable for some specific cases (even if overall it is marginal or negligible compared to that delivered by the terrestrial and/or freshwater ecosystems (B), or the marine abiotic environment (C) respectively), we have retained the ecosystem service category. For example, the *pollination and seed dispersal* service is mainly mediated by the abiotic environment in marine ecosystems, but there are some examples where marine animals are known to be a significant contributor to the dispersal of seed. For example, it has been suggested that biologically mediated seed dispersal of seagrasses, by fish, birds or turtles, could be as or more important than abiotic mechanisms of dispersal, with seeds potentially being dispersed to distances of around 20 km away. In addition, biologically mediated dispersal can allow isolated areas to be reached which would otherwise not be (Sumoski and Orth, 2012).

A full rationale for all the services *not* taken forward in our assessment approach based on the criteria above is given in Table 2.1 below. All other services in the CICES typology were retained and this delivered a list of 33 marine ecosystem services (see Table 2.2). However, some further changes that included: addition of services, deletion of part of a service as well as re-grouping and re-naming of services, were identified as being required in implementing the use of the typology for our assessment approach and these are described under Section 2.2.

Table 2.1 The CICES classification of ecosystem services version 4.3 (17/01/2013, available at https://cices.eu/resources/) and its customisation in a marine context

CICES for ecosystem service mapping and assessment ***(version 4.3)***					**Exclusion criteria for a CICES customisation in a marine context**
CICES for ecosystem accounting (version 4.3)				Note this section is open in that many class types can potentially be recognised and nested in the higher level classes, depending on the ecosystems being considered.	
Section	**Division**	**Group**	**Class**	**Class type**	
This column lists the three main categories of eco-system services.	***This column divides section categories into main types of output or process.***	***The group level splits division categories by biological, physical or cultural type or process.***	***The class level provides a further sub-division of group categories into biological or material outputs and bio-physical and cultural processes that can be linked back to concrete identifiable service sources.***	***Class types break the class categories into further individual entities and suggest ways of measuring the associated ecosystem service output.***	
Provisioning	Nutrition	Biomass	*Cultivated crops*	*Crops by amount, type*	*A*
			Reared animals and their outputs	*Animals, products by amount, type*	*A*
			Wild plants, algae and their outputs	*Plants, algae by amount, type*	
			Wild animals and their outputs	*Animals by amount, type*	
			Plants and algae from *in-situ* aquaculture	*Plants, algae by amount, type*	
			Animals from *in-situ* aquaculture	*Animals by amount, type*	
		Water	Surface water for drinking	*By amount, type*	*A*
			Ground water for drinking		*A*
	Materials	Biomass	Fibres and other materials from plants, algae and animals for direct use or processing	*Material by amount, type, use, media (land, soil, freshwater, marine)*	
			Materials from plants, algae and animals for agricultural use		
			Genetic materials from all biota		
		Water	Surface water for non-drinking purposes	*By amount, type and use*	*A*
			Ground water for non-drinking purposes		*A*
	Energy	Biomass-based energy sources	Plant-based resources	*By amount, type, source*	
			Animal-based resources		
		Mechanical energy	Animal-based energy	*By amount, type, source*	*A*

CICES for ecosystem service mapping and assessment ***(version 4.3)***					**Exclusion criteria for a CICES customisation in a marine context**
CICES for ecosystem accounting (version 4.3)				Note this section is open in that many class types can potentially be recognised and nested in the higher level classes, depending on the ecosystems being considered.	
Section	**Division**	**Group**	**Class**	**Class type**	
Regulation & Maintenance	Mediation of waste, toxics and other nuisances	Mediation by biota	Bio-remediation by micro-organisms, algae, plants, and animals	*By amount, type, use, media (land, soil, freshwater, marine)*	
			Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals	*By amount, type, use, media (land, soil, freshwater, marine)*	
		Mediation by ecosystems	Filtration/sequestration/storage/accumulation by ecosystems	*By amount, type, use, media (land, soil, freshwater, marine)*	
			Dilution by atmosphere, freshwater and marine ecosystems		*C*
			Mediation of smell/noise/visual impacts		Noise – A
	Mediation of flows	Mass flows	Mass stabilisation and control of erosion rates	*By reduction in risk, area protected*	
			Buffering and attenuation of mass flows		
		Liquid flows	Hydrological cycle and water flow maintenance	*By depth/volumes*	*C*
			Flood protection	*By reduction in risk, area protected*	
		Gaseous / air flows	Storm protection	*By reduction in risk, area protected*	*A*
			Ventilation and transpiration	*By change in temperature/humidity*	
	Maintenance of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Pollination and seed dispersal	*By amount and source*	
			Maintaining Nursery Populations and Habitats and habitats	*By amount and source*	
		Pest and disease control	Pest control	*By reduction in incidence, risk, area protected*	
			Disease control		
		Soil formation and composition	Weathering processes	*By amount/concentration and source*	*B*
			Decomposition and fixing processes		
		Water conditions	Chemical condition of freshwaters	*By amount/concentration and source*	*A*
			Chemical condition of salt waters		
		Atmospheric composition and climate regulation	Global climate regulation by reduction of greenhouse gas concentrations	*By amount, concentration or climatic parameter*	
			Micro and regional climate regulation		B

CICES for ecosystem service mapping and assessment ***(version 4.3)***					**Exclusion criteria for a CICES customisation in a marine context**
CICES for ecosystem accounting (version 4.3)				Note this section is open in that many class types can potentially be recognised and nested in the higher level classes, depending on the ecosystems being considered.	
Section	**Division**	**Group**	**Class**	**Class type**	
Cultural	Physical and intellectual interactions with biota, ecosystems, and land-/seascapes [environmental settings]	Physical and experiential interactions	Experiential use of plants, animals and land-/seascapes in different environmental settings	*By visits/use data, plants, animals, ecosystem type*	
			Physical use of land-/seascapes in different environmental settings		
		Intellectual and representative interactions	Scientific	*By use/citation, plants, animals, ecosystem type*	
			Educational		
			Heritage, cultural		
			Entertainment		
			Aesthetic		
	Spiritual, symbolic and other inter-actions with biota, ecosystems, and land- /seascapes [environmental settings]	Spiritual and/or emblematic	Symbolic	*By use, plants, animals, ecosystem type*	
			Sacred and/or religious		
		Other cultural outputs	Existence	*By plants, animals, feature/ecosystem type or component*	
			Bequest		

Notes:

- The services in the boxes coloured in dark grey were not taken forward in the approach to assess marine ecosystem capacity for service supply in the approach here as they were not considered to be relevant in a marine context, including when comparing the capacity of marine ecosystems with that of other ecosystems (the full rationale is given in the text below).
- The letter in the last right-hand column refers to the exclusion criteria used for the proposed change (see the introductory text above for full definitions of the criteria: A: no known marine examples of the service; B: marginal contribution of marine ecosystems to the service; C: *biotic* contribution to the (possible) service negligible in the marine environment).

A full description of each marine ecosystem service taken forward in our assessment approach is available in Section 4, where they are also discussed in light of those parts of the marine ecosystem that can contribute to their supply. Below the rationale for each service *not* taken forward (as per Table 2.1) is given:

Provisioning

- ***Cultivated crops*****:** Refers to terrestrial crops i.e. not marine; outputs from *in situ* aquaculture are considered a separate service
- ***Reared animals and their outputs*****:** Refers to terrestrial animals i.e. not marine; outputs from *in situ* aquaculture are considered as a separate service
- ***Surface water for drinking*****:** The *availability* of (fresh)water can be mediated ecologically (e.g. by trees), although this is only relevant in terrestrial systems and not marine and, thus, was not included here. Although seawater can be desalinated to be used as drinking water or used directly to cool power plants, as the availability (volume) of seawater is not ecologically mediated[19], seawater would be considered as a resource under an assessment of abiotic outputs (i.e. not an ecosystem service).
- ***Ground water for drinking*****:** Freshwater – not marine
- ***Surface water for non-drinking purposes*****:** See surface water for drinking
- ***Ground water for non-drinking purposes*****:** See ground water for drinking
- ***Animal-based (mechanical) energy*****:** No known marine equivalent

Regulation and Maintenance

- ***Dilution by atmosphere, freshwater and marine ecosystems*****:** Although bioturbators and filter feeders may facilitate dilution of substances/particles, this is on a significantly smaller scale compared to the dilution by seawater volume, wind driven mixing, global flows/currents and tidal movement of the marine environment; i.e. the biotic contribution to the (possible) service is negligible in comparison with the role played by the abiotic environment.
- ***Hydrological cycle and water flow maintenance*****:** There are localised coastal influences on the hydrological cycle by the Dimethyl sulphide (DMS) produced directly by phytoplankton or by bacteria degrading phytoplankton, as well as localised flow changes due to algal and higher plant structures. However, the major forces driving the hydrological cycle are physical processes, such as evaporation, condensation, precipitation, etc.; i.e. the biotic contribution to the (possible) service is negligible in comparison with the role played by the abiotic environment
- ***Storm protection*****:** Under the *Gaseous/air flows* group, the *Storm protection* class was not considered to be relevant for the marine environment as marine ecosystem components would not buffer the effects of wind and air movements as, e.g., a treeline would; i.e. the contribution from marine ecosystems to this service is marginal compared to terrestrial and/or freshwater ecosystem components.
- ***Weathering processes*****:** Physical and chemical weathering involves the breakdown of rocks, soil and minerals through contact with the earth's atmosphere and waters and in some cases biological elements. However, the marine biotic components involved are often lichens, plants and fungi in saltmarshes, i.e. the contribution from marine ecosystems to this service is marginal compared to terrestrial and/or freshwater ecosystems.

- ***Chemical condition of freshwaters*****:** Not marine

[19] Note that the *quality* of seawater is ecologically mediated, and that related services (including its direct use and processing) are dealt with in the Regulation and maintenance category. See Table 2.1 and also Section 4

- ***Micro and regional climate regulation*****:** This service is the biotically-mediated small-scale changes in temperature, humidity, wind patterns and precipitation which can be caused by forests, etc. However, the contribution from marine ecosystems e.g. from saltmarsh plants, occurs on a much smaller scale, i.e. the contribution from marine ecosystems to this service is marginal compared to terrestrial and/or freshwater ecosystems.

2.2 Further revisions – working names, changes in grouping of services, deletions and additions

Having adequately characterised the role of marine ecosystems in service supply by removing services that are not marine-relevant (Section 2.1 and Table 2.1), we then reviewed the remaining typology, and made a number of further revisions to both aid appropriate use of the typology and increase its coverage:

1. In some cases, it was difficult to differentiate between two CICES service 'classes' in the same 'group' and there were concerns that this could result in a 'double assessment' of the class level (and thus 'double counting' in an economic valuation exercise or monetary accounting, see Section 1.4.2). This could arise where the ecosystem components (and implicit functions and processes associated with those) involved in the delivery of the 'class' level services would be the same, and so there would be no difference in the capacity to supply those services. This was found to be the case for *Mass stabilisation and control of erosion rates* (shortened to the more marine-relevant name of *Erosion prevention* in this Report, see Table 2.2) and *Buffering and attenuation of mass flows* (shortened to the more marine-relevant name of *Sediment retention* in this Report, see Table 2.2). Both these regulation and maintenance service classes under the *Mass flows* group involve the accumulation and stabilisation of marine sediments, as well as the attenuation of wave energy. The same ecosystem components (biota such as seagrass and macroalgae, and relevant habitats) and processes would be involved in providing both these services, and so, we decided not to separate the group into these class level services; although we have given it the more intuitive 'working name' of *Erosion prevention and sediment retention* and considered it, de facto, as service class (rather than a service group).
2. Difficulty in differentiating between two CICES service 'classes' within one 'group' can also arise where it is difficult to separate out the beneficiaries that would make use of the class level services. This is certainly the case for the example given in (1) above, but we also found this to be the case for the *Physical use* and *Experiential use* categories under the cultural services *Physical and experiential interactions* group. In theory, one could separate out users that might be *most likely* to benefit from *physical use* (e.g. through sailing, leisure angling, etc.) from those that would benefit most from *experiential use* (e.g. through whale watching, snorkelling, etc.) (see EEA, 2015). However, we are not aware of conclusive evidence to suggest that, in practice, the beneficiaries of those use types would only benefit from either *physical or experiential* use of the marine ecosystem. Due to this, we decided not to separate the group into these class level services; although we have given it a more intuitive 'working name': *Recreation and leisure* and considered it, de facto, as service class (rather than a service group).
3. In one case we could not differentiate easily between two CICES service 'classes' from two different 'groups'. *Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals,* i.e. by biota, and *Filtration/sequestration/storage/accumulation by ecosystems* are treated as two separate (regulation and maintenance) service classes under different groups (which also separate mediation by biota and by ecosystems) in the v4.3 of CICES. However, biota are part of ecosystems and the waste etc. treated is the same in both cases, making these two separate services classes unnecessary; and again, likely to lead to 'double

assessment' (and thus 'double counting' in an economic valuation exercise). We have aggregated here across the two groups into one class level service instead and given it the more intuitive 'working name' of *Waste and toxicant removal and storage*.

4. *Gene pool protection* was not included in the CICES 4.3 classification table (Table 2.1) as a service 'class' but was included in the *Lifecycle maintenance, habitat and gene pool protection* 'group' name. We, therefore, believe this to have been an oversight, as we have identified this service in marine ecosystems, and we have added it in here, at the class level, under the *Lifecycle maintenance, habitat and gene pool protection* group (Table 2.2).
5. *Mediation of smell/noise and visual impacts* was changed to *Mediation of smell/visual impacts*. The CICES interpretation of this service class refers to green infrastructure, such as trees, screening transport corridors and reducing noise, smells and visual impacts. The interpretation for marine ecosystems in this assessment approach deviates from the CICES interpretation, in particular because the mediation of noise is excluded as it is not considered to be relevant in a marine context. Therefore, this part of the service class (i.e. noise) was excluded based on criterion A in Section 2.1.
6. As shown above, in a final step, more intuitive 'working names' were adopted for each service and were used (Table 2.2), and these, in some cases (but not all), differ from those in the CICES typology (Table 2.1). These working titles were adopted in order to be clearer on what each service means in practice and to be as specific as possible to the marine ecosystem where relevant (e.g. seafood), without the need for all hierarchical parts of the CICES tables to be displayed in order to understand what the service (class) in question means. Table 2.2 can, however, act as a cross-walk so that assessment results given under the 'working names' presented here can be easily related back to the original CICES classification names in Table 2.1.

Finally, we note that there is some 'blurring' across the names used by CICES at all the levels within the hierarchy. Thus, what is being conveyed by the name can, at times, be: (1) an ecosystem process or a function (i.e. an intermediate service); (2) a (final) service; (3) a human activity drawing on the service; (4) a service benefit; and/or (5) even a good (according to other assessment approaches) – *sensu* the ecosystem service 'cascade' model (see Section 1.4.1). For example, the name 'Nutrition' for one of the provisioning services divisions represents a benefit from using the relevant services (e.g. from eating wild or in situ cultured seafood), rather than the services themselves (e.g. the biota eaten as seafood). This blurring is also evident in some of the working names used here because a larger review of CICES was out of the scope of our work[20]. We have mostly limited our name changes to those that are necessary to refine the typology to be suitable in a marine context, or where we found the original name difficult to interpret (not intuitive).

Nevertheless, we found the cultural services were somewhat of a "special case" in terms of the 'blurring' of names (see also Haines Young & Potschin, 2013; Haines-Young & Potschin, 2016), in that the blurring is found right from the level of Division. At the 'Division' and 'Group' level within the CICES typology for Cultural Services, the name includes the word 'interactions', which suggests the activity/use that is drawn from the service, rather than being descriptive of the service itself. We have tried to resolve this 'blurring' here by redefining the cultural service names <u>at the CICES 'division' level</u>, to emphasize that the service is the "underpinning" (or "enhancing") of those interactions (by biota and/or ecosystems, including in land-/seascapes), rather than the interactions themselves (see Table 2.2).

[20] CICES version 4.3 underwent a review during 2016–2018 resulting in CICES version 5.1 (see Haines-Young & Potschin, 2018). See Section 7 and Annex VI.

Table 2.2 Typology of marine ecosystem services considered in the MECSA 'linkages framework' approach (in Section 4 of this Report)

CICES names (version 4.3)				This study	
CICES Section	**Division**	**Group**	**Class**	**Service No.**	**Marine Ecosystem Service Working Name**
Provisioning	Nutrition	Biomass	Wild plants, algae and their outputs	1	Seafood from Wild Plants and Algae
			Wild animals and their outputs	2	Seafood from Wild Animals
			Plants and algae from *in-situ* aquaculture	3	Plant and Algal Seafood from *in-situ* Aquaculture
			Animals from *in-situ* aquaculture	4	Animal Seafood from *in-situ* Aquaculture
	Materials	Biomass	Fibres and other materials from plants, algae and animals for direct use or processing	5	Raw Materials
			Materials from plants, algae and animals for agricultural use	6	Materials for Agriculture and Aquaculture
			Genetic materials from all biota	7	Genetic Materials
	Energy	Biomass-based energy sources	Plant-based resources	8	Plant and Algal-based Biofuels
			Animal-based resources	9	Animal-based Biofuels
Regulation & Maintenance	Mediation of waste, toxics and other nuisances	Mediation by biota	Bio-remediation by micro-organisms, algae, plants, and animals	10	Waste and Toxicant Treatment via Biota
			Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals	11	Waste and Toxicant Removal and Storage
		Mediation by ecosystems	Filtration/sequestration/storage/accumulation by ecosystems		
			Mediation of smell/noise/visual impacts	12	Mediation of Smell/Visual Impacts
	Mediation of flows	Mass flows	Mass stabilisation and control of erosion rates	13	Erosion Prevention and Sediment Retention
			Buffering and attenuation of mass flows		
		Liquid flows	Flood protection	14	Flood Protection
		Gaseous / air flows	Ventilation and transpiration	15	Oxygen Production
	Maintenance of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Pollination and seed dispersal	16	Seed and Gamete Dispersal
			Maintaining Nursery Populations and Habitats	17	Maintaining Nursery Populations and Habitats
			Gene pool protection	18	Gene Pool Protection
		Pest and disease control	Pest control	19	Pest Control
			Disease control	20	Disease Control
		Soil formation and composition	Decomposition and fixing processes	21	Sediment Nutrient Cycling
		Water conditions	Chemical condition of salt waters	22	Chemical Condition of Seawater
		Atmospheric composition and climate regulation	Global climate regulation by reduction of greenhouse gas concentrations	23	Global Climate Regulation

Table 2.2 Cont.

CICES names (version 4.3)				This study	
CICES Section	**Division**	**Group**	**Class**	**Service No.**	**Marine Ecosystem Service Working Name**
Cultural	Underpinning or enhancing physical and intellectual interactions (*through direct or indirect contact with marine biota and/or ecosystems, including in land-/seascapes [environmental settings]*)	Physical and experiential interactions	Experiential use of plants, animals and land-/seascapes in different environmental settings	24	Recreation and Leisure
			Physical use of land-/seascapes in different environmental settings		
		Intellectual and representative interactions	Scientific	25	Scientific
			Educational	26	Educational
			Heritage, cultural	27	Heritage
			Entertainment	28	Entertainment
			Aesthetic	29	Aesthetic
	Underpinning or enhancing spiritual, symbolic and other interactions (*through direct or indirect contact with marine biota and/or ecosystems, including in land-/seascapes [environmental settings]*)]	Spiritual and/or emblematic	Symbolic	30	Symbolic
			Sacred and/or religious	31	Sacred and/or religious
		Other cultural outputs	Existence	32	Existence
			Bequest	33	Bequest

Notes: This table shows the CICES names (version 4.3) for ecosystem services from all ecosystems in columns 1–4 on the left hand side (with the exception of the cultural services, where there has been a slight modification) with a cross walk to a number and the common/working names for the marine ecosystem services used in the MECSA approach in columns 5–6 on the right hand side (for a rationale of this typology see Sections 2.1 and 2.2 above, and for details on the definition of each service see Section 4).

2.3 Next steps

In Section 3 of this Report, an EU-policy relevant typology of marine ecosystem components is defined in order that all marine ecosystem components that have the potential to hold capacity for the supply of any one marine ecosystem service listed here and used in EU marine regions can be identified (in Section 4). As said, a detailed definition of each of the services from Table 2.2 is given in Section 4 of this Report, and the specific dependency on the ecosystem is also explained in Section 4 as well as in Annex I. Further discussion on the use of the CICES typology for a marine ecosystem service supply capacity assessment approach is given under Sections 6 and 7.

3 Marine ecosystem components for the MECSA approach

3.1 Marine ecosystem components in the context of the MAES marine ecosystem typology and the MSFD's Descriptor 1 (Biological diversity)

3.1.1 MAES marine ecosystem typology and marine ecosystem components

As mentioned in Section 1.1, Working Group (WG) MAES (Mapping and Assessment of Ecosystems and their Services) marine ecosystem types provide the framework for the initial characterisation of the ecosystem components for this assessment approach (see Maes et al., 2013). The MAES ecosystem typology is a hierarchical reference typology for European ecosystems, defining the ecosystem at two levels – Level 1 is the major ecosystem category and includes Terrestrial, Fresh Water and Marine categories, and Level 2 is the ecosystem types that should be relevant for ecosystem and services mapping and assessment (see columns 1 and 2 in Table 3 of Maes et al., 2013). In the marine category, there are four Level 2 ecosystem types:

1. Marine inlets and transitional waters
2. Coastal
3. Shelf, and
4. Open Ocean

The MAES ecosystem typology further disaggregates Level 2 ecosystem types to a list of habitat types under the '*Representation of habitats (functional dimension by EUNIS)/MSFD for marine ecosystems*' (column 3 in Table 3 of Maes et al., 2013), taken here as an additional hierarchical 'level' and herein referred to as 'Level 3'. To note, however, that there are some limitations in how the Level 2 marine ecosystem types have been defined as acknowledged in Maes et al. (2013, 2014) and Condé et al (2018) in terms underpinning the mapping and assessment of marine ecosystems and their services using EU policy-based information. These limitations include the repetition of 'Level 3' marine habitat types across some of the Level 2 marine ecosystem types. Also the fact that the MAES marine ecosystem typology *'ignores the important role of the photic zone (under influence of light), which drives the functioning of marine food webs'*, where '*introducing the photic limit in the typology requires a link to the MSFD zones, which is not straightforward and has not been undertaken at the moment'* (Maes et al., 2013).

Nevertheless, 'Level 3' on the 'Representation of habitats (functional dimension by EUNIS)/MSFD for marine ecosystems' of the MAES ecosystem typology is the entry point into our use of the MAES marine ecosystem typology for the development of our ecosystem components. This is because the 'Representation of habitats (functional dimension by EUNIS)/MSFD for marine ecosystems' comprises of a list of the predominant habitat types under the scope of the MSFD with some degree of aggregation (Table 3.1), and this allows our approach to be 'one-to-one' policy relevant with this key piece of EU marine legislation.

For the 'Marine inlets and transitional waters' ecosystem type, the MAES marine ecosystem typology also provides a set of (spatial) physiographic features occurring in this type when considering its spatial extent across the land-sea interface. The link between these features and the relevant MSFD pelagic habitat types has been made partially explicit in the typology, by linking a modification of the latter to a few individual features or groupings of features. This association is shown in the brackets used in the 'Level 3' column of Table 3.1, which corresponds to the 'Representation of habitats (functional dimension by EUNIS)/MSFD for marine ecosystems', i.e. the 3rd column, in the MAES marine ecosystem typology. However, the MAES typology did not link these features to the relevant MSFD benthic habitat types, which would have also been necessary. The full set of features is only made explicit in the 4th column of the MAES typology, called '*Representation of land-cover (spatial dimension*)' and referred to as 'Level 3bis' in Table 3.1 here. These features are: Coastal wetlands (saltmarshes, saline and intertidal flats), lagoons, estuaries and other transitional waters, fjords/sea lochs, and embayments. However, these features are not defined directly in Maes et al (2013), only indirectly in relation to Corine Land Cover classes, which is insufficient for their adequate discrimination across the EU as, e.g., in some cases, such as for 'other transitional waters', there is no direct equivalence.

Table 3.1 Summary of the MAES marine ecosystem typology

MAES Level 1 major ecosystem category	MAES Level 2 ecosystem type	MAES 'Level 3' (slightly modified) MSFD habitat types (1) (and 'Level 3bis' Features)	Physical properties of the habitat
Marine	Marine inlets and transitional waters	Low/reduced salinity water (of lagoons)	Photic/aphotic
		Variable salinity water (of coastal wetlands, estuaries and other transitional wa-	Photic/aphotic
		Marine salinity water (of other inlets)	Photic/aphotic
		Littoral rock and biogenic reef	Photic/aphotic, up to 50–70 m depth
		Littoral sediment	
		Shallow sublittoral rock and biogenic reef	
		Shallow sublittoral sediment	
	Coastal	Coastal waters	Photic/aphotic
		Littoral rock and biogenic reef	Photic/aphotic, up to 50–70 m depth
		Littoral sediment	
		Shallow sublittoral rock and biogenic reef	
		Shallow sublittoral sediment	
	Shelf	Shelf waters	Photic/aphotic
		Shelf sublittoral rock and biogenic reef	Aphotic, 70–200 m depth
		Shelf sublittoral sediment	
	Open Ocean	Oceanic waters	Photic/aphotic
		Upper bathyal rock and biogenic reef	Aphotic, > 200 m depth
		Upper bathyal sediment	
		Lower bathyal rock and biogenic reef	
		Lower bathyal sediment	
		Abyssal rock and biogenic reef	
		Abyssal sediment	

Notes:

(0) This summary uses columns 1 (Level 1), 2 (Level 2), 3 ('Representation of habitat types (functional dimension by EUNIS)/MSFD for marine ecosystems', i.e. 'Level 3') and 4 ('Representation of land-cover (spatial dimension)', i.e. 'Level 3bis') from Table 3 of Maes et al. (2013) directly. Some of these columns also provide information on the physical properties of the habitats, which has been used to develop the last column of the table here.

(1) These habitat types are an aggregation of the MSFD predominant habitat types in EC (2011b), without the full range of substrates associated to each benthic habitat, which were revised into broad pelagic and benthic habitat types in EC (2017).

As explained under Section 1.4.3 of this Report, it is the biota what, ultimately, hold the capacity to supply ecosystem services (as ecological structures in themselves, or through the ecological process and functions they are involved in). For this reason, it was necessary to consider how the ecosystem typology developed for the MECSA approach here could be organised by biotic groups, but also link to the representation of habitat types as specified by the MAES 'Level 3'. Under the MSFD, some taxa are included (embedded) within the 'predominant' habitat types (i.e. where seabed/benthic habitat types include macroalgae, angiosperms and invertebrate bottom fauna, and water column/pelagic habitat types include phytoplankton and zooplankton communities (cf. MSFD Annex III Table I; Table 8 in EC, 2011b))[21]. Then, the species groups not accounted for within predominant habitat types are treated separately as a list of 'functional groups', where these groups constitute the mobile species, such as fish and marine mammals (EC, 2011b).

We argue that in developing and categorising marine ecosystem components to link to ecosystem services, *it is necessary that all marine biotic groups are explicitly specified and then associated with all marine habitat types they can be found in*. The reasons for this are as follows:

1. Different biotic groups present within a given habitat can contribute in different ways to service supply. For the purposes of defining the contribution to this supply, it is important therefore to determine which biotic groups are contributing to a given service. For example, a seabed habitat could deliver the service Erosion prevention and sediment retention, which would be contributed to by biogenic reefs of invertebrates, macroalgae, macrophytes and microphytobenthos through stabilisation of sediments, accumulation of sediment and attenuation of wave energy (see Section 4). Another service delivered by a seabed habitat would be Seafood from wild animals provisioning, which would be contributed to through benthic invertebrates and macroalgae but not microphytobenthos.
2. Specific associations of biotic groups and habitats will be more important than others in the supply of a service. For example, for the service *Erosion prevention and sediment retention*, macroalgae may contribute more in a given seabed habitat than microphytobenthos. Thus, knowing which aspects of a habitat are the most important for the delivery of a service requires specifying the biotic groups involved in that delivery.
3. The same biotic group in different habitats may not contribute to the same services, e.g. biogenic reefs in shallow sublittoral habitats will contribute to *Erosion prevention and sediment retention,* but biogenic reefs in shelf sublittoral habitats will not as they are too far removed from the area where the erosion is occurring (i.e. do not have the possibility to supply the service from such locations, see Sections 1.4.4. and 4).

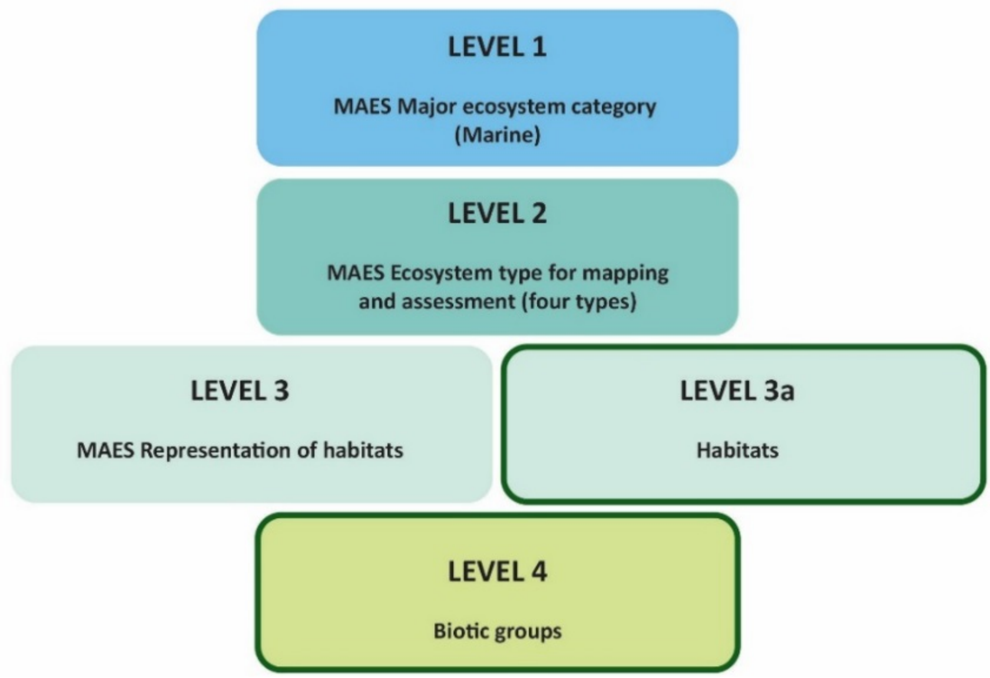
Another benefit of associating biotic groups (including mobile species) with habitats is that it allows the biotic group to be linked to a spatial unit from where the ecosystem service is derived, e.g. in the service *Seafood from wild animals* provisioning, demersal fish may be exploited from shelf sublittoral habitat types but not from abyssal habitat types (because of limitations on technology to fish at such depths). Knowing which habitats are important for supplying individual ecosystem services (or not), helps to then identify what to look for in terms of EU-level information for the actual assessment of marine ecosystem capacity for service supply. In the example given here, we know that we do not need to try and find out about the state of abyssal fish species if we are assessing the capacity to supply the *Seafood from wild animals* service. In another example (from above), we would not need to collate state information on epifaunal biogenic species (e.g. corals) in shelf sublittoral sediment

[21] We note the recent revisions of the MSFD's Annex III, where ecological characteristics are listed, and of the EC Decision on criteria and methodological standards on 'good environmental status, previously EC (2010) and now EC (2017), including for Descriptor 1, which may affect these characteristics. Both documents include the MSFD predominant habitat types and functional groups and so their reviews could have implications for the 'structural elements' of the assessment approach developed here. Further details on this are provided in Section 7.

habitat types if considering the capacity to supply the service *Erosion prevention and sediment retention*. However, biogenic habitat-forming epifauna in littoral sediment or shallow sublittoral sediments could be contributing to the ecosystem capacity for this service because these habitats are at the land-sea interface where erosion can occur.

As such, in the work going forward to develop linkages between ecosystem services and marine ecosystems for this MECSA approach, we argue that we must describe ecosystem components (see Section 3.2), where all marine biotic groups are documented *explicitly* in the ecosystem classification. To allow the documentation of biotic groups in the classification requires delineating further hierarchical 'Levels' from those outlined in MAES, which will effectively be those required for the purposes of linking services and components. These are the 'Level 3a' on 'Habitats', which builds on the original 'Level 3' of the MAES marine ecosystem typology (Table 3.1), and a 'Level 4' on 'Biotic groups', as shown in Figure 3.1. It would be possible to nest these 'Level 3a' habitats and 'Level 4' biotic groups under the four MAES 'Level 2' ecosystem types. However, doing so would require repetition of some of the 'Level 3a' habitats and many of the 'Level 4' biotic groups across the four MAES 'Level 2' ecosystem types. This is because of how the MAES 'Level 2' ecosystem types have been defined. For example, the same benthic habitat types, such as littoral sediment, are considered to part of the 'Marine inlets and transitional waters' and the 'Coastal' ecosystem types (see also Condé et al. 2018). The consequences of this duplication, along with other issues associated with the MAES 'Level 2', for linking to marine ecosystem services is discussed further in Section 4.1 and Section 6.4.

Figure 3.1: A hierarchical representation of levels of the ecosystem for the purposes of defining a classification of marine ecosystem components for the MECSA approach



Notes: Levels 1 and 2 as well as 'Level 3' come directly from the MAES typology of ecosystems for EU marine regions (from Table 3, Maes et al. 2013); while 'Levels' 3a and 4 have been specified in the MECSA approach for the purposes of linking ecosystem components to ecosystem services, and follow the relevant MSFD typologies (cf. EC, 2011b) very closely.

In the MECSA approach developed herein, 'Level 3a' is a list of habitat types that *inter alia* expands on the aggregation provided in the MAES 'Level 3' to cover all MSFD predominant habitat types[22]. Like the MSFD, these habitats naturally include biotic components. However, the embedded biotic components within these habitats (e.g. benthos) and also the MSFD (mobile) functional groups that could be attributed to them have been explicitly listed here. This is done in the next level, i.e. 'Level 4', and both embedded and mobile biota are referred to as 'biotic groups'.

The 'Level 3a' habitat types (described below) are an alternative list to the MAES 'Level 3' habitat types (see Table 3.4 for a crosswalk), hierarchically placed below the MAES Level 2 ecosystem types. These 'Level 3a' habitat types are considered to be a more representative and policy relevant (to the MSFD) list of habitats of the marine environment than those listed in the MAES 'Level 3' (see explanation below). This level is called 'Level 3a' here as it is considered to be horizontal to (or a substitute for), rather than ranked below, the MAES 'Level 3' habitat types in the hierarchy. It also includes, where relevant, an improved list of the physiographic features found in the MAES 'Level 3bis'.

'Level 4' explicitly lists the biotic groups which are associated with each 'Level 3a' habitat type; these include both those embedded within the habitats, such as benthic infauna, as well as mobile species that can move between habitats. The term *biotic groups* agglomerates all these biota and the groups are specified on the basis of how they contribute to the supply of services. We also note that for some ecosystem services it will be necessary to specify a still greater resolution than biotic groups associated with habitats. For example, when considering the capacity to supply the *Seafood from wild animals* service, it is most likely that state information will be available at the individual species level. In those cases, particular species could be specified, although these are considered to be captured within the 'Level' 4 biotic groups in this hierarchy. Below we describe how we delineated the 'Level 3a' habitat types (Section 3.1.2) and 'Level 4' biotic groups (Section 3.1.3). Linkages between these to establish the full set of ecosystem components are then covered in Section 3.2.

3.1.2 Habitat types and marine ecosystem components

The habitat types used in the MECSA approach going forward are shown in Table 3.2. Recapping and further developing what has been stated in the previous section: these MECSA habitat types are the general habitat types derived from the MAES 'Level 3' on the 'Representation of habitats (functional dimension by EUNIS)/MSFD for marine ecosystems' (from column 3 in Table 3 of Maes et al., 2013; Table 3.1 above), which were based on the MSFD predominant habitat types, with a series of adaptations and assumptions resulting in the so-called 'Level 3a' (see above).

[22] Note that a revision of the MSFD predominant habitat types listed in EC (2011b) types into broad habitat took place over 2014–2017 and is included in EC (2017). See Section 7.

Table 3.2 Habitat types ('Level 3a') adapted from the MSFD predominant habitat types and used for the development of marine ecosystem components in the MECSA approach

Ecological zone/realm	MECSA Habitat Types	Physical Properties of Habitat (1)	
Water column habitats	Variable salinity waters (pelagic parts of land-sea interface features: coastal wetlands(2); coastal lagoons; estuaries; and inlets and embayments (3))	Photic	
	Coastal waters (incl. pelagic parts of land-sea interface features with marine salinity(4), and fully open coastal waters extending up to the shelf)	Photic	
	Shelf waters	Photic/aphotic	
	Oceanic waters	Photic/aphotic	
Ice habitats	Ice-associated habitats	Seasonal sea ice and associated habitats within, on the underside and topside of the ice.	
Seabed habitats	Littoral rock and biogenic reef	Photic	Includes benthic parts of land-sea interface features occurring, in part or in full, across the supralittoral zone (5)(6) and the intertidal/eulittoral zone (7) (e.g. intertidal flats), or equivalent in non-(significantly)tidal seas. Both 'Variable salinity waters' and 'Coastal waters' pelagic types apply in terms of being the relevant overlying water column habitats to the seabed habitats here.
	Littoral sediment		
	Shallow sublittoral rock and biogenic reef		Includes benthic parts of land-sea interface features that are relatively deep and comprised of shallow sublittoral substrates, as well as the benthos of fully open coastal waters extending up to shelf. Both 'Variable salinity waters' and 'Coastal waters' pelagic types apply in terms of being the relevant overlying water column habitats to the seabed habitats here.
	Shallow sublittoral coarse sediment		
	Shallow sublittoral sand		
	Shallow sublittoral mud		
	Shallow sublittoral mixed sediment		
	Shelf sublittoral rock and biogenic reef	Aphotic(8)	Up to shelf end (200 m depth)
	Shelf sublittoral coarse sediment		
	Shelf sublittoral sand		
	Shelf sublittoral mud		
	Shelf sublittoral mixed sediment		
	Upper bathyal rock and biogenic reef		From 200 m – 1450 m depth
	Upper bathyal sediment		
	Lower bathyal rock and biogenic reef		From 1450 m – 2700 m depth
	Lower bathyal sediment		
	Abyssal rock and biogenic reef		> 2700 m depth
	Abyssal sediment		

Notes:

(0) The MSFD predominant habitat types are found in Table 7 of the Commission Staff Working Paper on the 'Relationship between the initial assessment of marine waters and the criteria for good environmental status' (EC, 2011b).

(1) The physical properties of the habitat are defined for this study based on overlapping the MAES habitats' physical properties (see Table 3.1) with those of the MSFD predominant habitat types, and with some modifications. This is, in particular, regarding the inclusion of the 'photic limit' (see Box 3.1) and consideration of spatial elements or features covered under the scope of other EU environmental legislation or EU-level habitat classifications and descriptions.

(2) Coastal wetlands: Saltmarshes, saltmeadows, salines and intertidal flats (the latter only in tidal seas, where they would actually be integrated in most of the other features there).

(3) Inlets and embayments include, inter alia, fjords, sea lochs, rias, and bays and straits in internal waters.

(4) Land-sea interface features that can have marine salinity are coastal wetlands, coastal lagoons, and inlets and embayments, as well as the nearshore, open coastal waters (up to 1nm from the territorial baseline, i.e. the WFD coastal waters). The latter are always marine and include waters along straight coastlines, and bays and straits when beyond internal waters.

(5) Supralittoral elements in land-sea interface features are their splash zone, including in the lower part of seacliffs; seacliff caves; semi- or exposed rocks; and rockpools, which are under strong marine influence through, e.g., spray, splash and/or sporadic inundation above the highest astronomical tide (HAT), or equivalent in non-(significantly)tidal seas.

(6) Coastal wetlands, such as saltmarshes, and coastal lagoons can fully occur in the supralittoral zone.

(7) The marine zonation here refers to the sea's zonation, not that within the land-sea interface features.

(8) Note that as in EC (2011b), the slope should occur where the shelf ends (200 m) and the upper bathyal begins (750 m) but as there is no 'slope' habitat category, this zone has been included under the upper bathyal category for the purposes of this exercise. For the deep sea benthic habitats, indicative depth categories are based on Howell (2010) following EC (2011b).

The adaptations and assumptions of the general habitat types derived from the MAES 'Level 3', based on the MSFD predominant habitat types, into the habitat types used in the MECSA approach are as follows:

1. The MAES habitats are further disaggregated to cover all the MSFD predominant habitat types[23] (from Table 7 in EC, 2011b; see Table 3.2), where the habitats' substrates have been split into coarse, sand, mud, and mixed sediment.

2. Like the MSFD predominant habitat types, the habitat types defined here address both the abiotic characteristics and the associated biological community, treating both elements together in the sense of the term biotope. This does not preclude the need for all associated (embedded) biological communities to be explicitly acknowledged as part of documenting *all* marine biotic groups explicitly in the ecosystem classification (see 3.1.3 below).

3. The MAES *low/reduced salinity water* habitat type (Table 3.1) has been removed as this is considered to be captured under the existing *variable salinity water* habitat type, which has been retained here (Table 3.2). The rationale here is that the one category given as a *low/re-*

[23] We note the recent revisions of the MSFD's Annex III, where ecological characteristics are listed, and of the EC Decision on criteria and methodological standards on 'good environmental status' (EC, 2010), including for Descriptor 1 may affect them. Both documents include the MSFD predominant habitat types and functional groups and so their reviews will have implications for the 'structural elements' of the assessment approach developed here. Further details on this are provided in Section 7.

duced salinity water habitat, 'lagoons', is actually more fittingly described as a *variable salinity* physiographic feature (when the lagoons are of a different salinity than that of the offshore marine environment). The reason for the inclusion of a *low/reduced salinity water* habitat type in the MAES 'Level 3' typology is thought to have be an artefact from the MSFD initial classification of predominant habitat types. Thus, the MSFD used absolute salinity and included a *reduced salinity water* pelagic habitat type to accommodate for the lower salinities of the Baltic and Black seas compared to the other MSFD regions (see Table 7 in EC, 2011b[24]). Here we require an EU-level generic typology, and although salinities may differ between these regions, the marine waters are still all marine relative to freshwater. In addition, this *variable salinity waters* habitat type is used to refer to what is mainly brackish water, although it actually comprises all possible salinities that are not (offshore) marine salinity for a given region, and which would range from oligohaline to hyperhaline over space and time at a given location. Furthermore, there would be no difference in the capacity for service delivery between *low/reduced salinity* habitats and *variable salinity* habitats (based on differences in salinity alone), which further supports the deletion of the former category.

5. The *variable salinity water* habitat type defined here is only linked to physiographic features in the land-sea interface (see point 12). Thus, the MSFD included a *variable salinity (estuarine) water* pelagic habitat type, but this would not apply in the land-sea interface as regular estuaries, which could – in principle- extend up to the 12 nm (territorial water) limit of the WFD transitional waters, are out of the scope of the MSFD (as well as other transitional waters). Therefore, this *variable salinity (estuarine) water* habitat type is assumed[25] to apply to estuarine plumes that would extend offshore beyond that 12 nm limit.

6. The MAES *marine salinity water (of other inlets)* (Table 3.1) habitat type, where the 'other inlets' refer to the above mentioned features in the land-sea interface (when they have marine salinity, see point 12), has been removed as these other inlets are considered to be captured under *coastal waters* (Table 3.2). There would be no difference in the capacity for service delivery between these coastal waters and waters of fully marine features at the coast, which further supports the deletion of this category.

7. The benthic habitats types defined here are divided according to substrate type (rock, sediment type) and are assumed to be either photic – *littoral*, *shallow sublittoral* – or aphotic – *shelf sublittoral*, *bathyal*, *abyssal*. Therefore, the delineation of the shallower benthic habitats is – *de facto*- in relation to the inclusion of the photic zone, with the 'photic limit' falling between the *shallow* and *shelf sublittoral* habitat types[26]. The 'photic limit' established here would be the absolute limit of the photic zone (i.e. that of the oligophotic zone), rather than the limit of its most productive layer (i.e. the euphotic zone). However, this is the only photic limit that can be established across the MSFD benthic habitat types because delineating the euphotic limit would require cutting through the *shallow sublittoral* habitat types (see also Box 3.1). It is acknowledged, however, that whether these shallower habitats are actually photic or aphotic will depend on the turbidity or, in a few instances, the actual depth of the water column. This will vary per EU marine region and cannot be specified in an EU-level

[24] The exclusion of this *reduced salinity water* pelagic habitat type in the list of broad pelagic habitat types in EC (2017), which revised the MSFD predominant habitat types listed in EC (2011b), supports its removal from the MECSA habitat typology

[25] This assumption has been confirmed by a note in the list of MSFD broad pelagic habitat types in EC (2017), which revised the MSFD predominant habitat types listed in EC (2011b).

[26] The assumption on the delineation of the 'photic limit' across the MSFD benthic predominant habitat types here is supported in the 2016 revision of the Level 2 of the EUNIS classification of marine benthic habitat types (cf. Evans et al., 2016).

generic typology.

8. The pelagic *variable salinity* and *coastal water* habitat types defined here are assumed to be associated with the benthic *littoral* and *shallow sublittoral* habitat types, whilst the *shelf* waters are associated with the benthic *shelf sublittoral* habitat types and the *oceanic* waters are associated with the benthic *bathyal* and *abyssal* habitat types. These associations imply that the *variable salinity* and *coastal* waters are assumed to (also) be fully photic and so that pelagic habitats have also been delineated – *de facto*- in relation to the 'photic limit'. However, it is again acknowledged that whether these waters are actually photic or aphotic will depend on the turbidity and, in a few instances, the actual depth of the water column, which will vary per EU marine region and cannot be specified in an EU-level generic typology (see also Box 3.1).

9. The assumptions made under points (7) and (8) above, mean that the spatial magnitude of the capacity for ecosystem service supply by the pelagic and (associated) benthic habitats deemed to be only photic could be overestimated when assessing any services that rely on photosynthetic biota (and see Box 3.1). However, this 'spatial overestimation' would not affect the *number* of services that can be supplied in the 'photic' habitat types overall, and it is the number of services that the linkages aim at establishing (see Table AI.24 in Annex I).

Box 3.1 Implications from the benthic 'photic limit' considered in the ecosystem typology used in the MECSA approach

The MECSA habitat typology, underpinning the MECSA ecosystem typology and assessment, follows the MSFD predominant habitat types in EC (2011b). Photic habitat types within this MECSA typology need to be separated from the aphotic ones because they can supply different services due to the different service supply capacity of the photosynthesising biotic groups (see Section 4 and Annex I). The 'photic zone' is defined here as that where there is sufficient light penetrating the water column to allow growth of marine plants and macroalgae to happen on the seafloor, and so comprising both the euphotic and oligophotic sub-zones. The initial basic assumption when defining an absolute benthic 'photic limit' for the MECSA typology was that the transition between the MSFD benthic shallow and shelf sublittoral habitat types would be at the point where there is no longer enough light penetration for such growth.

The growth of crustose coralline (red) macroalgae marks the absolute limit of the 'photic zone', i.e. that of the oligophotic zone, which we have assumed to be the actual boundary between the MSFD's shallow and shelf sublittoral habitat types (*), and which can be modelled using the 0.01% of surface incident light on the seafloor (cf. EUSeaMap 2012, Cameron & Askew, 2011). However, we know that not all photosynthetic benthic species have the same light requirements (see examples in Gattuso et al, 2006). Higher plants, e.g. angiosperms, and other (green and some brown) macroalgae require more light and their growth limit would occur within the shallower parts of the marine zonation. Their growth limit would, thus, mark the limit of the most productive layer of the 'photic zone', i.e. the euphotic zone, which can be linked to 1 % of surface incident light on the seafloor (cf. EUSeaMap 2012, Cameron & Askew, 2011). However, this boundary cannot be delineated across the MSFD benthic predominant habitat types because doing so would require cutting through the *shallow sublittoral* habitat types.

<u>In conclusion</u>: We have assumed that MSFD predominant littoral and shallow sublittoral habitat types include the entire benthic area where there is sufficient light to allow the growth of marine plants and macroalgae; although we recognise that not all the relevant species can photosynthesise in such an area (e.g. angiosperms would not in its deeper part). This assumption, in turn, implies that the growth limit for benthic higher plants, e.g. angiosperms, and some macroalgae could have been overestimated by the inclusion of the shallow sublittoral habitat types in the MECSA 'photic zone'. Such an overestimation *could* then lead to overestimating the spatial magnitude of the ecosystem services underpinned by photosynthesis from higher benthic plants and certain macroalgae, or of the area over which the services linked to these benthic species are supplied, if the assessment relies on the actual extent of

the MECSA photic habitat types, which is not the case here. However, when it comes to the most suitable information to use to carry out the actual service supply capacity assessment (see Section 5 and example in Annex III), it is often possible to be more specific about the area being assessed and the contributions of the biotic groups within ecosystem components supplying a service than would be possible from the 'Level 3a' habitat typology. We also recognise that whether the MECSA 'photic' habitats are actually photic or aphotic will depend on the turbidity and, in a few instances, the actual depth of the water column, which will vary per EU marine region and cannot be specified in an EU-level generic typology.

(*) This assumption on the delineation of the 'photic limit' across the MSFD benthic predominant habitat types is supported in the 2016 revision of the Level 2 of the EUNIS classification of marine benthic habitat types (cf. Evans et al., 2016).

10. The *ice-associated* habitats defined here include the seasonal sea-ice found in the Baltic Sea. The Arctic is not included in the geographical scope of this assessment (see Section 1). These ice habitats occur within, or on the underside and topside of, the ice. We consider *ice* to be its own habitat type, different from pelagic and benthic habitat types, but to be closely associated with the pelagic habitats as it is floating on the surface of the pelagic zone.

11. The EU marine regions covered in this assessment correspond in geographical scope to those listed in Article 4 of the MSFD and delineated in the map on the 'Marine regions and subregions of the MSFD'[27]. However, the nature of these seas, in terms of their coverage of marine zones and the physical features they include, differs in this assessment from those in the MSFD's. These differences are described in full in points 12 and 13 below.

12. We consider littoral habitat types to be inclusive of benthic habitats at the land-sea interface where the sea has a direct connection to the benthic habitat. This means that our littoral habitat definition includes the intertidal/eulittoral zone (and equivalent in non-(significantly) tidal seas) as well as what is elsewhere termed the 'supralittoral', and which would lay above the highest astronomical tide (HAT) (or equivalent in non-(significantly) tidal seas). This definition is fully in line with the WFD's as this defines the intertidal/eulittoral zone as that ranging 'from the highest to the lowest astronomical tide' (COAST, 2003). However, it differs to varying degrees from interpretations of the littoral or supralittoral zones, or what is considered 'marine' habitats, in the MSFD[28], MAES and EUNIS marine habitat typologies, although is largely in line with EUNIS (2004) (see Table 3.3 and Condé et al, 2018). As such, the MECSA littoral habitat type(s) can extend to and occur in the supralittoral zone. This is either in full – when these habitats make up the benthos of land-sea interface features (see point 13) occurring in the supralittoral, or in part – when part of the benthos of land-sea interface features occurs in the supralittoral[29]. The former would be in coastal wetlands and coastal lagoons when these happen in the supralittoral zone (e.g. saltmarshes). The latter would be in the supralittoral elements within land-sea interface features (e.g. estuaries, inlets and embayments), namely their splash zone (including in the lower part of sea cliffs), and specific (supralittoral) enclaves, such sea cliff caves, semi- or exposed rocks, and rockpools. Thus, these elements are under strong

[27] http://eea.maps.arcgis.com/apps/MapSeries/index.html?appid=e11c991280f54d3b839d9b8cc695b168

[28] Note the MSFD littoral predominant habitat types in EC (2011b) excluded the supralittoral zone; where the littoral was equal to the eulittoral (i.e. intertidal) zone in the North East Atlantic; the hydro-littoral zone in the Baltic Sea; and the medio-littoral zone in the Mediterranean Sea (see footnote 8 in Table 7 of EC, 2011b); and which would also be equivalent to the pontic littoral in the Black Sea. The EUNIS (2004) marine habitat classification reflected the possibility of such a supralittoral occurrence, which has been confirmed and expanded via its 2016 and 2019 revisions. Coverage of the supralittoral is now also, although implicitly, reflected in the MSFD benthic broad habitat types in EC (2017) as these follow, one-to-one, the 2016 revision of the EUNIS Level 2 benthic habitat classification (cf. Evans et al., 2016 and Condé et al, 2018). See also Section 7.

[29] The marine zonation here refers to the sea's zonation, not that within the land-sea interface features

marine influence through, e.g., spray, splash and/or sporadic inundation above the HAT or equivalent in non-(significantly) tidal seas. The justification for going beyond the MAES and, in particular, the MSFD classifications is to be inclusive of all significant marine habitats, and, hence, of all the biotic groups that these can support (as those, ultimately, hold the capacity to supply marine ecosystem services). Nevertheless, a line must be drawn somewhere for the purposes of an assessment and there may still be services supplied by habitats outside of the typology used in this approach, which could arguably be called 'marine' ecosystem services (e.g. flood protection from sand dune systems) (see Table 3.3). In addition, there are further habitats not included here which may support marine biota and, thus, the services these can supply (e.g. inshore freshwater lakes for some seabirds). However, these other habitats should be captured in a MAES terrestrial ecosystem service capacity assessment, and this is also discussed in Section 6.

13. We include a number of land-sea interface physiographic features[30], which further expand and refine those listed in the 4th column of the MAES marine ecosystem typology on the '*Representation of land-cover (spatial dimension)*' (i.e. the MAES 'Level 3bis', see section 3.1.1 and Table 3.1), and which we have linked to the MECSA habitat types. These features are: coastal wetlands; coastal lagoons; estuaries; inlets and embayments; and nearshore, open coastal waters. They can occur, *in part or in full*, across the supralittoral zone of all seas and the intertidal/eulittoral zone in tidal seas, or equivalent in non-(significantly) tidal seas[31]; although some can be relatively deep and include sublittoral substrates (which, in the open sea, would belong to the shallow sublittoral zone where depth is a maximum of 50-70 m according to Maes et al, 2013, see Table 3.1). Such features, therefore, can contain the following MECSA habitat types: variable salinity waters; coastal waters; littoral seabed habitats; and shallow sublittoral seabed habitats. These features are included here to better characterise/help visualise the inshore and nearshore brackish and marine area, which is where most services tend to be supplied because it is where service capacity tends to be most accessible to people and can be realised into actual services (see Sections 1 and 4). Each of these features has also been defined, building on Maes et al (2013) as well as the relevant EUNIS[32] (2004) and Corine Land Cover (2012) descriptions, as follows:

- *Coastal wetlands*, including saltmarshes, saltmeadows, salines and intertidal flats (such as mud and sandflats). The latter are only applicable in tidal seas and would actually be integrated in many of the other features, e.g., in estuaries. Coastal wetlands can have variable salinity or marine salinity, and are relatively shallow (i.e. do not extend to the shallow sublittoral). They can fully occur in the supralittoral zone as, e.g., saltmarshes (see Table 3.3).
- *Coastal lagoons*, which can have variable salinity or marine salinity, and tend to also be relatively shallow. They can also fully occur in the supralittoral zone (see Table 3.3).
- *Estuaries*, which always have variable salinity and can be deeper than the above features, i.e. include shallow sublittoral substrates
- *Inlets and embayments*, including, inter alia, fjords, sea lochs, rias, and bays and straits (when inside straight baselines, i.e. in internal waters[33]), which can have variable salinity or marine salinity, and which can also be relatively deep and include shallow sublittoral substrates.

[30] Physiographic features are spatial characteristics of the coast.
[31] The marine zonation here refers to the sea's zonation, not that within the land-sea interface features.
[32] The European Nature Information System (EUNIS, http://eunis.eea.europa.eu/about) includes the EUNIS habitat classification, which is the 'EU reference' classification for all habitat types.
[33] Internal waters are those between the low-water line and the territorial baseline. Where the coastline is indented, such as in estuaries and coastal lagoons, the baseline is a straight line running across designated locations of the estuarine and lagoon entrances. Where the coastline is not considered to be indented, the territorial baseline coincides with the low-water line, and hence there are no internal waters.

- *Nearshore, open coastal waters*, such as waters along straight coastlines, and bays and straits (when outside straight baselines, i.e. beyond internal waters), which extend from the territorial baseline out to 1 nm. These waters would always have marine salinity and can also be relatively deep and include shallow sublittoral substrates. They are not so much a physiographic feature as a way of encompassing the WFD coastal waters within the set of land-sea interface features.

14. The ‘Level 3a’ littoral habitat types, therefore, cover all the habitats in brackish and marine water features with a connection to the sea, including when these habitats occur in the supralittoral zone. This is shown in Table 3.2 above through the land-sea interface features occurring fully in the supralittoral zone and the supralittoral elements of land-sea interface features considered ‘marine’ there, as indicated in the last column. Thus, for example, we include habitats in coastal wetlands and the splash zone, as these support marine biotic groups and supply marine ecosystem services. As said, this spatial scope is broader than the spatial scope of the littoral habitat types covered and assessed under the MSFD (*sensu* EC, 2011b), which were limited by the HAT (or equivalent in non-(significantly)tidal seas), and this difference would have consequences for the assessment part of the MECSA approach. Less individual biota from the relevant biotic groups occurring in the MECSA littoral habitats would be able to be assessed (when assessing their service supply capacity), if the input information for the assessment came solely from EU-level reporting on MSFD implementation. However, EU-level reporting from other EU environmental legislation, e.g. the WFD and HD, relating to the status of both water bodies/habitats and biological elements/species respectively, is relevant and could be used to fill *some* of these gaps in the operationalisation of the MECSA approach. Nevertheless, doing that may still not be sufficient[34] and, as a result, other global, European or regional-level sources of information would still need to be found and used (see Sections 1 and 5 and Annexes II and III).

[34] For example, the coverage and assessment of coastal wetlands and coastal lagoons under the WFD would not be systematically fulfilled across the EU (because the way they have been defined, see COAST, 2003), which means that not all the biota occurring there would be assessed.

Table 3.3 Specific EU-policy relevant land-sea interface features that can fully occur in the supralittoral zone, or supralittoral elements found in land-sea interface features, and where they fit in the MECSA habitat typology

	Considered to belong to marine or terrestrial ecosystems?			
Land-sea interface features that can fully occur in the supralittoral zone, or supralittoral elements of land-sea interface features	**MAES habitat types(1) (2013)**	**EUNIS habitat types (2004)**	**MSFD predominant habitat types(2) (2011)**	**MECSA habitat types**
Coastal wetlands (saltmarshes, salt meadows and salines) and coastal lagoons (above HAT(3) or equivalent in non-(significantly) tidal seas)	Marine	Marine	N/A	Marine
'Dry' beaches (above HAT or equivalent in non-(significantly) tidal seas) and dunes	Terrestrial	Terrestrial (coastal)	N/A	Terrestrial
Splash zone (including lower part of sea cliffs)	Terrestrial	Marine and Terrestrial (coastal)(4)	N/A	Marine
Semi- or exposed rocks, rockpools and sea cliff caves under strong marine influence	Terrestrial	Marine	N/A	Marine
Cliffs (beyond splash zone)	Terrestrial	Terrestrial (coastal)	N/A	Terrestrial

Notes:

(1) For an improved characterisation of the MAES terrestrial ecosystems and habitats see Table 3.2 in EEA (2016a)

(2) As noted already, the MSFD's littoral predominant habitat types in EC (2011b) excluded the supralittoral zone but this has been reversed, although implicitly, in the MSFD benthic broad habitat types in EC (2017) as these follow, one-to-one, the 2016 and 2019 revisions of the EUNIS Level 2 benthic habitat classification, which include the supralittoral zone (cf. Evans et al., 2016; Condé et al, 2018). This means that the scope of the MECSA littoral habitat types is now the same as for EUNIS and the MSFD.

(3) HAT is the Highest astronomical tide

(4) Note there was some ambiguity in the 2004 version of marine EUNIS regarding the attribution of the splash zone to marine and/or terrestrial (called 'coastal' there) habitat types; where here we strictly follow the definitions of (marine) littoral habitats A1 and A1.45, which included the splash zone. This ambiguity has been resolved as part of the revision of the marine EUNIS classification, completed mid-2019, where the splash zone is solely attributed to marine habitats.

The adaptations and assumptions above resulted in a final list of 23 'Level 3a' MECSA habitat types as shown in Table 3.2, which links back to the MAES 'Level 3' habitat types shown in Table 3.4. Further description of the habitat types is given in Table 3.5.

Table 3.4 Crosswalk between the MAES 'Level 3' habitat types and the 'Level 3a' MECSA habitat types

MAES Habitat Types ('Level 3')	Ecological zone/realm	MECSA Habitat Types ('Level 3a')
Low/reduced salinity water (of lagoons)	**Water column habitats (PELAGIC)**	Variable salinity waters
Variable salinity water (of coastal wetlands, estuaries and other transitional waters)		
Marine salinity water (of other inlets)		Coastal waters
Coastal waters		
Shelf waters		Shelf waters
Oceanic waters		Oceanic waters
n/a	**Ice habitats (ICE)**	Ice-associated habitats
Littoral rock and biogenic reef	**Photic Sea-bed habitats (BENTHIC: PHOTIC)**	Littoral rock and biogenic reef
Littoral sediment		Littoral sediment
Shallow sublittoral rock and biogenic reef		Shallow sublittoral rock and biogenic reef
Shallow sublittoral sediment		Shallow sublittoral coarse sediment
		Shallow sublittoral sand
		Shallow sublittoral mud
		Shallow sublittoral mixed sediment
Shelf sublittoral rock and biogenic reef	**Aphotic Sea-bed habitats (BENTHIC: APHOTIC)**	Shelf sublittoral rock and biogenic reef
Shelf sublittoral sediment		Shelf sublittoral coarse sediment
		Shelf sublittoral sand
		Shelf sublittoral mud
		Shelf sublittoral mixed sediment
Upper bathyal rock and biogenic reef		Upper bathyal rock and biogenic reef
Upper bathyal sediment		Upper bathyal sediment
Lower bathyal rock and biogenic reef		Lower bathyal rock and biogenic reef
Lower bathyal sediment		Lower bathyal sediment
Abyssal rock and biogenic reef		Abyssal rock and biogenic reef
Abyssal sediment		Abyssal sediment

Notes: See Tables 3.3 and 3.5 for further detail on the delineation of the 'photic limit' and depth categorisations across the MECSA habitat types as well as the land-sea interface features associated to them.

Table 3.5 Short description of the habitat types in the marine habitat typology used by the MECSA approach

Habitat type	Short description
Variable salinity waters	Habitats where freshwater mixes with marine salinity water, hence they are normally the closest to the shore, including in internal waters ([1]). They can be found in the water column of: • Land-sea interface features, such as coastal wetlands (i.e. saltmarshes, saltmeadows, salines and intertidal flats), coastal lagoons, estuaries([2]), and inlets and embayments (e.g. fjords, sea lochs and other inlets as well as some bays), which can occur, in part of in full, within the intertidal/eulittoral zone([3]) (or equivalent in non-(significantly)tidal seas), some of which may be relatively deep and comprise shallow sublittoral substrates • The supralittoral elements of any of those land-sea interface features (in, e.g., rock pools) • Coastal wetlands (such as saltmarshes and saltmeadows) and coastal lagoons fully in the supralittoral These habitats encompass pelagic biotic groups (within their surrounding water column), and are considered to be photic (i.e. allowing the growth of photosynthesising organisms). They are distinguished from other pelagic habitats close to the shore based on their salinity, which would normally be brackish but can actually range from oligohaline to hyperhaline. Corresponding benthic habitats would be those out to and including the shallow sublittoral habitat types.
Coastal waters	Marine salinity water habitats relatively close to the shore, including in internal waters, and (normally) extending up to the shelf. They can be found in the water column of: • Land-sea interface features with marine salinity, such as coastal wetlands, coastal lagoons, and inlets and embayments, as well as the nearshore, open coastal waters (up to 1 nm from the territorial baseline), which can occur, in part or in full, within the intertidal/eulittoral zone (or equivalent in non-(significantly)tidal seas), some of which may be relatively deep and comprise shallow sublittoral substrates • The supralittoral elements of any of those land-sea interface features (in, e.g., rockpools) • Coastal wetlands (such as saltmarshes) and coastal lagoons fully in the supralittoral In addition, coastal water habitats occur outside these features in fully open coastal waters (over the shallow sublittoral zone). These habitats encompass pelagic biotic groups (within their surrounding water column), and are considered to be photic (i.e. allowing the growth of photosynthesising organisms). Corresponding benthic habitats would be those out to and including the shallow sublittoral habitat types.
Shelf waters	Marine salinity water habitats over the shelf. These habitats encompass pelagic biotic groups (within the surrounding water column), and can be photic (i.e. allowing the growth of photosynthesising organisms) or aphotic. Corresponding benthic habitats are the shelf sublittoral habitat types. In some regions, however, the shelf may be close to the shore.
Oceanic waters	Marine salinity waters over the slope and beyond. These habitats encompass pelagic biotic groups (within their surrounding water column), and can be photic (i.e. allowing the growth of photosynthesising organisms) or aphotic. Corresponding benthic habitats are the bathyal and abyssal habitat types.
Ice-associated habitats	Habitats associated to the seasonal sea ice that occurs in the Baltic Sea region, and which occur within, or on the topside or the underside of, the ice where zooplankton and fish may accumulate and feed.

Table 3.5 Cont.

Habitat type	Short description
Littoral habitats (rock and biogenic reef; and sediment)	Rocky and biogenic reef, and sedimentary habitats in the supralittoral zone and the intertidal/eulittoral zone (or equivalent in non-(significantly) tidal seas). They can be found in the seabed of: • Land-sea interface features, such as coastal wetlands, coastal lagoons, estuaries, and inlets and embayments, as well as the nearshore, open coastal waters (up to 1 nm from the territorial baseline), which can occur, in part or in full, within the intertidal/eulittoral zone (or equivalent in non-(significantly)tidal seas) • The supralittoral elements of any of those land-sea interface features (such as rock pools, caves and the splash zone of cliffs) • Coastal wetlands (such as saltmarshes and saltmeadows) and coastal lagoons fully in the supralittoral These habitats encompass benthic biotic groups (within their surrounding seabed), and are considered to be photic (i.e. allowing the growth of photosynthesising organisms). Corresponding pelagic habitats are the variable salinity water and coastal water habitat types.
Shallow sublittoral habitats (rock and biogenic reef; coarse sediment; sand; mud; and mixed sediment)	Rocky and biogenic reef, coarse and mixed sedimentary, sandy, and muddy habitats in the shallow, photic sublittoral zone. They can be found in the seabed of certain land-sea interface features (such as estuaries, and fjords, sea lochs and other inlets), including in the nearshore, open coastal waters (up to 1 nm from the territorial baseline). In addition, they occur outside these features as the seabed of fully open coastal waters. These habitats encompass benthic biotic groups (within their surrounding seabed), and are considered to be photic (i.e. allowing the growth of photosynthetic organisms). Corresponding pelagic habitats are the variable salinity water and coastal water habitat types.
Shelf sublittoral habitats (rock and biogenic reef; coarse sediment; sand; mud; and mixed sediment)	Rocky and biogenic reef, coarse and mixed sedimentary, sandy, and muddy habitats in the shelf, which can extend to depths of 200 m (before the slope begins). These habitats encompass benthic biotic groups (within their surrounding seabed), and are considered to be aphotic (i.e. cannot support photosynthetic organisms). In some regions, however, the shelf may be close to the shore. The corresponding pelagic habitat is the shelf water habitat type.
Upper bathyal habitats (rock and biogenic reef; and sediment)	Rocky and biogenic reef, and sedimentary habitats along the slope, which can extend from depths of 200 m to 1450 m. These habitats encompass benthic biotic groups (within their surrounding seabed), and are aphotic (i.e. cannot support photosynthetic organisms). The corresponding pelagic habitat is the oceanic water habitat type.
Lower bathyal habitats (rock and biogenic reef; and sediment)	Rocky and biogenic reef, and sedimentary habitats extending from depths of 1450 m to 2700 m. These habitats encompass benthic biotic groups (within their surrounding seabed), and are aphotic (i.e. cannot support photosynthetic organisms). The corresponding pelagic habitat is the oceanic water habitat type.
Abyssal habitats (rock and biogenic reef; and sediment)	Rocky and biogenic reef, and sedimentary habitats extending from depths of greater than 2700 m. These habitats encompass benthic biotic groups (within their surrounding seabed), and are aphotic (i.e. cannot support photosynthetic organisms). The corresponding pelagic habitat type is the oceanic water habitat type.

Notes:

(0) Definitions build on the MSFD (EC, 2011b), Maes et al (2013), EUNIS[35] (2004) and Corine Land Cover (2012) descriptions as well as Evans et al (2014) and Condé et al (2018).

(1) Internal waters are those between the low-water line and the territorial baseline. Where the coastline is indented, such as in estuaries and coastal lagoons, the baseline is a straight line running across designated locations of the estuarine and lagoon entrances. Where the coastline is not considered to be indented, the territorial baseline coincides with the low-water line, and hence there are no internal waters.

(2) Estuaries could – in principle – extend beyond the baseline up to the 12 nm (territorial water) limit of the WFD transitional waters (and even beyond that, see EC, 2017).

(3) The marine zonation here refers to the sea's zonation, not that within the land-sea interface features.

3.1.3 Biotic groups and marine ecosystem components

To define our biotic groups we started from the list of MSFD 'Functional Groups' in the Commission Staff Working Paper on the 'Relationship between the initial assessment of marine waters and the criteria for good environmental status' (EC, 2011b) (see Table 3.6). The list was then added to and adapted (as described below) to represent the minimum number of possible groups required to fully cover the differences in ecosystem functioning relevant for the supply of ecosystem services[36].

The three main adaptations we made to develop our final list of biotic groups were based on the:

1. Relevance of certain descriptions or categories in the original list when the functional group would be associated with a particular (physical) habitat type. For example, for *coastal* fish, the 'coastal' descriptor is unnecessary as this would be accounted for once fish are associated with a specified habitat type.
2. Relevance for the supply of services by the functional group (resulting from its contributions to ecosystem functioning, or from the physical presence or biomass of individual biota).
3. Need to make explicit which are the biotic groups that are not documented in the functional group list, because they are implicitly included (embedded) in the MSFD predominant habitat types (PHTs), but should be specified for the MECSA approach typology of ecosystem components due to their role in the supply of services, e.g. macroalgae.
4. Need to add taxon groups that had not been included in the MSFD's functional groups, nor embedded explicitly in the MSFD's PHTs (bacteria).

[35] The European Nature Information System (EUNIS, http://eunis.eea.europa.eu/about) includes the EUNIS habitat classification, which is the 'EU reference' classification for all habitat types.

[36] Although we acknowledge that we do not include fungi or viruses, which are currently less well understood in terms of their role in supporting the capacity to supply ecosystem services.

Table 3.6 MSFD 'Functional Groups' of highly mobile and widely dispersed species of marine birds, mammals, reptiles, fish and cephalopods

Species Group	Functional Group
Birds	Intertidal-benthic feeding birds
	Inshore benthic-feeding birds
	Inshore surface-feeding birds
	Inshore pelagic-feeding birds
	Inshore herbivorous-feeding birds
	Offshore surface-feeding birds
	Offshore pelagic-feeding birds
	Ice-associated birds
Mammals	Toothed whales
	Baleen whales
	Seals
	Ice-associated mammals
Reptiles	Turtles
Fish	Diadromous fish
	Coastal fish
	Pelagic fish
	Pelagic elasmobranchs
	Demersal fish
	Demersal elasmobranchs
	Deep sea fish
	Deep sea elasmobranchs
	Ice-associated fish
Cephalopods	Coastal/Shelf pelagic cephalopods
	Deep sea pelagic cephalopods

Notes: This list is from the Commission Staff Working Paper on the 'Relationship between the initial assessment of marine waters and the criteria for good environmental status' (EC, 2011b).

A full rationale for the changes made to the list above is given per functional group below. The final list of marine biotic groups used in the MECSA approach is shown in Table 3.7.

Birds

- The prefixes 'inshore', 'offshore', 'intertidal', 'ice-associated' were removed. Habitat affinity will be illustrated once biotic groups are associated with specific (physical) habitat types.
- The prefix 'herbivorous-feeding' was removed. Affinity for photic habitat types will be illustrated once biotic groups are associated with specific (physical) habitat types.
- The prefixes 'surface', 'pelagic' and 'benthic-feeding' were removed. Any differences in how birds contribute to service supply are considered to be at the species level and not related to feeding types, thus this group could be aggregated to 'birds'.

Mammals

- The prefix 'ice-associated' was removed. Habitat affinity will be illustrated once biotic groups are associated with specific (physical) habitat types.

- 'Mammals' are split into two groups: whales and seals. Whales (baleen and toothed) all contribute to service supply, such for the *Recreation and leisure from whale watching* service, in a similar way. Seals contribute to service supply differently from whales as they additionally supply the *Recreational hunting* service. This is linked to occasional, regulated hunting, to which whales do not contribute in an EU context where whale hunting is not allowed (see Section 4).

Reptiles

- This group has been left as it is, 'reptiles', but refers only to turtles in European waters and it is, thus, only relevant to the North East Atlantic Ocean and Mediterranean Sea.

Fish

- The prefixes 'coastal', 'pelagic', 'demersal', 'deep-sea' and 'ice-associated' were removed. Habitat affinity will be illustrated once biotic groups are associated with specific (physical) habitat types.
- The prefixes 'diadromous', 'bony' and 'elasmobranchs' were removed. Although there are differences in how different fish contribute to service supply, these groups do not adequately capture these differences. For example, bony fish contribute to *Seafood from wild animals* provisioning service, but that is not true for all bony fish. Any differences in how fish contribute to service supply are considered to be better captured at the species level. Thus, these distinctions are not helpful for this assessment.

Cephalopods

- The prefixes 'coastal/shelf' and 'deep sea pelagic' were removed. Habitat affinity will be illustrated once biotic groups are associated with specific (physical) habitat types.

Plankton (added)

- Two commonly used biotic groups were added for plankton. These groupings are thought to be important because their functional roles and/or distributions are likely to mean that their contributions to (at least some) ecosystem services differ.
    - Phytoplankton
    - Zooplankton

Benthos (added)

- Five groups of benthos were added to cover both invertebrates, plants and algae, and to distinguish between groups whose functional roles and/or distributions are likely to mean that their contributions to ecosystem service supply differ.
    - Epifauna
    - Infauna
    - Macrophytes[37]
    - Macroalgae (including pelagic macroalgae)
    - Microphytobenthos

Bacteria (added) – not accounted for in any other groups and have an important role in supplying regulation and maintenance services.

[37] Here we use the term 'macrophytes' to mean all marine plants (bryophytes, such as mosses, liverworts and hornworts, which can occur in saltmarshes.; and vascular/higher plants such as angiosperms) that can be found living in one or more of the habitat types included for this typology (Table 3.3). Note that the term 'macrophytes' is sometimes used to include both angiosperms and macroalgae in contrast to what has been applied here. Under the MSFD (see EC, 2011b), macroalgae is listed separately to true plants, but only angiosperms (as a vascular plant) are included to represent true plants (rather than using the term 'macrophytes').

The refinements above resulted in a final list of 14 taxon groups making up the MECSA 'Level 4' biotic groups as shown in Table 3.7.

Table 3.7 The MECSA biotic groups ('Level 4') used for the development of marine ecosystem components in the MECSA approach

MECSA Biotic Group	Where MECSA biotic groups fit within the MSFD	
	Embedded within the MSFD predominant habitat types	Linked to the MSFD functional groups of highly mobile or widely dispersed species
Birds	-	X
Whales (all cetaceans)	-	X
Seals	-	X
Reptiles	-	X
Fish	-	X
Cephalopods	-	X
Phytoplankton (p)	Water column habitats; Ice-associated habitats	-
Zooplankton	Water column habitats; Ice-associated habitats	-
Epifauna	Seabed habitats	-
Infauna	Seabed habitats	-
Macrophytes (p)	Seabed habitats	-
Macroalgae (p)	Water column habitats; Seabed habitats	-
Microphytobenthos (p)	Seabed habitats	-
Bacteria	Water column habitats; Seabed habitats; Ice-associated habitats	-

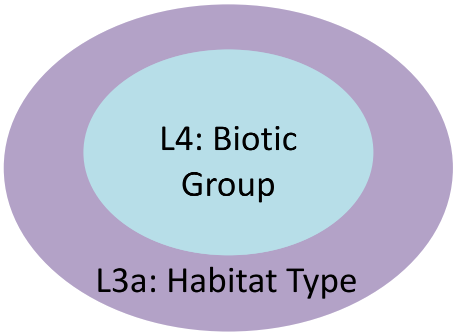
Notes:

- List adapted from the Commission Staff Working Paper on the 'Relationship between the initial assessment of marine waters and the criteria for good environmental status' (EC, 2011b).
- These biotic groups are a combined list of the species groups linked to the original MSFD 'functional groups' and those species groups that are considered to be implicitly (embedded) part of the MSFD predominant habitat types, but which are explicitly shown here (see explanation above the table)
- 'p' indicates photosynthesising species groups, where photosynthesising bacteria are included with phytoplankton

3.2 Developing marine ecosystem components: Linking biotic groups to habitat types

The MECSA marine ecosystem components constitute the EU policy-based[38] 'spatial units' holding the capacity to supply marine ecosystem services within the MECSA approach. They are defined as all the possible combinations between habitat types ('Level 3a', Table 3.2) and biotic groups ('Level 4', Table 3.7) where there is a known association of a specific biotic group with the specific habitat type, e.g. fish in *oceanic waters* or microphytobenthos in the *littoral sediment* habitat type (Figure 3.2).

Figure 3.2: MECSA marine 'ecosystem component' consisting of a 'Level 4' (L4) marine biotic group associated with a 'Level 3a' (L3a) marine habitat type



Four aspects should be noted about how we have developed the ecosystem components:

1. The links are qualitative. They are established based on the possible presence/absence of a specific biotic group within a specific habitat type using the literature and/or through expert judgment.
2. A link between a biotic group and a habitat type simply reflects *the possibility* for a biotic group to spend some or all of its life in that habitat type. This can be either: (1) embedded within the habitat type, e.g., sessile benthic invertebrates, or (2) associated with the habitat type, e.g., a highly mobile species, such as a seal, feeding temporarily in a certain habitat type.
3. For highly mobile groups, their activities/life histories have been considered (where known from the literature and/or expert judgment) when associating them with habitat types, e.g. littoral rock – seals (through haul outs), littoral sediment – reptiles (through getting to nests found further up the beach above the 'wet' supralittoral[39]), and sublittoral sediment –whales (through feeding).
4. Only naturally occurring ecosystem components are described here (but see additional 'man-made' components, such as the structures used for in situ aquaculture, added for some eco-system services under Section 4).

A total of 214 marine ecosystem components were established as shown in the overview provided in Figure 3.3. Each biotic group and habitat type association takes into consideration those factors de-termining such associations, e.g. depth, substrate type, sufficient light for photosynthesis, availability of prey items etc., i.e. the specifications of each habitat type as described in Table 3.2 (including sub-strate type) were taken into account when identifying which biotic groups would occupy those habitat types.

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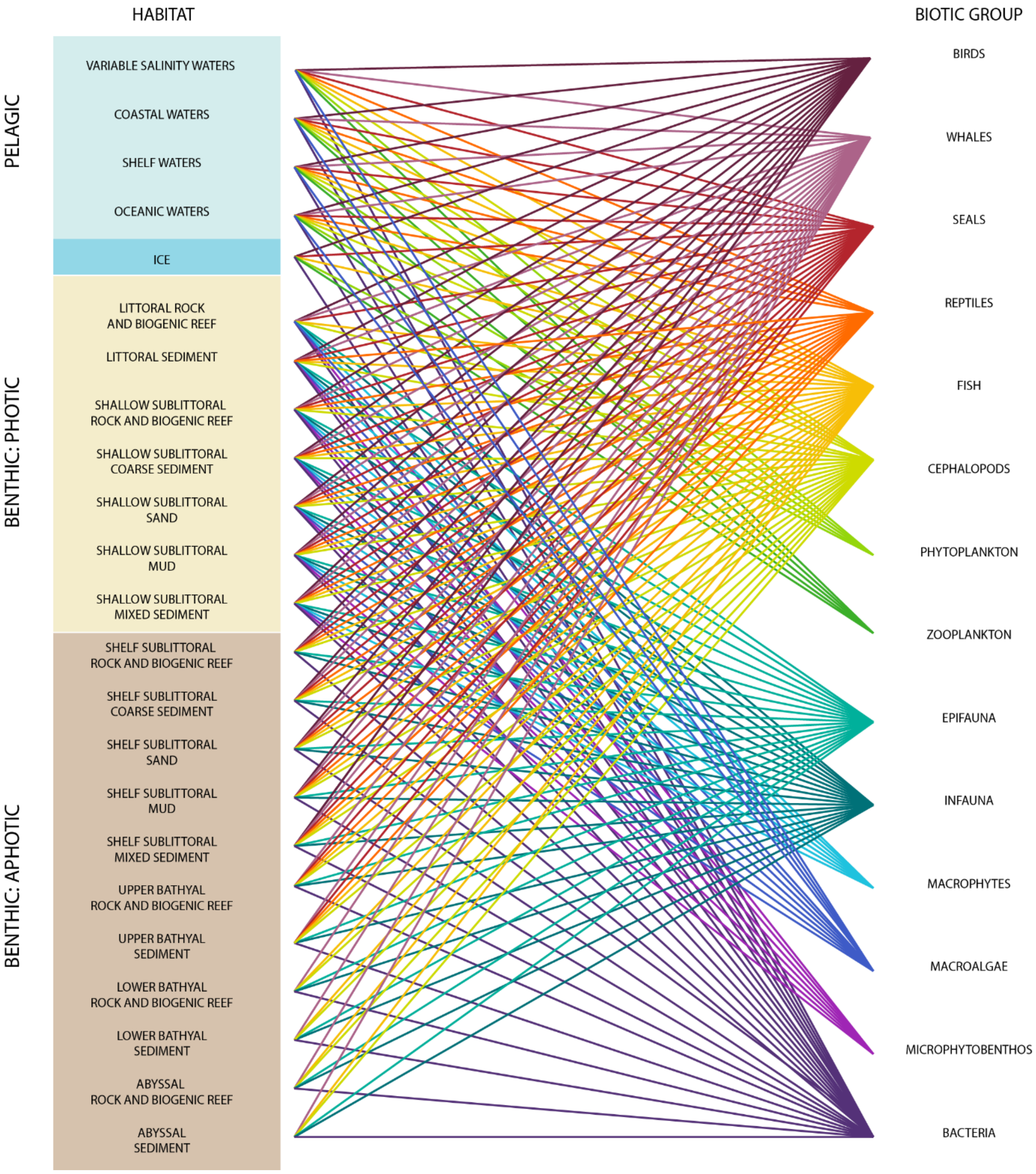
[38] It is important to note that the definition of marine 'ecosystem components' used in this report differs to that used in some related policies and reports, where marine ecosystem components may be used to describe one or more of the following: 'species groups', 'functional groups', 'habitats' or 'ecosystems' (e.g. the MSFD (EC, 2011b); the EEA 'State of Europe's Seas' Report (EEA, 2015); and the revised EC Decision on the criteria and methodological standards for 'good environmental status' (EC, 2017)).

[39] The 'dry' part of beaches is beyond the scope of the MECSA habitat typology as shown in Table 3.3

These ecosystem components cover all combinations of biotic groups and habitats that are necessary to represent the different ways in which the ecosystem can supply ecosystem services, where the development of and the actual specific linkages between ecosystem components and services are shown in Section 4. As explained in Section 3.1.2, these service linkages could easily link back (through the MECSA habitat types, 'Level3a', Table 3.4) to the MAES marine habitat types ('Level 3').

Following Figure 3.3, the ecosystem components, i.e. all possible combinations of the associations (linkages) between each biotic group and their habitats, are discussed, listed for each biotic group. The text there indicates the association of biotic groups broadly with pelagic, ice or benthic habitats, while the accompanying figures show the specific habitat type associations.

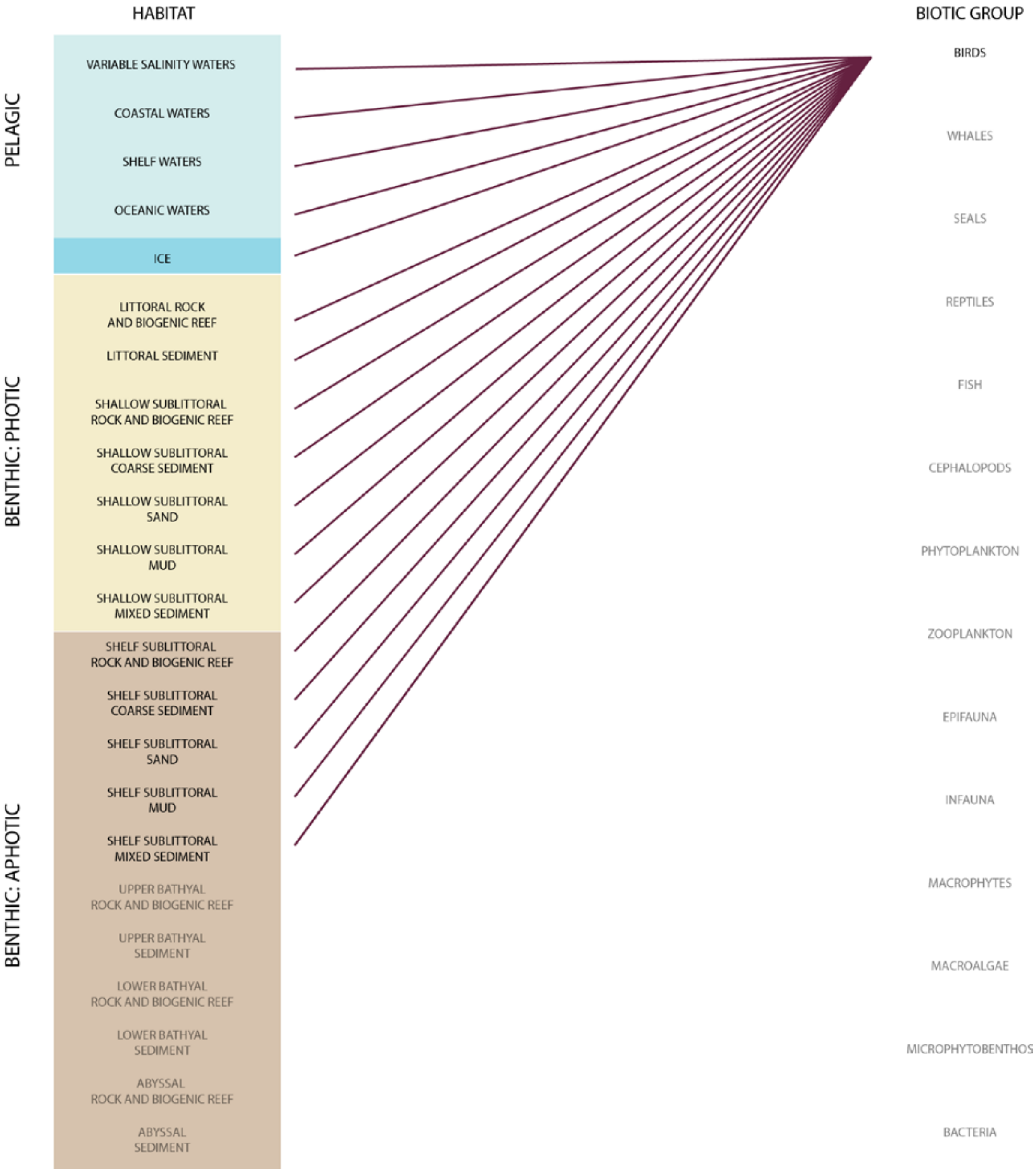
Figure 3.3: Diagram representing all possible combinations of the association (linkages) of all biotic groups with all habitat types used in the MECSA approach. Each link is one 'ecosystem component' and there are a total of 214 ecosystem components



Birds: Birds are highly mobile species and are found inhabiting/in association with benthic, pelagic, and sea-ice habitats (Figure 3.4). The different activities of birds need to be considered when associating birds with different habitats. Whilst particular bird species may be primarily benthic or pelagic feeders, in the intertidal, inshore or offshore; their activities lead many species to utilise a wide range of habitats during their lives. Thus, the state of pelagic, ice and benthic habitats could influence bird populations.

- **Pelagic zone:** Pelagic feeding birds are found close to shore as well as offshore, exploiting *variable salinity waters*, and *coastal*, *shelf* and *oceanic marine waters*, for example cormorants forage up to 200 kilometres offshore whereas, black headed gulls and curlew follow the tide line (Balmer et al. 2013). Benthic feeding birds could also be found resting in surface waters.
- **Ice:** Seasonal sea *ice* can be important for wintering birds as, for example, a resting place where birds can retain greater warmth than floating in water (J. Green, pers. comm). The timing of the break-up of ice also has implications for breeding waterfowl (Lehikoinen et al. 2006).
- **Benthic zone:** The benthic photic zone will include intertidal and inshore feeders, and birds which feed on vegetation as well as fish and invertebrates. *Littoral* habitats could also be used by many birds as a resting place at low tide for example wading birds, gulls and geese (Balmer et al. 2013), and some birds could nest within the splash zone (on the relevant parts of cliffs) (Newell et al. 2015). In the benthic aphotic zone, benthic feeding birds which can dive to greater depths are included, although beyond the shelf sea floor the depth is too great (e.g. European shags typically dive to 30–40 m) (Wanless et al. 1999).

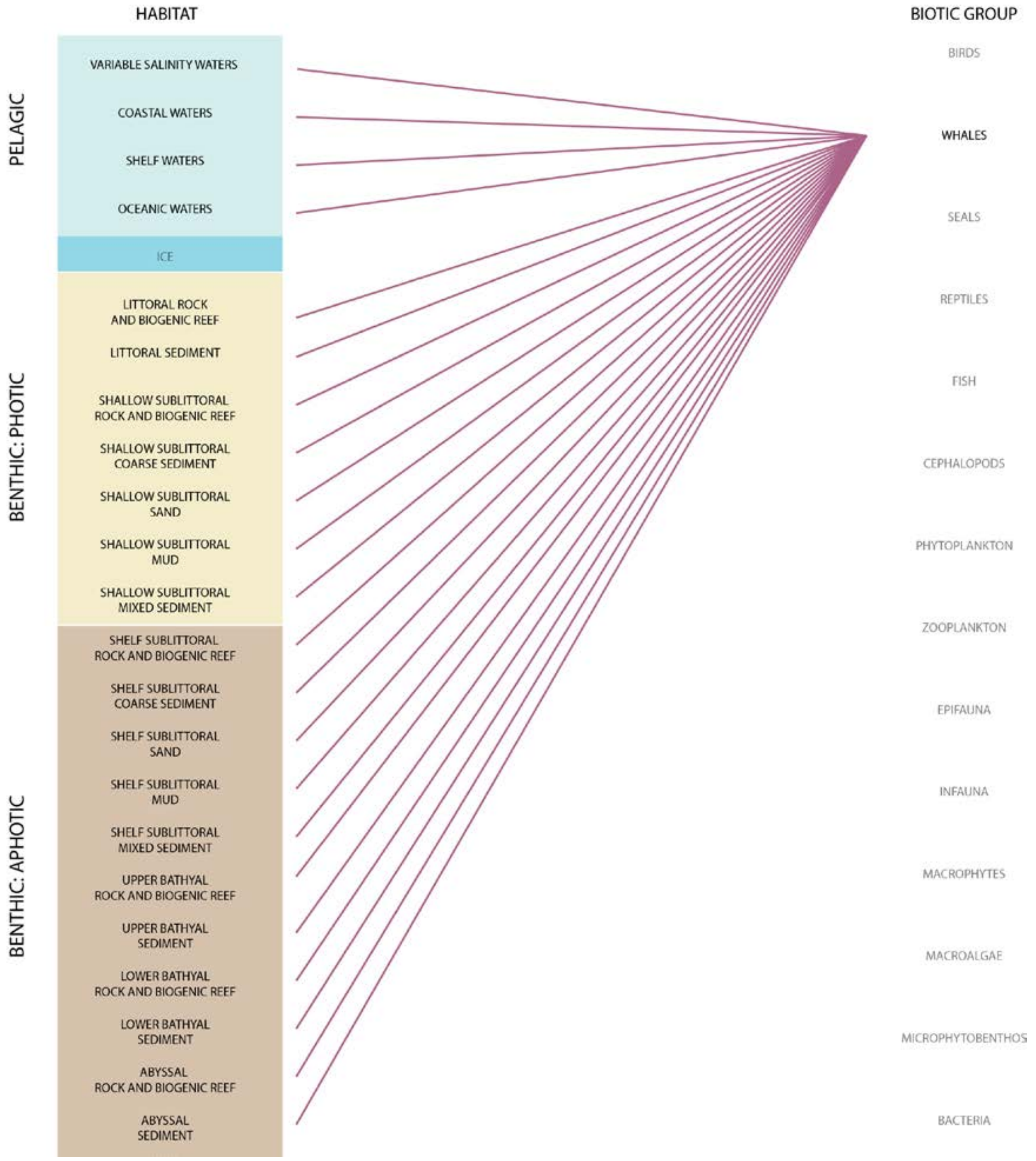
Figure 3.4: Diagram representing the associations between birds and habitat types



Whales: Whales include both baleen whales, such as the North Atlantic right whale (Reilly et al. 2012a), and toothed whales, such as the bottlenose dolphin (Reilly et al. 2012b). They are highly mobile and, depending on the species, are found inhabiting/in association with benthic and pelagic habitats (Figure 3.5). While particular whale species may be primarily benthic (e.g. the Gray Whale, Reilly et al. 2012c) or pelagic (e.g. the blue whale, Reilly et al. 2012d) feeders, their high mobility leads them to utilise a wide range of habitats during their lives. Thus, the state of pelagic and benthic habitats could influence whale populations.

- **Pelagic zone:** All whales are found in the pelagic zone, feeding in *variable salinity waters* and *coastal* and *shelf waters*, e.g. dolphins, as well as in *oceanic waters*, e.g. humpbacks.
- **Ice:** European whales are not associated with sea-ice (harbour porpoises are the only cetaceans in the Baltic Sea and are primarily found in the southern Baltic, i.e. below the range of seasonal sea-ice, Benke et al. 2014 and Carlen et al 2018).
- **Benthic zone:** Benthic feeding whales have the potential to exploit *shallow sublittoral* habitats, for example the harbour porpoise (Hammond et al. 2008c), shelf waters, for example the bottlenose dolphin (Hammond et al. 2012b), and the *bathyal* and *abyssal* zone (e.g. Cuvier's beaked whale has been found to dive to abyssal depths (Schorr et al. 2014) and is present in Atlantic waters[40]). Whales, in part of in full, are occasionally beached/washed up into *littoral* habitats, where they can provide services – through their full bodies (e.g. cadavers for scientific research) or parts of them (e.g. sperm whale ambergris, a raw material for the manufacturing of perfume, can wash up on the intertidal/eulittoral part of beaches (or equivalent in non-(significantly) tidal seas)).

Figure 3.5: Diagram representing the associations between whales and habitat types

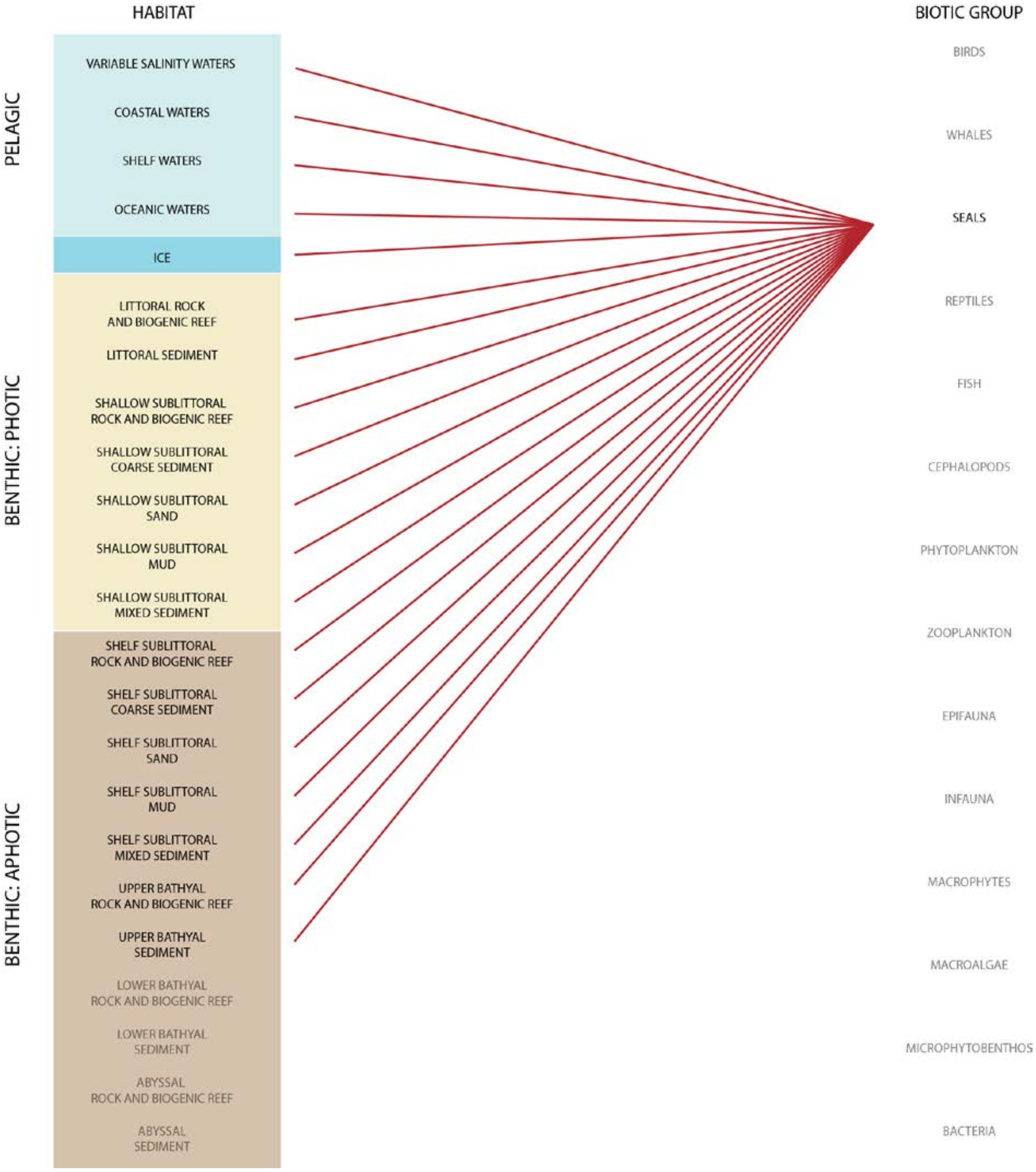


[40] https://iwdg.ie/

Seals: Seals are highly mobile species and are found inhabiting/in association with benthic, pelagic and sea-ice habitats (Klimova et al, 2014; Wilson et al. 2014) (Figure 3.6). The life history and activities of seals leads them to utilise a wide range of habitats during their lives. For example, grey seals utilise *coastal waters* as their preferred habitat, but can dive to depths of 200 m to feed on demersal prey, such as cod and plaice (Thompson & Harkonen, 2014). Seals show a preference for pupping on sea *ice,* where pre-weaning mortality is almost zero, and which contrasts with land based pupping, where mortality, primarily by predation, can exceed 25 % (Thompson & Harkonen, 2014). Harbour seals utilise shallow water habitat across a wide variety of salinities, from almost fresh to fully saline (Thompson & Harkonen, 2008). Both harbour seals and grey seals are opportunistic feeders that utilise all habitat types within the water column to forage for prey (Thompson & Harkonen, 2008). Thus, the state of pelagic, ice and benthic habitats could influence seal populations.

- **Pelagic zone:** All seals are found in the pelagic zone in all types of pelagic habitats. Seals feed on pelagic fish from *variable salinity waters* to *oceanic* marine waters.
- **Ice:** Seals are associated with *ice* habitats as they use these habitats as breeding grounds (Jussi et al. 2008).
- **Benthic zone:** Seals breed in *littoral* habitats (including, e.g., the splash zone, as per the typology of habitats used here) and feed on benthic fish and crustaceans in *shallow sublittoral*, *shelf sublittoral* and down to the *upper bathyal*, but not beyond (Smale & Cliff, 2012).

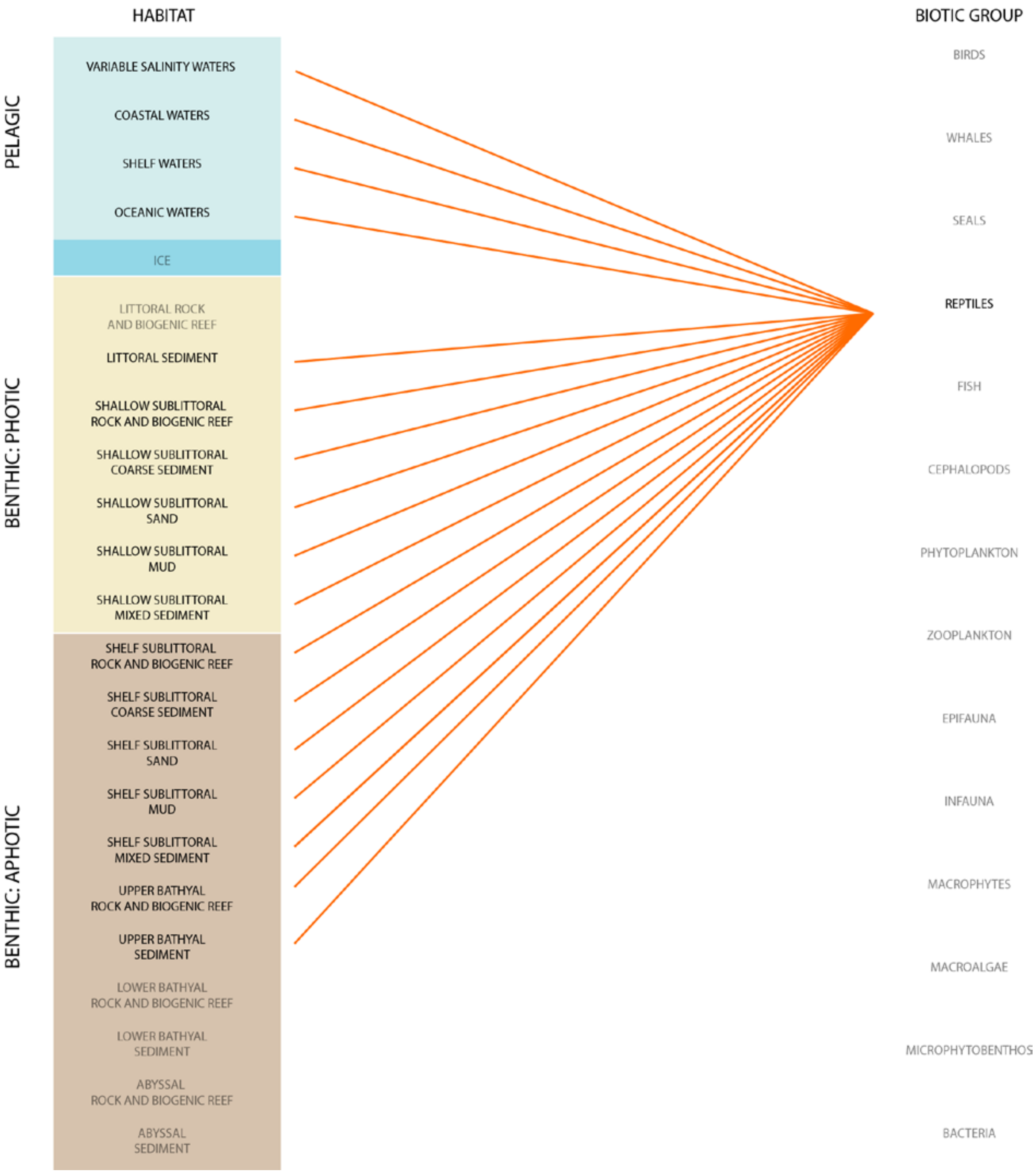
Figure 3.6: Diagram representing the associations between seals and habitat types



Reptiles: Turtles are the only marine reptile that occurs natively in Europe (Chiari et al. 2012; Baez et al. 2006). Turtle habitat includes the North East Atlantic Ocean and the Mediterranean Sea (Chiari et al. 2012). The Green Turtle *Chelonia mydas* and the Loggerhead Turtle *Caretta caretta* both nest in the Mediterranean Sea (Baez et al. 2006). Turtles are found inhabiting/in association with benthic and pelagic habitats (Doyle et al. 2008) (Figure 3.7). The life history of turtles leads them to utilise a wide range of habitats during their lives. Thus, the state of pelagic and benthic habitats could influence turtle populations.

- **Pelagic zone:** Turtles spend most of their time in the water column, and can be found in *variable salinity waters* out to *coastal*, *shelf* and *oceanic* marine waters where they feed on pelagic species such as jellyfish (Doyle et al. 2007).
- **Ice:** Turtles are not associated with *ice* habitats (Baez et al. 2006).
- **Benthic zone:** Turtles (Green Sea and Loggerhead) use *littoral* habitat sediments to move to or from their nesting sites (which may be in ('dry') beaches above littoral habitats and, therefore, not included in the typology of habitats used here) of the Mediterranean Sea (Broderick & Godely, 1996). Green Sea turtles feed on benthic algae/plants in the photic *shallow sublittoral* zone (Godley et al, 2002). Other turtle species also feed on benthic invertebrates down to the *shelf* and can dive beyond the shelf to the *upper bathyal* zone (e.g. loggerhead sea turtles (Godley et al 1997; Sakamoto et al. 1990)), but do not go to greater depths than *upper bathyal* (Doyle et al. 2008).

Figure 3.7: Diagram representing the association between reptiles and habitat types

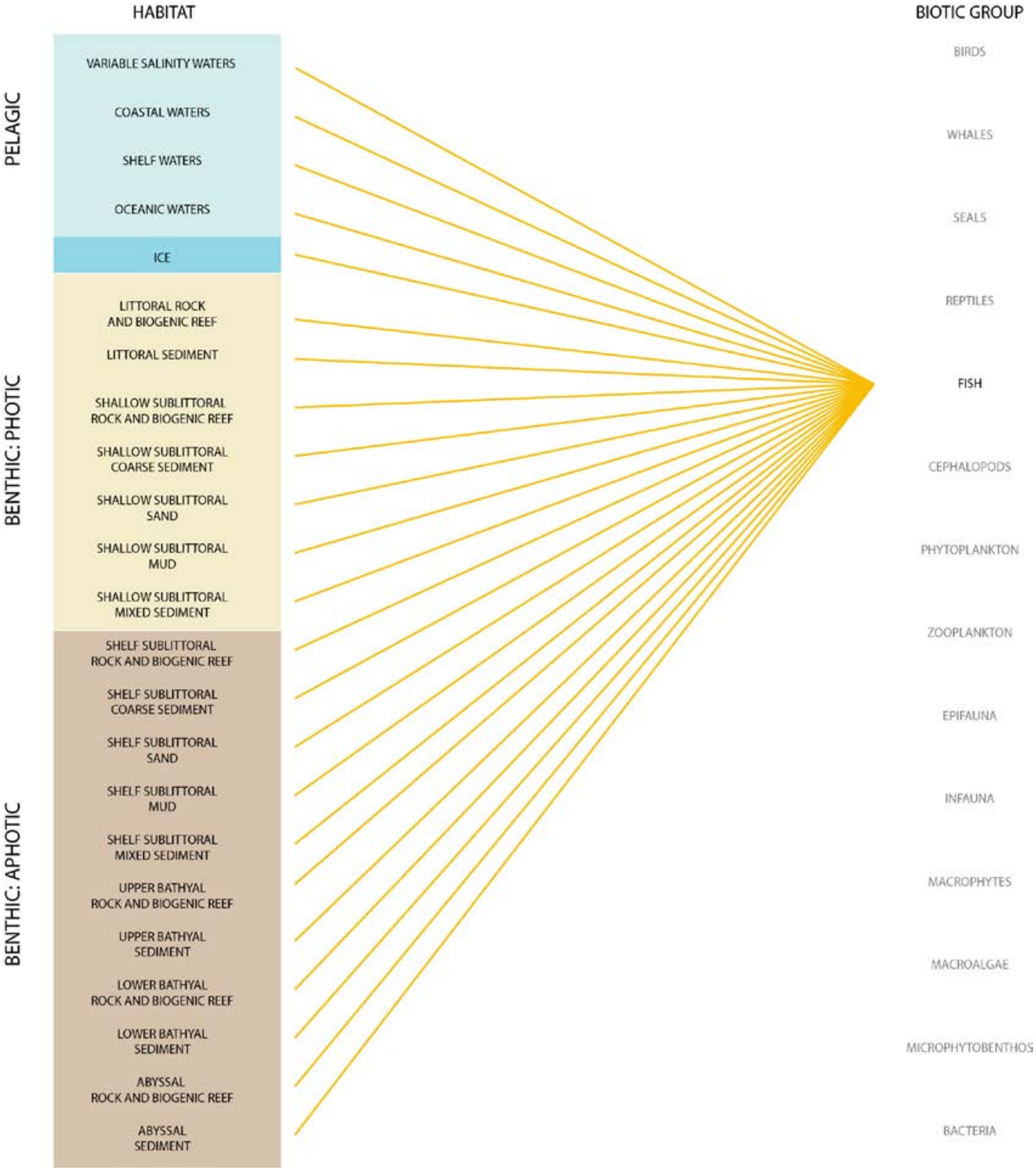


Fish: Fish were deemed to have an affinity for all habitats, depending on the particular species (Figure 3.8). The habitat indicates the specific ecosystem component for relevant fish species, e.g. fish in benthic habitats include demersal fish, such as plaice and flounder (Freyhof, 2014); while fish in pelagic habitats include pelagic fish, such as mackerel and herring (Herdson & Priede, 2010).

Where fish contribute to the supply of ecosystem services, not all of these habitats may be relevant for the supply of a specific service. For example, fish in *abyssal* habitats would not contribute to the supply of the *Seafood from wild animals* service since fish are not exploited from these habitats (because of limitations on technology to fish at such depths, see Section 4). However, they would still contribute to a range of regulation and maintenance services for which there is a passive human demand, e.g. *Global climate regulation* through carbon sequestration.

- **Pelagic zone:** Fish can be found in all pelagic habitats, from *variable salinity waters*, such as grey mullet (Freyhof & Kottelat, 2008), to *oceanic waters*, for example mackerel (Collette et al. 2011).
- **Ice:** Fish can be associated with sea *ice* as they can feed on invertebrates on the underside of the ice[41].
- **Benthic zone:** Fish can be found in *littoral* habitats, e.g., in rockpools (as per the typology of habitats used here), e.g. the blenny[42], and in all other benthic habitats down to the deep sea, e.g. the angler fish[43].

Figure 3.8: Diagram representing the associations between fish and habitat types

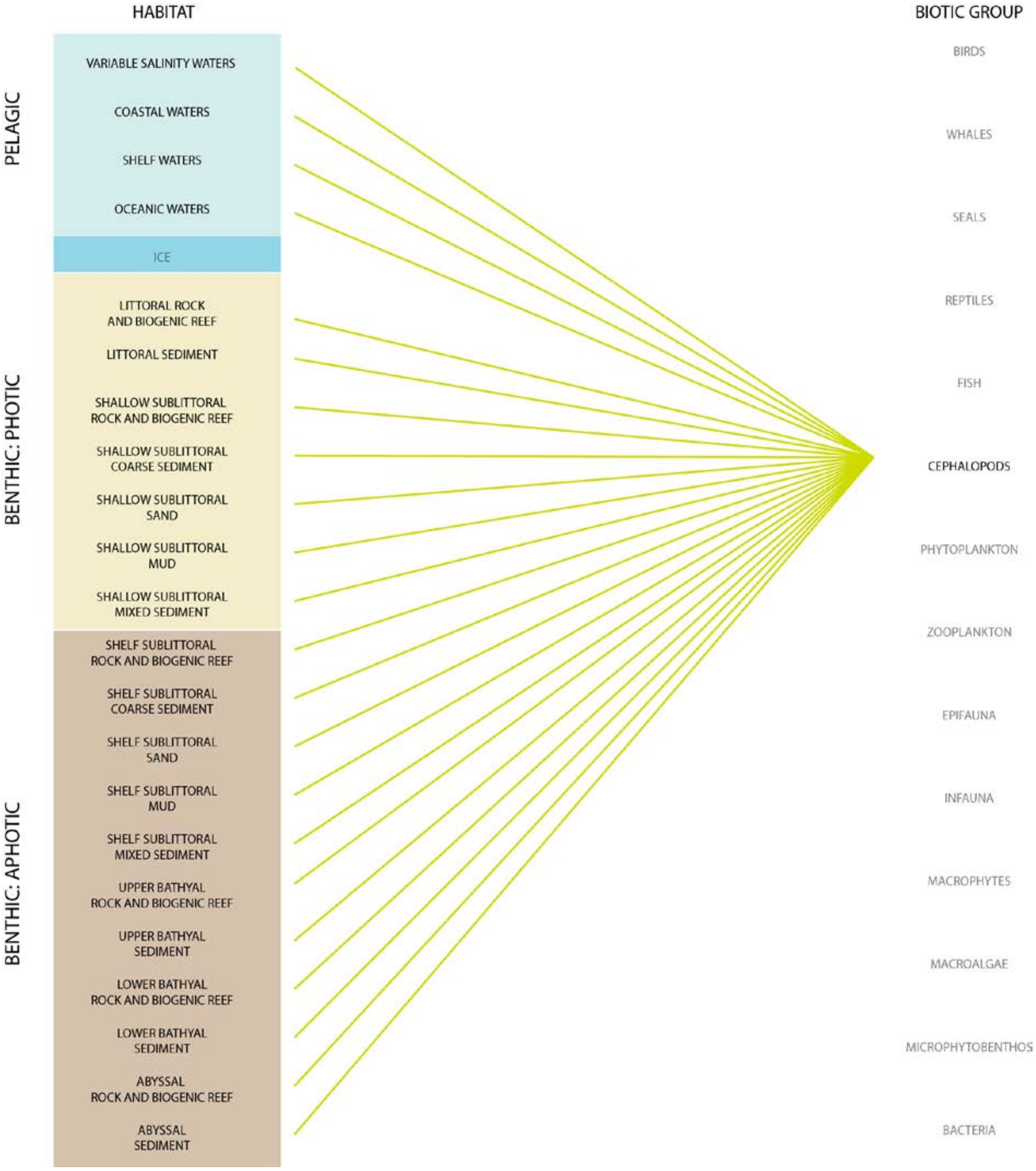


41 http://www.vliz.be/wiki/Sea_ice_ecosystems
42 https://www.glaucus.org.uk/fish2.htm
43 https://www.britannica.com/animal/deep-sea-fish

Cephalopods: Cephalopods, including squid, octopus and cuttlefish, inhabit/are associated with all habitats apart from *ice* (Figure 3.9); although cephalopods do not live in the Baltic Sea (*sensu* MSFD marine region) nor in the Black Sea. Pelagic associated cephalopods include species such as squid; while benthic associated cephalopods include species such as cuttlefish (Pierce et al. 2010).

- **Pelagic zone:** Many species of cephalopod are associated with the pelagic zone, from *variable salinity waters* out to *oceanic* marine waters.
- **Ice:** Cephalopods are not associated with sea *ice*.
- **Benthic zone:** Benthic species of cephalopods live at all depths of benthic habitats from *littoral* habitats to *abyssal*. Five species of cephalopod, associated with European waters, have been found at depths of 3400 m (Nesis and Shvetsov, 1977).

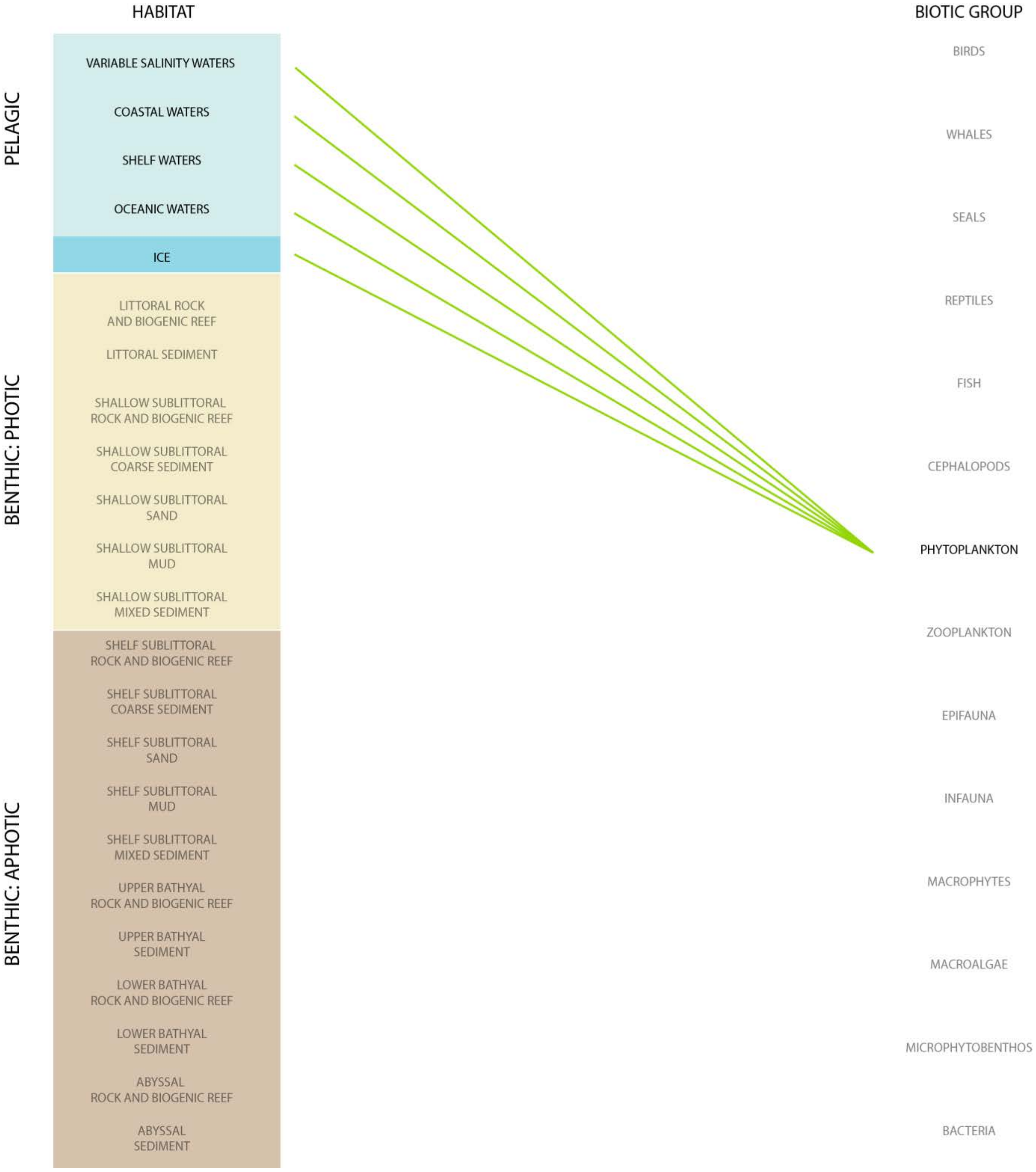
Figure 3.9: Diagram representing the associations between cephalopods and habitat types



Phytoplankton: Phytoplankton includes all microscopic photosynthesising organisms (microalgae). Phytoplankton require light to photosynthesise (i.e. convert light to energy for growth, etc.) and only live where sufficient light penetrates the water column for photosynthesis to happen, i.e. in the photic zone (Jaeger et al. 2010). For the purposes of an assessment relating to the supply of ecosystem services, we also include photosynthesising bacteria in this group.

- **Pelagic zone:** Phytoplankton is composed of purely pelagic species (Figure 3.10).
- **Ice:** Phytoplankton can get trapped in and form a film under sea ice (Arrigo, 2014).

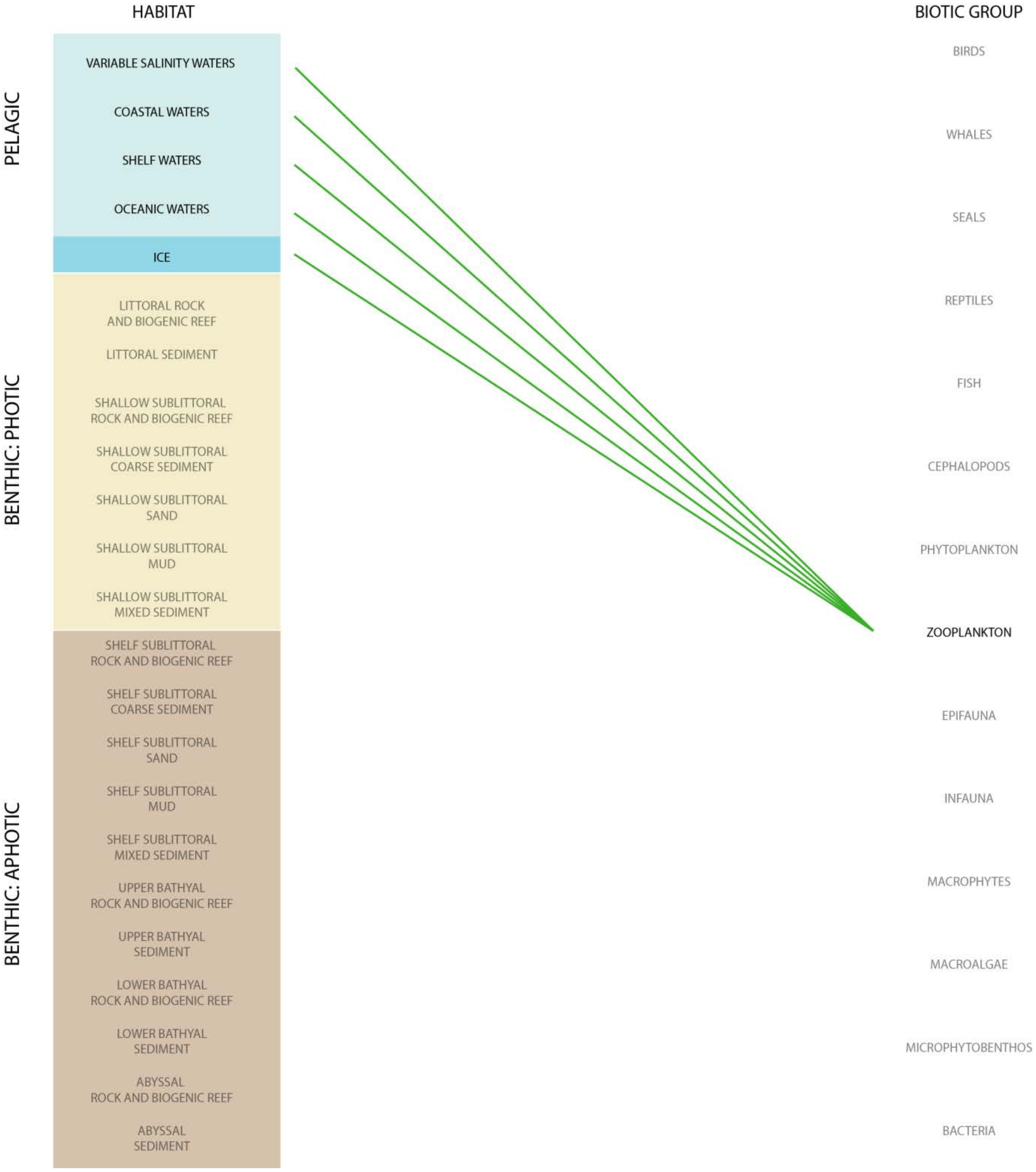
Figure 3.10: Diagram representing the associations between phytoplankton and habitat types



Zooplankton: Zooplankton includes micro- and macro-scopic pelagic fauna, such as copepods, jellyfish and the larvae of benthic species.

- **Pelagic zone:** Zooplankton are found in all pelagic habitats (Duncan, 1997) (Figure 3.11).
- **Ice:** Zooplankton are found associated with ice, feeding on the microalgae that build up on the underside of the ice (Arrigo, 2014).

Figure 3.11: Diagram representing the associations between zooplankton and habitat types

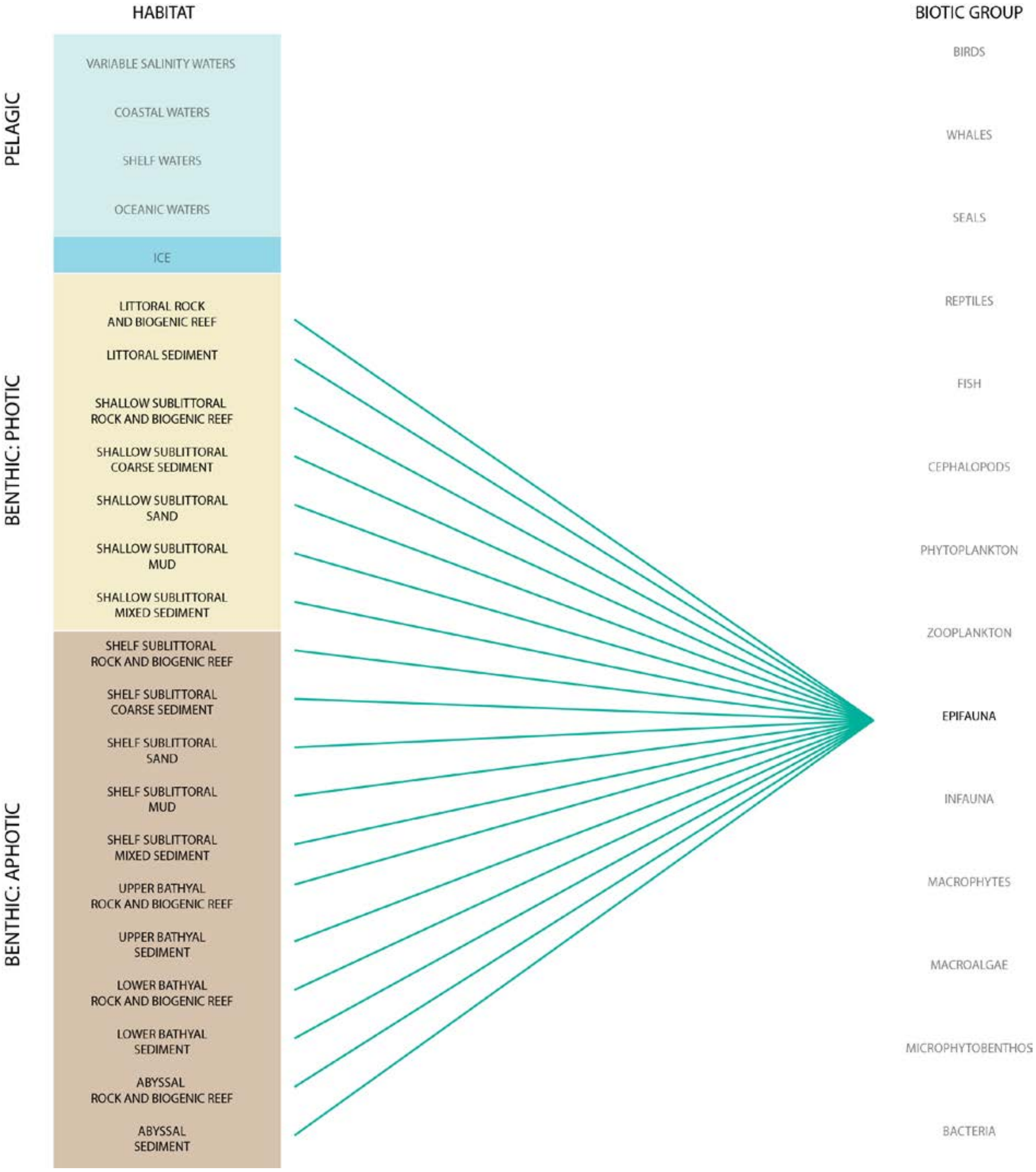


Epifauna: Epifauna include all invertebrate fauna attached to or freely occupying the surface of rocky and sediment substrates in the benthic habitat, ranging from the *littoral* (intertidal zone or equivalent in non-(significantly) tidal seas), to deep sea habitats (Figure 3.12). Biogenic reefs composed of formations of epifauna are also included here.

Examples of epifauna include oysters, sponges, sea squirts, sea stars, sea urchins, barnacles and brittlestars[44] Biogenic habitats, such as coral reefs, composed of formations of epifauna are also included here.

- **Benthic zone:** all benthic habitats can be occupied by epifauna.

Figure 3.12: Diagram representing the associations between epifauna and habitat types

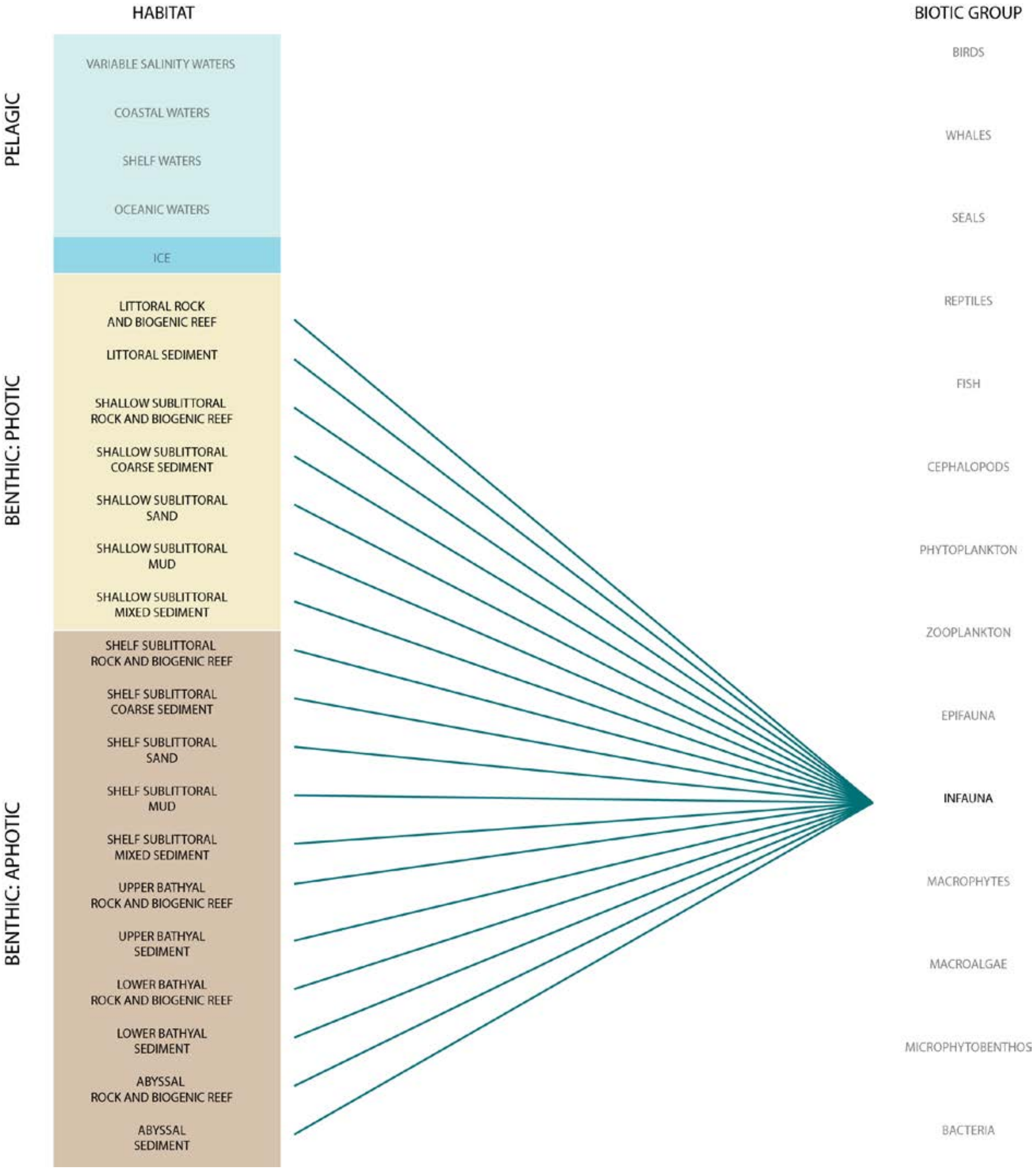


[44] https://eunis.eea.europa.eu/habitats/5534 and https://eunis.eea.europa.eu/habitats/5532

Infauna: Infauna include all burrowing, tube dwelling or boring invertebrate organisms living in all the types of substrate found in all benthic habitats, from the *littoral* to the *abyssal* zone (Figure 3.13). Biogenic reefs composed of tube-dwelling invertebrates, such as *Sabellaria*, are also included here. Other examples of infauna include lugworms, razorclams and *Nephrops*.

- **Benthic zone:** all benthic habitats can be occupied by infauna (e.g. Reiss et al, 2009)[45].

Figure 3.13: Diagram representing the associations between infauna and habitat types

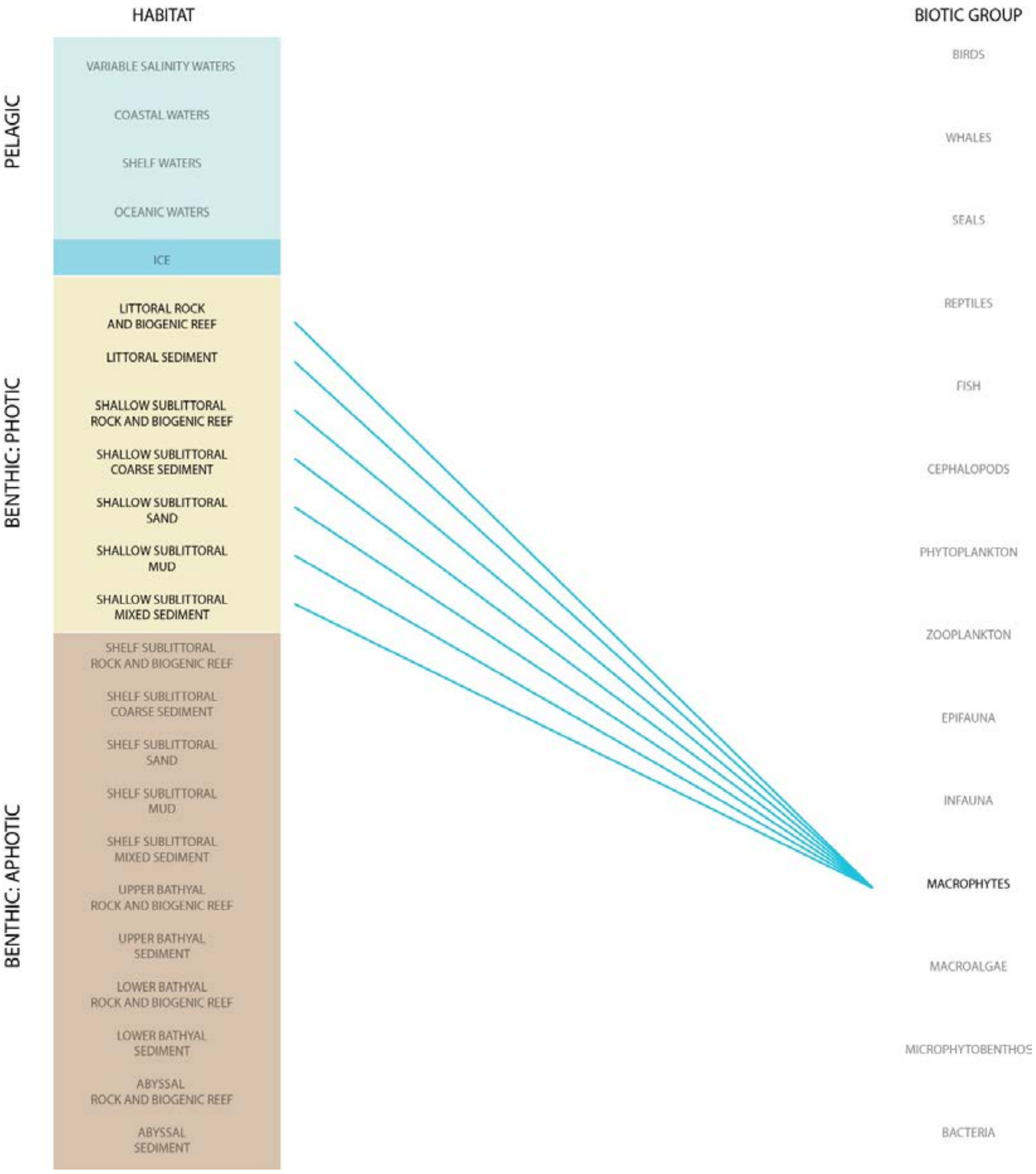


[45] See also by searching in EUNIS https://eunis.eea.europa.eu/

Macrophytes: Macrophytes are marine plants, such as angiosperms, e.g., seagrasses and *Salicornia* sp., which can grow on rock and sandy habitats (Díaz-Almela E. & Duarte C.M. 2008) as well as in fine sediment/muddy habitats[46]. This group also includes other plants such as bryophytes, e.g. *Hennediella heimii* a halophytic moss found on saltmarshes[47]. Macrophytes are photosynthetic organisms, thus live in the photic benthic zone (Figure 3.14). Although some may be found in rocky habitats, these habitats are likely to be of less importance to these species than sediment habitats since they have roots. Algae are not included in here[48].

- **Photic benthic zone:** all photic benthic habitats (but see Box 3.1) can be occupied by macrophytes[49].

Figure 3.14: Diagram representing the associations between macrophytes and habitat types



[46] http://eunis.eea.europa.eu/habitats/1733

[47] https://forum.eionet.europa.eu/european-red-list-habitats/library/terrestrial-habitats/b.-coastal/a2.5c-atlantic-coastal-salt-marsh

[48] Here we use the term 'macrophytes' to mean all marine plants (bryophytes, such as mosses, liverworts and hornworts, which can occur in saltmarshes.; and vascular/higher plants such as angiosperms) that can be found living in one or more of the habitat types included for this typology (Table 3.3). Note that the term 'macrophytes' is sometimes used to include both angiosperms and macroalgae in contrast to what has been applied here. Under the MSFD (see EC, 2011b), macroalgae is listed separately to true plants, but only angiosperms (as a vascular plant) are included to represent true plants (rather than using the term 'macrophytes'.

[49] See by searching in EUNIS https://eunis.eea.europa.eu/

Macroalgae: Macroalgae (seaweed) are photosynthesising organisms commonly found in rocky and coarse sediment areas within the photic zone, e.g. kelp, but can also be found in finer sediments including mud, e.g. *Enteromorpha* sp. and *Ulva* sp. (Figure 3.15). Most species are benthic and attach to substrate using a holdfast (non-rooting). Some species such as S*argassum* can be pelagic and are found free-floating at the surface of the water column[50]; while other, normally benthic, species can live and continue to photosynthesise floating in clumps in the water column (Vandendriessche et al. 2007).

- **Pelagic zone:** Macroalgae in the pelagic zone, in general, is only considered to include floating algae. Floating macroalgae can be found in all areas of the pelagic zone.
- **Photic benthic zone:** all photic benthic habitats (but see Box 3.1) can be occupied by macroalgae[51].

Figure 3.15: Diagram representing the associations between macroalgae and habitat types

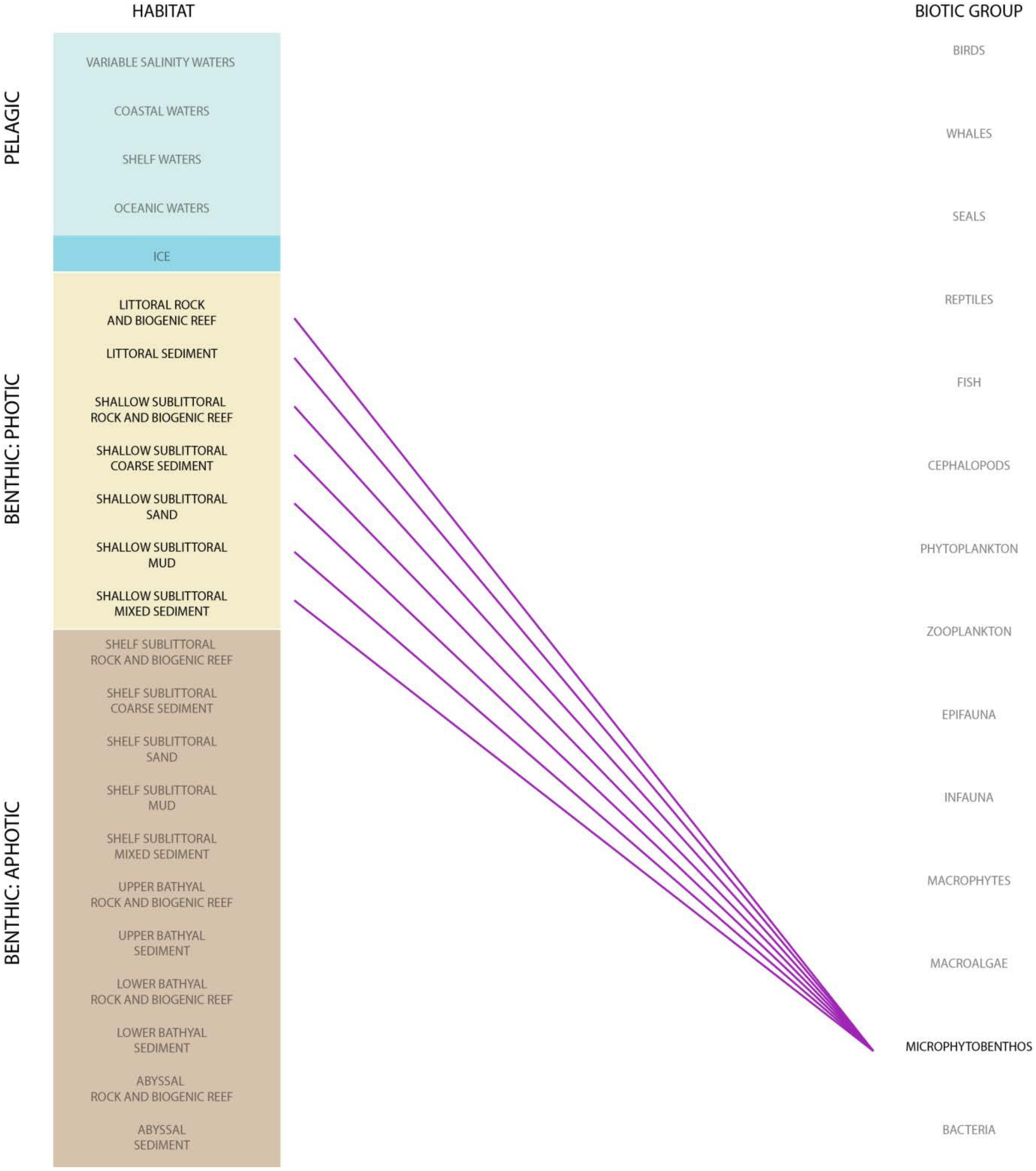
[50] http://jncc.defra.gov.uk/page-1677

[51] http://www.seaweed.ie/algae/seaweeds.php; see also by searching in EUNIS https://eunis.eea.europa.eu/

Microphytobenthos: Microphytobenthos includes the photosynthetic biofilm, i.e. microorganisms, which convert light to energy for growth; where these biofilms are found sticking to one another over a surface, forming a thin, adherent layer. Microphytobenthos occur in all photic benthic habitats and substrates, from littoral rock and sediment to shallow sublittoral substrates (Figure 3.16).

- **Photic benthic zone:** all photic benthic habitats (but see Box 3.1) can be occupied by microphytobenthos[52]. Note that algae associated with sea ice could be considered to be microphytobenthos but here we capture this ice associated algae under phytoplankton to reflect the stronger association between sea ice and the pelagic zone.

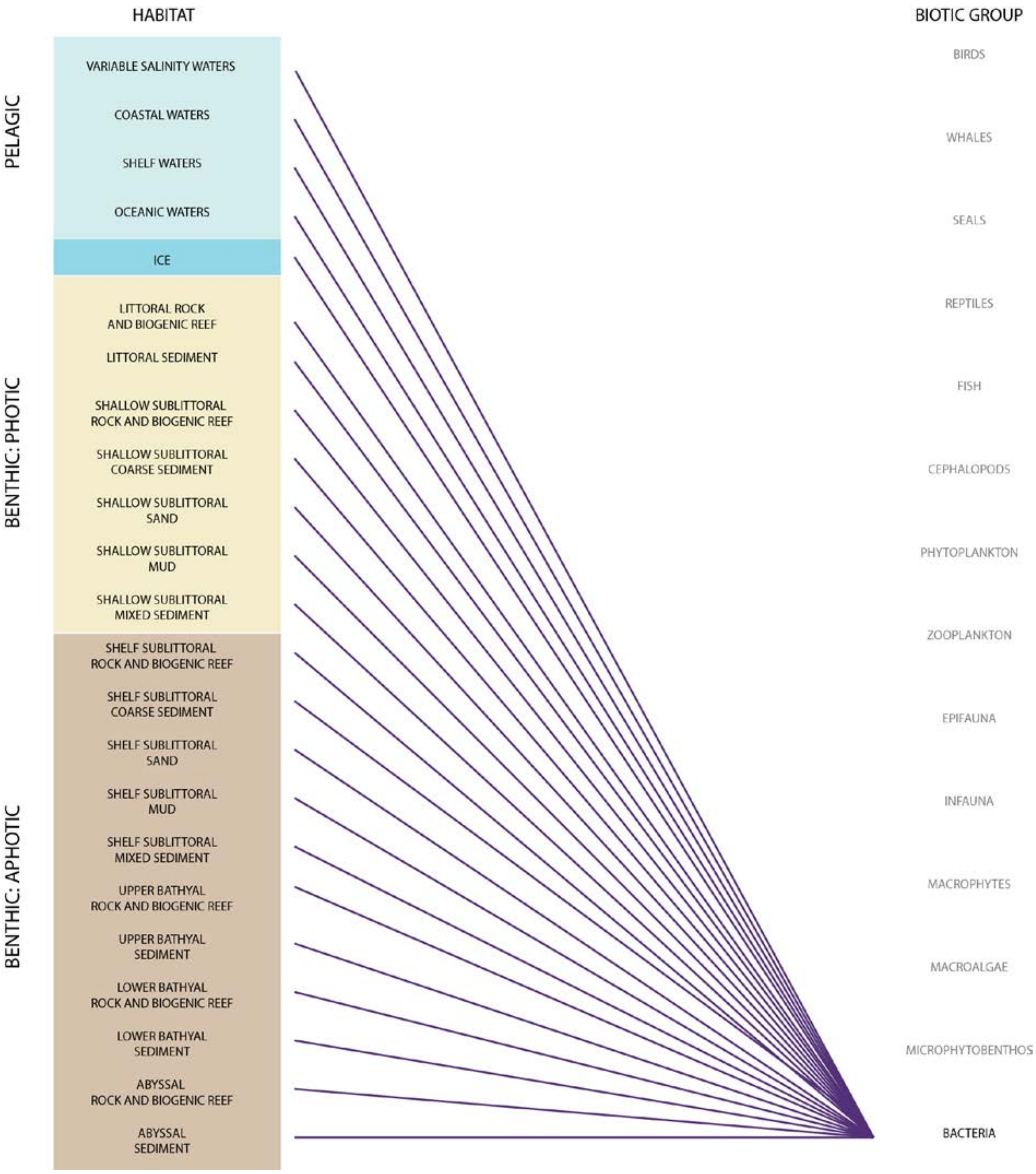
Figure 3.16: Diagram representing the associations between microphytobenthos and habitat types



52 http://eunis.eea.europa.eu/habitats/5587

Bacteria: Bacteria, within the context of the MECSA approach, include all heterotrophic or chemoautotrophic bacteria. These taxa have unique and important functional roles in marine ecosystems and are, therefore, given their own biotic group. Photosynthetic prokaryotic bacteria have been included within the phytoplankton group, since, by definition, phytoplankton include all autotrophic organisms. The non-photosynthesising bacteria are ubiquitous throughout our oceans and are found in all habitats, both in sediments and in the water column (Figure 3.17).

Figure 3.17: Diagram representing the association between bacteria and habitat types



3.3 Next steps

In Section 4, the ecosystem services (from Section 2) are linked to these ecosystem components, constituting the first stage of the MECSA approach; whereby all ecosystem components that can hold capacity to supply any one marine ecosystem service in EU marine regions are identified. In Section 5, we describe the full MECSA method (second stage of the MECSA approach), and summarise results from trialling the approach through three case studies where we assess three marine ecosystem services (covered in full in Annexes II–IV). Further discussion on the use of marine ecosystem components in the MECSA approach is provided in Sections 6 and 7, including limitations, assumptions and recommendations for future work.

4 Linking marine ecosystem components and marine ecosystem services

Section 4 describes how the links between ecosystem components (defined as all possible combinations of the associations of biotic groups with habitats) and ecosystem services are established. The work includes linkages matrices made up of each link from ecosystem component to ecosystem service, constructed using the MESCA ecosystem services classification described in Section 2 (Table 2.2) and the MECSA ecosystem components described in Section 3 (Figure 3.3). In terms of ecosystem services, we work at the level of 'class' here (e.g. *Seafood from wild animals*). General properties of links are described in Section 4.1 and how confidence in the links was assessed in Section 4.2. In Section 4.3, more detailed explanations of how we have interpreted each individual service are given, and then we describe the linkages between each service and ecosystem components, which have been specified in terms of the biotic groups included in the components (as it is the biota and their processes and functions within the ecosystem that, ultimately, hold the capacity to supply the services). No specific habitats are mentioned but this is based on the starting assumption that service links to each biotic group occur in all habitats where these biota are present (i.e. cover all ecosystem components relevant to the specific biotic group, see Section 3.2). However, when only a subset of the specific habitats where a biotic group can occur was deemed relevant to the supply of a service, this has been stated. This can happen when, for example, a service is only supplied by a subset of the species within the broad biotic group, and these are found in a subset of the habitats occupied by the broader biotic group (e.g. waders in the 'seabirds' biotic group). It can also happen when the capacity to supply a service is held across all habitats the biotic group is found in (e.g. 'deep sea fish' have capacity to supply *Seafood from wild animals*), but this capacity cannot be realised into an actual service in all habitats (e.g. abyssal habitats in this example) because people cannot access it there (see Section 1), i.e. it is impossible to use the service in those habitats.

The linkages are visualised in full in Figure 4.2, which covers both the 'Level 4' biotic groups and the 'Level 3a' habitat types (see Section 3), and summarised per 'Level 4' biotic group in Table 4.3. The full linkages matrix organised by 'Level 3a' habitat types can be found in Annex I.

4.1 Structure and meaning of links

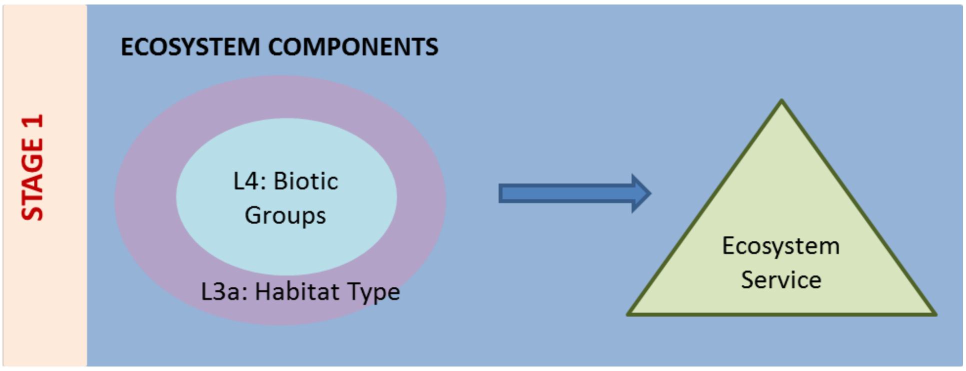
Links illustrate a one-way interaction between ecosystem services and the parts of the marine ecosystem (ecosystem components) that hold the capacity to supply those ecosystem services (Figure 4.1). They are established based on ecological knowledge, in particular an understanding of the (ecosystem) state-service (generation) relationship (see Section 5, and explanation below), and indicate the potential for an ecosystem component to have the capacity to supply, or to contribute[53] to the supply of, that service. Links are confirmed using scientific literature, other information sources (including web-based evidence, see list of information sources in Section 4.2; references are included in the text or in the footnotes of Section 4.3, or both), and expert judgement. They are qualitative (i.e. they express the potential presence/absence of an interaction, which is only counted once, rather than a magnitude). Linkages are generic and unrelated to the specifics of any one EU marine region.

Links always represent the potential capacity of the ecosystem to supply services. However, the specific meaning of the links (in terms of *how* the biota contribute, i.e. at the level of ecosystem structures or of ecosystems processes/functions, see Section 1) may differ between services, or between the components that can supply the same service, and this will again be dependent on the (ecosystem) state-service (generation) relationship. For example, the link between fish and the supply of the *Seafood from wild animals* service is a straight contribution of the component (the fish) to the supply of

[53] 'Contribute' is used to illustrate where multiple marine ecosystem components may be important to underpinning the capacity to supply a particular ecosystem service

the service, while the link between epifauna and the *Waste and toxicant removal and storage* service s fulfilled through the process of filtration. Within the cultural services, ecosystem components contribute to the supply of services in a variety of ways, including through their own existence and through animal behaviour (relating to, e.g., recreation and leisure from wildlife watching activities). All of these types of links, regardless of the mechanisms involved, are considered direct links here. The nature of the relationship between the state of relevant ecosystem components and the capacity to supply ecosystem services is explored when moving to the next stage of the approach (see Section 5 of this Report).

Figure 4.1: Representation of a single link (blue arrow) that fits within the full linkages matrix between the MECSA ecosystem components and ecosystem services (see Figure 4.2)



Notes: The full linkages matrix between the MECSA ecosystem components ('Level 4' biotic groups associated with 'Level 3a' habitat types and ecosystem services is shown in Figure 4.2. These links are direct and the output of Stage 1 of the MECSA assessment (see Stage 2 of the assessment in Section 5 of this Report).

To note that in the linkages matrices organised by 'Level 3a' habitat type in Annex I, a direct link as defined above is marked using 'x', which indicates both that there is potential for a contribution of the component to the supply of a service and that the service would actually be supplied in that habitat. However, in some cases there are indirect links, which should also be represented to highlight the importance of other habitats in supporting a biotic group that directly contributes to a service in a given habitat. Thus, an indirect link occurs where a habitat is essential for the adult stage[54] of a biotic group that is directly contributing to a service elsewhere (in another habitat), and has been marked using 'o'. This distinction allows taking into account the fact that individuals in the biotic groups holding the capacity to supply a service may move in and out of the relevant habitat where the service is actually supplied. This is where individuals make use of different habitats, for example migrating between feeding grounds or, where dead parts of an individual may wash into another habitat where it contributes to the supply of a service. For example, the *Recreation and leisure from whale watching* service (type), i.e. recreation and leisure taken from whale-watching activities, would mainly be supplied in coastal areas, but the whales found in oceanic waters may be the same individuals that are found in coastal areas at other times. Therefore, an 'x' link should be placed in the coastal areas, where the service can actually be supplied, but an 'o' is placed in oceanic habitats because the state of whale populations in these habitats is relevant for the overall marine ecosystem capacity to supply this service over a longer timescale. A further example is dead parts of an animal, e.g. seashells, which may

[54] Because we only consider where a biotic group is directly contributing to a service elsewhere, we do not consider the larval stages of animals in indirect links. This is because the larval stages of marine animals function in different ways to the adults and for many, the planktonic stage will be picked up in the consideration of the services that can be supplied by zooplankton at the same time.

wash onto a (littoral) beach where they can provide a raw material. For this service, an 'o' is given where the living biotic groups exists and an 'x' link is given in the habitat where the service is supplied. Given that the overall MECSA approach designed here should inform the user on the sustainability of the capacity of marine ecosystems to supply ecosystem services, it is important also to consider these indirect links for all components.

The individual tables organised by 'Level 3a' habitat type in Annex I only show 'o' links where there are no 'x' links present at the same time. That is, if there is a direct ('x') link in a particular habitat noting the contribution of a biotic group to a particular service, an 'o' link will not be shown, even if one also exists. This is because the 'x' link supersedes the 'o' link. Thus, in the example above where shells are collected from the seashore, only an 'x' link would be shown in the tables because infauna and epifauna live in *littoral* habitats, and these directly contribute to the supply of *raw materials*, and so the 'o' link is no longer relevant. This has also been the case in the full linkages matrix organised by 'Level 3a' habitat types at the end of Annex I.

An example of a partial linkages matrix is shown below (Table 4.1), which includes the links for the service *Raw materials* and *a subset* of the relevant biotic groups found in coastal waters. In this table, an 'x' is given for a direct link, e.g. cephalopods and raw materials (cuttlebone), and an 'o' is given for an indirect link, e.g. whales and raw materials (ambergris from sperm whales can be found and taken from littoral habitats, e.g. an intertidal beach (or equivalent in non-tidal seas), but the population of whales in coastal (and other) waters still tells us something about the state of the ecosystem overall to supply this service). *Note that this table does not show the full range of biotic groups and habitats that can supply the Raw materials service. The full linkages matrices per 'Level 3a' habitat type are shown in Annex I.*

Table 4.1 Example of a *partial* linkages matrix for the habitat 'Coastal waters' showing one service, *Raw materials*, and only a *subset* of the biotic groups that can deliver this service

Ecosystem Service	**Biotic Group (subset only) in coastal water habitats**				
	Birds	Whales	Fish	Cephalopods	Bacteria
Raw Materials	O	O	X	X	-

Notes:

- This table does not show the full range of biotic groups and habitats that can supply the *Raw materials* service. These are shown, per 'Level 3a' habitat type, in Annex I.
- x = biotic groups with the capacity to supply the service do so directly in this habitat; o = biotic groups spend some of their life in this habitat but supply the service in another habitat (= an indirect link).

Although the linkages considered here represent the capacity of the ecosystem to supply services, rather than whether there is an *actual use* of that capacity, we still consider aspects of use. Thus, we ascertain whether service supply capacity *would be susceptible of being realised* into a service, i.e. whether the possible service *could be* used because people would be able to access that capacity (see the definition of 'service supply capacity' in Section 1). In doing so, we consider that services can be used actively, with intention (e.g. eating seafood), or passively, without intention (e.g. breathing oxygen), or both, and that they can be used *in-situ* (in the marine environment) or *ex-situ* (outside of the marine environment) or both. We also consider that there would be constraints to the realisation of the service supply capacity of certain ecosystem components into actual services. These constrains would result in having to consider certain exclusion criteria when establishing the linkages, as follows:

- *Access*: The habitats where the species groups with the capacity to supply the service occur have to be directly accessible to people. This is to ensure that there would be an active or passive human demand on this service supply capacity (held by the relevant biotic groups or their outputs) and that the service would actually be supplied (see Section 1).
- *Cultural relevance*: The scope of the linkages here excludes ecosystem services that are not used in the EU. An example, is the seaweed *Sargassum,* which although known to be used as wild seafood in some areas of the world (e.g. Asia), is not harvested in the EU to be used as such. Thus, pelagic (floating) macroalgae are not linked to the ecosystem service *Seafood from wild plants and algae* in an EU context. The scope of the linkages here is limited to ecosystem services that are known to have at least one current clear example of use in EU Member States, and so the link may be relevant to just one EU marine region. However, this is still considered in the generic linkages matrices to be inclusive of current practices across the EU.
- *Technological feasibility*: For example, it is not currently (technologically) possible to undertake commercial fishing at abyssal depths; thus no links are given for fish and the *Seafood from wild animals* service in abyssal habitats, even though fish in these habitats could act as a source of nutrition[55].
- *Legal feasibility:* This includes reflecting on and respecting EU regulation for the protection of marine species, including EU implementation of relevant global agreements. For example, seafood from whales (i.e. whale meat) is not considered part of the *Seafood from wild animals* service in an EU policy context because of the EU regulation for the protection of whale species that prevents their hunting, even though the whale population in EU marine waters has the potential to act as a source of nutrition. Another example is fish and the *Seafood from wild animals* service, as where fish can be fished in EU waters is also limited by legal obligations[56].

The above means that the linkages matrix generated here is only relevant to current Member States usage patterns within EU marine regions and current EU legislation (including EU implementation of global agreements). Therefore, in any subsequent applications, or applications in other areas, the linkages would need to be re-visited to consider whether they are appropriate and/or complete enough for that assessment.

We also note that whilst it would be possible to establish links between the MAES 'Level 2' marine ecosystem types (see Table 3.1, Section 3) and marine ecosystem services by using the links identified here for the marine ecosystem components (i.e. the 'Level 4' biotic groups and the 'Level 3a' habitat types, see Figures 3.1, 3.2 and 3.3, Section 3), this would not provide a meaningful output. The reason

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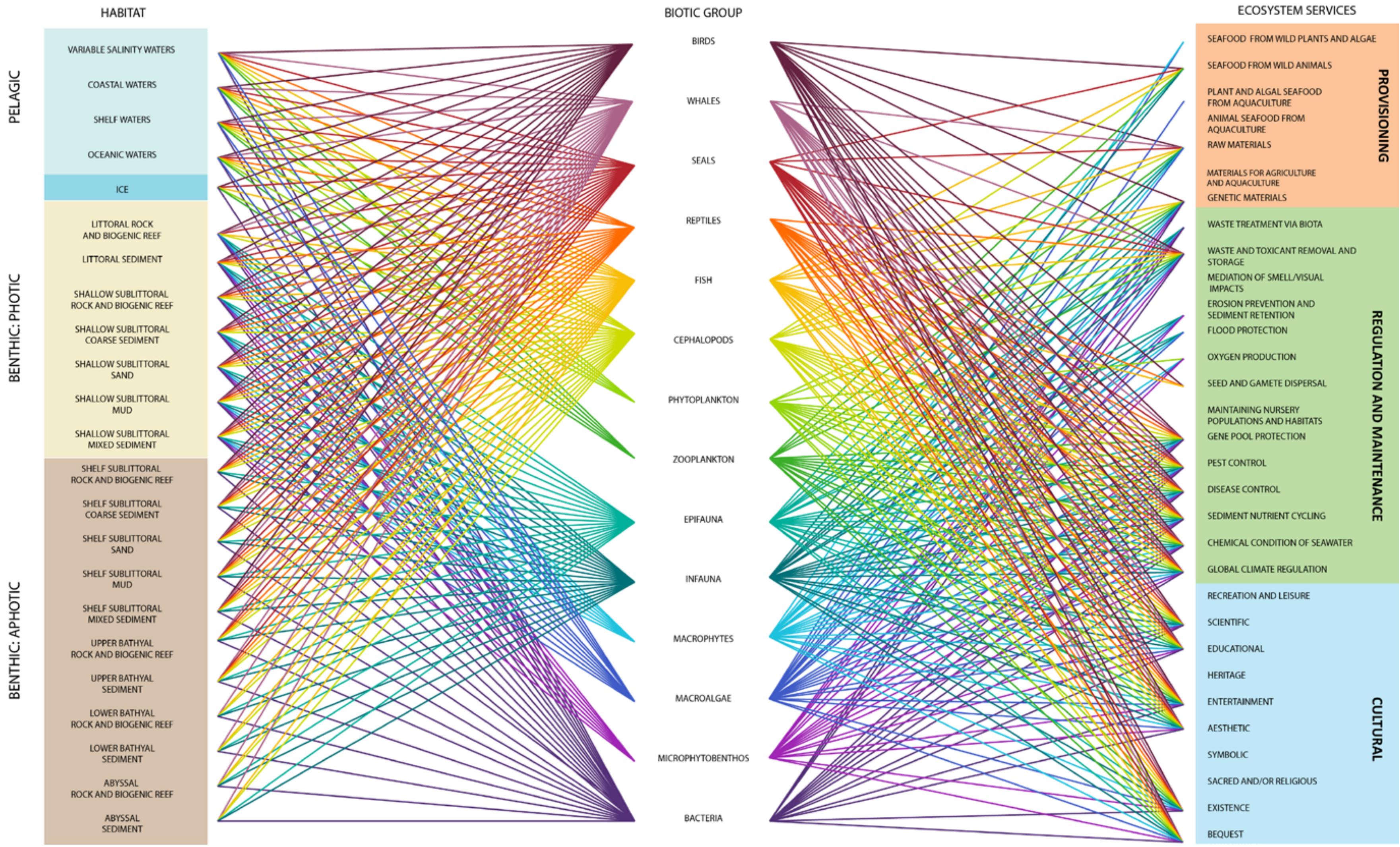
[55] Abyssal habitats have been defined as those over 2700 m depth (see Table 3.2), but deep-sea fishing does not take place below 2000 meters (FAO, 2010–2016) as it is technologically unfeasible.

[56] Regulations for the protection of deep-sea commercial fish stocks and vulnerable marine ecosystems in the North East Atlantic (NEA, Regulation (EU) 2016/2336) and for the Mediterranean Sea (Recommendation GFCM/29/2005/1) limit commercial deep-sea fishing through different restrictions, such as on gear type (e.g. bottom trawls), vessel capacity, fishing area and/or the species that can be fished as well as through a fishing depth limit of 800 m and 1000 m respectively. Note commercial deep-sea fishing is not relevant for other EU marine regions. Such regimes inter alia can prevent bottom trawling in the deep part of the upper bathyal zone (as per Table 3.2, the upper bathyal ranges from 200 m to 1450 m) in the EU waters of the NEA (and so from 800 m to 1450 m) or in the Mediterranean Sea (and so from 1000 m to 1450 m). However, some bottom gear types are excluded from these regulations and could be used there and in the lower bathyal zone (as per Table 3.2, the lower bathyal ranges from 1450 m to 2700 m), providing vessels fulfil relevant authorisation and control measures, and do not fish in protected habitats. Nevertheless, the scope of the linkages here does consider commercial fishing in the benthic habitats of the upper and parts of the lower bathyal zone (down to 2000 m) because the above-mentioned restrictions would greatly reduce (through reducing bottom trawling) but not stop commercial fishing there.

is the limitations associated with the definitions of the MAES ‘Level 2’ marine ecosystem types, including habitat duplications across them (see Section 3.1.1) and gaps (e.g. ice habitats). Furthermore, the MAES ‘Level 2’ marine ecosystem types do not distinguish between pelagic and benthic habitats, or photic and aphotic habitats. These limitations would mean that each of the MAES ‘Level 2’ marine ecosystem types would be linked to the majority of marine ecosystem services, thus providing no useful information when trying to discern which services are supplied by which ecosystems for planning or management purposes. This limitation is further discussed in Section 6.4.2.

The full linkages matrix is represented in Figure 4.2, which shows all possible combinations of the MESCSA biotic groups and habitats (see Section 3), which, together, hold the capacity to supply EU-policy relevant marine ecosystems services (see Section 2) in EU marine regions.

Figure 4.2: The full MECSA linkages matrix: Marine ecosystem components (habitats linked to their associated biotic groups) and the marine ecosystem services they can supply (via those biotic groups)



Notes: The diagram does not include the words '*in-situ*' for the aquaculture-based services.

4.2 Confidence in links

A confidence assessment in the links between an ecosystem component and a service has been carried out based on three aspects as follows:

1. The association of a *biotic group with a habitat*. This has been established using peer reviewed literature (see Section 3) and confidence in these links is high.
2. The link between the *biotic group and the services* it has the capacity to supply or contribute to (Table 4.3). This has been carried out using the following classification of confidence scores:
   - Peer reviewed literature – highest confidence
   - Grey literature, e.g. environmental consultancy technical report – moderate confidence
   - Website, e.g. Wikipedia or company website showing evidence of use of ecosystem services – low confidence
   - We also included one classification for expert judgement but did not rate this in terms of high, moderate or low confidence.
3. In addition, we have also addressed the link between a biotic group and a service it has the capacity to supply, or contribute to supply, in a specific habitat. This additional aspect has mainly been determined using expert judgement and no confidence assessment has been made. However, references are given where other information sources were used as part of the process. For example, the literature may state that fishing takes place and that the fish caught is used for human nutrition; however, information sources do not state that fishing takes place in shallow sublittoral habitats specifically. Thus, while information sources were used to: (i) associate a biotic group with a habitat, and (ii) link a biotic group to the service it has the capacity to supply, expert judgement was mostly used to determine whether a specific service is supplied by a specific biotic group in a specific habitat.

The qualitative ranking of confidence in the linkages as shown in Table 4.3 is based on point 2 above, since for points 1 and 3 the outcome is the same for all links (high confidence and not assessed, respectively).

4.3 Linkages between marine ecosystem components and marine ecosystem services

In the following sub-sections, we describe each ecosystem service in more detail building on the marine customisation of CICES described in Section 2 of this Report (see Table 2.2). We then discuss the ecosystem components that contribute to the ecosystem capacity to supply each of these services in EU marine regions, based on the scope of the approach outlined under Section 4.1[57]. The full linkages matrix showing the links between each ecosystem component and each service, per biotic group, is presented in Table 4.3 and, per habitat, in Annex I. This section here also highlights both broad and more specific issues in relation to our marine customisation of CICES (Section 2) that have arisen whilst identifying the specific links between ecosystem components and ecosystem services. This section focuses on services at the CICES 'class' level (as outlined in Section 2, Table 2.2); although in Section 5 (Step 1.1 of the assessment method), we explain that an assessment may need to be carried out at a lower level than the 'class' level. Following CICES, we call that the service 'type' and we carried out three test case assessments (Annex II–IV) at this service type level.

[57] In this way we take into account current EU legislation (including EU implementation of global agreements) and current EU marine regions Member States patterns on the protection and use of marine species respectively

4.3.1 Provisioning services

Provisioning services include all materials and biota constituting tangible outputs from marine ecosystems; people can exchange or trade these outputs as well as consume them or use them in, e.g., manufacturing (Box 2.1). The ecosystem functions leading to the capacity to supply these services include the growth of populations and individuals, i.e. the accumulation of biomass, of the relevant marine biota, which is achieved through ecosystem processes such as feeding, respiration and absorption of nutrients. However, the names of CICES Divisions or Groups comprising these services often reflect the 'good' or 'benefit' from the service, e.g. raw materials or nutrition (see Section 2 for issues with the 'blurring' of services names in CICES version 4.3). We, nevertheless, consider that the relevant biota are (also) the service, regardless of whether these biota grow in the wild or through *in situ* aquaculture. This is because these biota constitute the final ecosystem output (holding the biomass) that is harvested and used, in part or in full, by people because it provides them with the direct benefit (e.g. nutrition).

All of these services are actively used by people both in the marine environment itself (*in-situ*) and outside the marine environment (*ex-situ*), or even both. An example of the former are the people harvesting or collecting seafood or raw materials directly in the marine environment to sell (making an economic profit). Examples of the latter are people eating the seafood at home (and benefiting from its nutrition), or using the raw materials for various purposes in factories (and benefiting economically from selling the manufactured products). All of these uses are direct, and so provisioning services are clearly final services.

1. Seafood from Wild Plants and Algae

This service includes all wild macroalgae and macrophytes collected in the marine environment (*in-situ* use) and used for human consumption anywhere within the EU (*ex-situ* use). No examples of related outputs (cf. this CICES class in Table 2.2, Section 2) of wild plants and algae could be identified as contributing directly to nutrition, i.e. people do not consume marine seeds.

In defining the service:

- We found no evidence of consumption of pelagic **macroalgae** occurring in the EU, thus no link was identified.
- There are numerous examples of both benthic **macroalgae** (e.g. Dulse *(Palmaria palmata*), Kelp (*Laminaria sp.*)) and **macrophytes** (e.g. *Salicornia* and other saltmarsh plants) harvested in the shallow sublittoral and/or littoral habitats ([58]; Defra, 2010, Mishra et al. 2015).

2. Seafood from Wild Animals

This service includes all wild marine animals (vertebrates and invertebrates) collected in the marine environment (*in-situ* use) and used for human consumption anywhere within the EU (*ex-situ* use). Animal outputs such as eggs can also provide nutrition, e.g., in the form of caviar or roe. Wild animals used for nutrition can be captured commercially, through artisanal methods, or through recreational activities. We note that there will also be a link to the *recreation and leisure* service (see Service 24 – *Recreation and leisure*) for biota caught by recreational fishers. However, we felt it important to leave in the additional link here because where marine animals caught (as a sport) are consumed, there is a nutritional value (benefit) associated. This means that there are several services associated with the same activity in some cases (see discussion in Section 6).

[58] http://www.donalskehan.com/2012/07/seaweed-foraging-on-irelands-west-coast/

Wild animals that can provide the seafood service are:

- **Seals,** which, in small numbers, are killed for (licensed) hunting or during authorised culls. For example, seals are culled to protect fisheries (e.g. Finland and Sweden[59]), although they are protected under the Habitats Directive and, thus, they still must be monitored and remain in favourable conservation status. In 2007, approximately 200 seals were shot in Finland and 100 in Sweden (HELCOM 2010). Shot seals can subsequently be used for meat[60] (Ministry of Forestry and Agriculture, 2007; Hovelskrud-Broda, 1999). This would result in seal meat displacing other nutrition sourced from elsewhere, thus a link is included here for seals contributing to this service. As with many mobile species, the same population will be associated with multiple habitats; however, harvesting may not occur in all of these habitats. Previously, seals were only permitted to be taken from land but recent legislation (in Sweden) allows hunters to take seals from boats[61]. It is therefore, not known in which habitats the seals are directly harvested from but, as the same population may still contribute to the service, a link is given for all ecosystem components that include seals.
- Wild **seabirds,** as game, are hunted for human consumption[62] under certain conditions. For example, in the UK, provided quantities are small (10,000 head per annum), any hunter registered as a food business can supply game in an untreated form to primary consumers or suppliers, such as local butchers. This practice is colloquially known as 'wildfowling'[63]. Wild birds are shot in intertidal estuaries and saltmarsh (littoral *sensu* the MECSA habitat typology) habitats (e.g. off the Norfolk coast in the UK; Defra, 2010). Wildfowling is also a traditional activity in the Baltic region (HELCOM, 2009). Although also a recreational activity, the consumption of birds represents nutrition. Other seabirds are consumed in small amounts by some communities, e.g., baby gannets eaten in the Hebrides (The Guga Hunt[64]). This occurs at a very small scale but is included here for completeness. Gannets are known to be collected from nests, some of which could be located within the splash (littoral *sensu* the MECSA habitat typology) zone.
- **Seabird eggs** can also be harvested at a small scale. For example, black headed gull eggs are harvested within the UK at an EU special protection area in Hampshire, England (Wood et al. 2009). The eggs are collected under license for resale, mainly through the restaurant trade. Some nests could be located within the splash (littoral *sensu* the MECSA habitat typology) zone.
- Many species of **Fish** caught in EU marine waters are well understood to contribute to seafood in all EU marine regions, although fish are also imported to the EU from other regions (e.g. Miller & Mariani, 2010). Fish were considered to contribute to this service in all habitats apart from those in the abyssal zone. Deep-sea fishing is known to occur beyond 200 m in the upper- and parts of the lower-bathyal (down to 2000 m[65]) but not into the abyssal, which starts at beyond 2700 m

[59] https://www.luke.fi/wp-content/uploads/2017/10/Impact_of_food_quality_nutritional_status_birth_rate_and_hunting_pressure_on_Baltic_grey_seals.pdf; http://www.thepetitionsite.com/516/143/957/stop-sweden-from-killing-40-000-seals/; http://sverigesradio.se/sida/artikel.aspx?artikel=5839412
[60] https://mmm.fi/documents/1410837/1721042/4b_Hylkeen_enkku_nettiin.pdf/aeb2abf7-d6f0-422e-8a6a-94ba8403df31
[61] http://sverigesradio.se/sida/artikel.aspx?artikel=5839412
[62] http://www.bbc.co.uk/scotland/nature/the_guga_hunters_of_ness_creating_the_programme.shtml
[63] https://www.shootinguk.co.uk/shooting/wildfowling/wildfowling-for-beginners-5187
[64] www.scotsman.com/news/odd/gannet-eating-world-championship-set-for-hebrides-1-3248882; https://www.virtualheb.co.uk/guga-hunters-of-ness-isle-of-lewis-western-isles/
[65] FAO 2010–2016. Fisheries and Aquaculture topics. Deep-sea fisheries. Topics Fact Sheets. In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 8 April 2013. [Cited 13 December 2016]. http://www.fao.org/fishery/topic/4440/en

(however, see footnote[66]). It was considered unlikely that populations in abyssal waters would overlap with those in shallower habitats and hence they would not have any contribution to this service.

- **Cephalopods** such as squid and octopus are harvested and consumed as seafood in the EU (e.g. Chapela et al. 2006). Twelve species of cephalopods are of commercial value within EU marine waters, and are contained within four groups: long finned squid; short finned squid; octopus; and cuttlefish (Pierce et al. 2010). The fishing effort for cephalopods has increased considerably since 1987 and, within the North East Atlantic and the Mediterranean Sea, they are now an important component of overall fish landings (Pierce et al. 2010). Cephalopods were considered harvested in all habitats apart from benthic habitats beyond the shelf as, at present, cephalopods are only targeted commercially at depths up to 400 m (Pierce et al. 2010). Populations in the deeper bathyal and abyssal habitats are considered unlikely to overlap with populations harvested in shallower waters and hence have no contribution to the service.
- Both **Epifauna** and/or **Infauna** are harvested from benthic habitats. Epifauna, such as lobsters (Browne et al. 2001) and sea urchins[67], and infauna, such as langoustines (Nephrops; Revill et al. 2006), are harvested for food. Epifauna are harvested from all habitats up to 2000 m, the technologically deepest fishing depth, and fishing for them is subject to relevant regulations for deep-sea stocks (as for fish above). An example of a deep-sea epifauna species is the Deep-water red crab. Infauna are harvested from all types of benthic habitats for food, apart from those beyond the shelf, where no known species of infauna are targeted in deep-sea habitats.
- **Zooplankton**, which is limited to jellyfish for this service, can be commercially harvested from pelagic habitats in the Mediterranean Sea and may be consumed in EU Member States (Purcell et al. 2013).´

3. Plant and Algal Seafood from *in-situ* Aquaculture

This service includes all macroalgae and macrophytes cultivated *in-situ* for human consumption (*ex-situ*) anywhere within the EU. The assessment approach here considers that the actual plants and algae being cultured *in-situ* hold the capacity to supply the service. This is because these biota biologically mediate (i.e. produce/accumulate) the biomass that is used/consumed by people, and which is what people value because it holds the benefit (e.g. nutrition). These biota are also considered to be the service, given that they constitute the final ecosystem output (holding the biomass) that is directly harvested and used, in part of in full, by people because it provides them with the benefit. The ecosystem functions underpinning service supply capacity include the biota's growth (i.e. accumulation

[66] Regulations for the protection of deep-sea commercial fish stocks and vulnerable marine ecosystems in the North East Atlantic (NEA, Regulation (EU) 2016/2336) and for the Mediterranean Sea (REC.CM-GFCM/29/2005) limit commercial deep-sea fishing through different restrictions, such as on gear type (e.g. bottom trawls), vessel capacity, fishing area and/or the species that can be fished as well as through a fishing depth limit below 800 m and 1000 m respectively. Note commercial deep-sea fishing is not relevant for other EU marine regions. Such regimes *inter alia* can prevent bottom trawling in the deep part of the *upper bathyal zone* (as per Table 3.2, the upper bathyal ranges from 200 m to 1450 m) in the EU waters of the NEA (and so from 800 m to 1450 m) or in the Mediterranean Sea (and so from 1000 m to 1450 m). However, some bottom gear types are excluded from these regulations and could be used there and in the *lower bathyal zone* (as per Table 3.2, the lower bathyal ranges from 1450 m to 2700 m), providing vessels fulfil relevant authorisation and control measures, and do not fish in protected habitats. Nevertheless, the scope of the linkages here does consider commercial fishing in the benthic habitats of the *upper* and parts of the *lower* (down to 2000 m) *bathyal zone* because the above-mentioned restrictions would greatly reduce (through reducing bottom trawling) but not stop commercial fishing there.

[67] https://www.finedininglovers.com/stories/sea-urchin-facts-figures/

of biomass), which occurs through its interactions with the environment and is due to ecosystem processes such as photosynthesis and feeding on bacteria. This is analogous with the way in which crop production is considered by CICES version 4.3 as a (final) service in terrestrial assessments. Note, however, that it is debated whether this (final) service should be (the biomass of) the 'crop' or the (supporting/intermediate) services involved in its production, e.g. nutrient cycling (where the crop would thus be a 'good' and the supporting/intermediate services would become final services)[68].

Some species of seaweed can be cultivated vegetatively (asexual reproduction), whereas others can only be grown by facilitating the alternation of generations (i.e. a separate reproductive cycle)[69]. Where cultivation is used to produce seaweeds for the hydrocolloid industry (agar and carrageenan), the vegetative method is mostly used. However, the main seaweeds used as seafood must be taken through the alternation of generations for their cultivation. Spores or reproductively mature samples are removed from the marine environment and are artificially cultured before being returned to the marine environment suspended on ropes and frames[70] (Handa et al. 2013). This is an example of where care should be taken to avoid the 'double assessment' or the 'double counting' of (the benefits from) the same, or related, ecosystem outputs (see Section 1). Thus, the wild spores initially taken and cultured in an artificial environment would count as genetic materials here, see Service 7, whereas the biomass of growing seaweed that is later grown up *in-situ* from the cultured spores would be counted as supplying the service *Plant and algal seafood from in-situ aquaculture*.

Regarding service linkages:

- There is no known cultivation of marine macrophytes for consumption in the EU; thus only links with **macroalgae** have been identified. The links for this service are in the pelagic zone to represent that benthic algae are grown suspended on ropes in the water column (an exception has been made to include such a 'manmade' habitat in our ecosystem components, see Section 3).

4. Animal Seafood from *in-situ* Aquaculture

This service considers *in-situ* aquaculture of fish and shellfish, which could include shellfish farming and caged fish farms as well as 'ranching', such as for tuna, producing seafood that can be consumed *ex-situ*.

In-situ aquaculture of animal seafood is analogous to reared animals in the terrestrial realm. Reared animals is included as a (final) service in CICES (version 4.3); although, similarly to the case of cultivated crops, there could be questions on whether the (final) service should be the animals (which are also the 'goods') or the (currently) supporting/intermediate services, e.g. grass, which feeds the animals. In this assessment approach (and following what has been done for the algal seafood from aquaculture service – see relevant footnote under Service 3 – *Plant and Algal Seafood from in-situ aquaculture* above) the actual animals being cultured *in-situ* are what holds the capacity to supply the service. This

[68] There has been a debate in terms of whether the provisioning service 'cultivated crops' (crop production) should actually be a measure of the crop biomass following CICES (version 4.3). This is because crop biomass can also be considered to be the benefit or good produced, depending on the exact position of the 'production boundary' (cf. Figure 1.3 in Section 1). Here we follow the CICES (version 4.3) approach, which kept cultivated crops-as a (final) service because it specifies that (final) services are at the 'production boundary' where the link to ecosystem structures, processes and functions is broken (Potschin and Haines-Young, 2016). Accordingly, we have considered the biota farmed through in situ aquaculture to hold the capacity for this service. We note that the latest version of CICES (i.e. version 5.1) defines the services for cultivated plants and reared animals as the contributions that the ecosystem makes to their production but recognises that these services may be best quantified using proxy measures such as volumes of harvest biomass (Potschin and Haines-Young, 2018). See also Section 7 and Annex VI.

[69] http://www.fao.org/3/y4765e/y4765e0b.htm

[70] http://www.bim.ie/media/bim/content/publications/Aquaculture,Explained,Issue,27,-,Cultivating,Palmaria,palmata.pdf

is because these biota biologically mediate (i.e. produce/accumulate) the biomass that is used/consumed by people, and which is what people value because it holds the benefit (e.g. nutrition). These biota are also considered to be the service, given that they constitute the final ecosystem output (holding the biomass) that is directly harvested and used, in part of in full, by people because it provides them with the benefit. The ecosystem functions underpinning service supply capacity include the growth or accumulation of biomass, which occurs with the interaction of the biotic group with its environment, as well as ecosystem processes such as feeding. Cultured molluscs would feed (naturally) on other marine biota, such as bacteria and plankton. In the case of fish in cages, even if most of the food is provided artificially, the animal carries out the action of feeding, including on other marine biota, such as bacteria, plankton and smaller fish, and uses the nutrition for growth.

Regarding service linkages:

- There is a link with **fish** for this service (e.g. salmon). Fish farms using cages are mainly located in coastal areas, but can also be located offshore (Lane et al. 2014). In this assessment approach, links are placed with habitats from near-shore bays out to shelf waters. These fish are not expected to ever be wild – eggs are harvested, fertilised and reared in artificial conditions.
- **Tuna ranching**, where juvenile and young adult wild tuna are 'herded' into pelagic enclosures and fattened up, is a different situation from *in-situ* fish cage farming. Thus, the captured juvenile tuna are wild animals, not artificially reared and, therefore, could be considered under the *Seafood from wild animals* service. However, tuna ranching is included in this assessment approach under the *in-situ* aquaculture service to reflect the time and resources input by tuna ranchers prior to the use of the adult tuna for nutrition, which is analogous to other types of *in-situ* aquaculture.
- There is a link with **epifauna** (e.g. mussels) and **infauna** (e.g. cockles) for this service. Invertebrate seafood (shellfish), such as mussels, oysters, cockles, scallops and abalone, are cultured in EU marine waters and can be grown in a variety of ways, including suspended in the pelagic zone or on the seabed (Robert et al. 2013). Culture of epifauna and infauna can be found in littoral habitats and shallow sublittoral habitats. It is not considered that aquaculture of invertebrates would take place in shelf habitats. This service is an example of where care should be taken to avoid the 'double assessment' or the 'double counting' of (the benefits from) the same, or related, ecosystem outputs (see Section 1). The reason is that, in some cases, wild spat is initially taken from the sea and cultured in an artificial environment (accounted for under the *Genetic materials* service, see Service 7), and then placed back in the sea (accounted for under the *Materials for agriculture and aquaculture* service, see Service 6) to be allowed to grow bigger (where this final accumulation of biomass is what is accounted for under this service here). Depending on the circumstances, the beneficiaries of the genetic materials and the seafood farmers are sometimes the same, but can be different (e.g. different companies/individuals involved at each stage, where some could be dealing exclusively with gathering the wild spat), and where people eating the cultured seafood for nutrition would also be a different beneficiary. Note that for shellfish grown suspended on ropes or trays in the pelagic zone, a link is placed in pelagic habitats to represent the contribution of this habitat to the service. This is a special case for *in-situ* aquaculture as epifauna are not naturally found in pelagic environments (and therefore, are not identified as a separate ecosystem component under Section 3, but note the exception for 'manmade' habitats there).

5. Raw Materials

This service refers to a variety of raw materials that can be collected in the marine environment (*in-situ* use) for any uses (including *ex-situ*) apart from agri- or aqua-culture, and excluding any genetic resources. It includes marine biotic material used in/as ornaments, medicines and other pharmaceutical products, cosmetics, food/nutritional supplements, etc.

Due to the broad nature of this service there are links with several components.

Some *examples* include:

- **Macroalgae** used for thickening agents, agar, superconductor electrodes (Fan et al. 2014) and food supplements[71].
- **Macrophytes** used in the cosmetic industry, e.g. *Salicornia*[72] (Surget et al. 2015), and washed up aggregations of seagrass (*Posidonia oceanica*) litter can be used as building insulation[73]
- **Fish/cephalopods** – from which oils can be extracted for health purposes (e.g. Omega-3[74]) and also used to make cosmetic and pharmaceutical products (Rabasco Alvarez and Gonzalez Rodriguez, 2000)
- **Birds** – fly fishing lures use pin feathers from birds hunted as part of wildfowling[75]
- **Whales** – ambergris from sperm whales used in the EU perfume industry[76] and to make derivative products (Shen et al. 2007).
- **Seals** – fur used as a result of hunting – on a very small scale, limited to authorised culls (Ministry of Agriculture and Forestry, 2007; Hovelskrud-Broda, 1999).
- **Epifauna** – used as ornamental shells, sponges[77] (Castritsi-Catharios, 2016)
- **Infauna** – shells used for ornamental industry, and (live) bait for fishing[78]
- **Zooplankton** – jellyfish used to produce collagen for various purposes[79]

No evidence found for current exploitation of reptiles for any raw materials (they are protected under EU and global regulations).

Specific examples for a component-service link can also be found within the text accompanying the linkages matrices in Annex I.

Components such as bacteria, microphytobenthos and phytoplankton are used in the biotechnology industry for various products (e.g. cosmetics, food supplements). However, the actual mass of products comes from artificial cultures from labs/mesocosms as naturally harvested micro-organisms have a short shelf life and it is often cheaper to culture them artificially (once they've been removed from the wild). For this reason, no link is placed between these components and this service. Given that these components are not continually exploited for the provision of raw materials, this sort of exploitation is indeed more appropriately placed under 'genetic materials'.

[71] http://halieutique.agrocampus-ouest.fr/pdf/3744.pdf
[72] http://cordis.europa.eu/result/rcn/87311_en.html
[73] http://cordis.europa.eu/news/rcn/35568_en.html, and https://neptugmbh.de/
[74] https://www.healthline.com/nutrition/13-benefits-of-fish-oil#section2, and https://www.feednavigator.com/Article/2013/02/11/EU-fisheries-discard-ban-can-help-meet-booming-omega-3-oil-demand-IFFO#
[75] http://www.fishing-mart.eu/; for example https://www.fishing-mart.com.pl/en4/veniard-cdc-super-select/s/6
[76] http://www.cosmeticsdesign-europe.com/Formulation-Science/Sperm-whale-found-with-unusual-amount-of-ambergris-promising-for-EU-perfume-makers
[77] http://www.bellini-sponge.com/eng/prodotti/baby.php
[78] https://dutchredworms.com/company
[79] http://www.wired-gov.net/wg/news.nsf/articles/International+launch+for+Jellagens+innovative+collagen+products+from+jellyfish+29102014112045?open

6. Materials for agriculture and aquaculture

This service includes any components that can be collected in the marine environment (*in-situ* use) that contribute to materials used in agriculture (*ex-situ* use) or aquaculture, including *in-situ* aquaculture.

Some *examples* include:

- Animals used as raw material would include cuttlefish (bones) and shellfish (shells) for poultry nutrition[80], or fish used in fishmeal (Shepherd et al. 2005). Thus, there are links for **fish**, **cephalopods**, **epifauna** and **infauna**.
- **Macroalgae** have historically been and still are used for fertilisers within agriculture; seaweed extracts and suspensions have achieved a broader use and market than raw seaweed and seaweed meal[81] (Makkar et al. 2016). They are sold in concentrated form, are easy to transport, dilute and apply and act more rapidly. Macroalgae is used as animal feed; there are companies in Europe advocating the use of seaweed meal as a feed additive for sheep, cattle, horses, poultry, goats, dogs, cats, emus and alpacas. Macroalgae is used for fishmeal as it is cheaper to use finely ground seaweed meal made from brown seaweeds rather than processed thickening agents. Harvesting of wild seaweed can range from small scale (e.g. by Crofters – small-scale landholders who use traditional agricultural methods in Scotland[82]) to much larger scale[83].
- **Macrophytes** have also been traditionally used as fertilisers and may still be used on a small scale in this way[84]. In addition, sheep which are grazed on intertidal saltmarsh (littoral *sensu* the MECSA habitat typology) plants can produce lamb which is sold at a premium[85]. Other specialist products such as sea lavender honey can also be produced forming a link with saltmarsh plants[86].

Live animals and plants which are captured and moved to then directly stock *in-situ* aquaculture (without any intermediate culturing, see Service 7 – *Genetic materials* below), such as aquaculture wild spat, are also considered to be included here. Care should be taken to avoid the 'double assessment' or the 'double counting' (of service benefits) of this and the *in-situ aquaculture* services (Services 3 and 4) if beneficiaries are the same (see Section 1). In addition, plant and animal stock or species that can be used for biological pest control for *ex-situ* aquaculture or pet fish tanks (Pérez-Sánchez et al., 2018; Marine Conservation Society, 2018) are included here, where they constitute a final service for the gatherer of the marine organisms, who sells them and makes a profit (e.g. BioMar[87]). There is no overlap with the *in-situ aquaculture* service or the *pest control* service (19) as these both occur *in-situ*. This does not add any further links from those already identified above.

No evidence for collection of guano from birds or seals in the EU could be found.

[80] http://www.fao.org/docrep/t0690e/t0690e08.htm
[81] http://www.fao.org/tempref/docrep/fao/006/y4765e/y4765e06.pdf
[82] http://marine.gov.scot/sites/default/files/r3007_wild_seaweed_harvesting_scoping_report_17july2018lr_0.pdf
[83] http://halieutique.agrocampus-ouest.fr/pdf/3744.pdf
[84] http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=3694,
[85] http://www.albertmatthews.com/salt-marsh-lamb-shoulder
[86] https://www.fondazioneslowfood.com/en/ark-of-taste-slow-food/sea-lavender-honey/
[87] https://www.biomar.com/en/uk/products--species/cleaner-fish/

7. Genetic Materials

This service refers to resources (cells, tissues, and entire organisms) that are removed (*in-situ* use) and then cultured, grown artificially, or used (*ex-situ* use) for biotechnology, bioengineering, bioprospecting, etc. such as in the food industry, or for the production of pharmaceuticals, cosmetics and food supplements, and for other non-scientific research purposes (for purely scientific research see Service 25 – *Scientific*). Genetic resources extracted for agricultural/aquaculture use are also included here, where 'seed' is removed from the sea which then goes on to be cultured in an artificial environment (e.g. spores of macroalgae, which are removed from the environment to be cultured in tanks for various uses). This service can also include wild seed/spat for fish farms and shellfish farms where they are taken from the wild and cultured in an artificial environment, before being moved out into farms for growth (see Service 4 – *Animal seafood from in-situ aquaculture*).

Regarding service linkages:

- This service includes links with **all biotic groups except whales**, **seals, birds** or **reptiles**, which are not considered to be taken for genetic materials due to their protection under EU legislation (e.g. the Habitats Directive) or global treaties. All the relevant biotic groups are expected to be taken from any habitat for this service (e.g. bioprospecting in deep sea habitats, which may not normally be exploited for other provisioning services, because there were no regulations restricting bioprospecting in these habitats[88] when we carried out this study).

8. Plant and Algal-based Biofuels

Energy from plant biomass, called here biofuels, can be based on any plant or algae – macroalgae, macrophytes, phytoplankton or microphytobenthos growing *in-situ*, for an *ex-situ* use. There are numerous trials and laboratory experiments taking place across Europe to develop plant and algal-based liquid biofuels, e.g. EABA[89], AquaFUELs[90], ENalgae[91]. However, no evidence was found of current harvesting of wild algae or macrophyte species for solid fuel (although this has been the case in the past for, e.g. seagrass peat, and may change in the future). Algal resources harvested from the marine environment for subsequent *ex-situ* artificial cultivation/experimentation are covered under the *Genetic materials* service within the definition and uses above (Service 7). Therefore, current experimentation into algal biofuels could give rise to that service. At present, this service here has no links with ecosystem components as there is no known exploitation of macrophytes and macroalgae for use as biofuels in Europe. Our approach has been that the current experimental use of algae as biofuels falls under the *Scientific* service (25), i.e. scientific research.

No links identified.

[88] http://www.europarl.europa.eu/RegData/etudes/STUD/2015/547401/EPRS_STU(2015)547401_EN.pdf
[89] https://www.eaba-association.org/en
[90] https://www.aquafuels.eu/
[91] http://www.enalgae.eu/

9. Animal-based Biofuels

There is no known exploitation of wild harvested animal resources (*in-situ* use) for energy/fuel use currently in Europe (*ex-situ* use). There are demonstration projects in Norway currently considering the use of fish waste from aquaculture for the production of liquid biofuels, but these use fish waste from, primarily, *ex-situ* aquaculture. Previously sand-eels have been used as solid fuel in Denmark during a time of high oil prices. Research shows that there is potential for animal based resources such as tunicates[92] to be used in the future as liquid biofuels, although – as the tunicates may be cultured in an artificial environment (such as suspended from artificial substrate in an *ex-situ* water column) – this service could come under the *Genetic materials* service given the definition above (see Service 7). However, our approach has been that the current experimental use of marine animals as biofuels falls under the service *Scientific* (25), i.e. scientific research.

No links identified.

4.3.2 Regulation and Maintenance Services

Regulation and Maintenance services include all the ways in which marine biota and ecosystems control or modify the biotic and abiotic parameters defining the environment of people (i.e. all aspects of the 'ambient' environment). People do not consume these marine ecosystem outputs, but they affect the performance of individuals, communities and populations (Box 2.1). These services are mainly used passively by people (e.g. breathing oxygen produced by marine ecosystem components, such as phytoplankton) and include some *ex-situ* uses. Some could be considered to be used both actively and *in-situ* (e.g. waste and toxicant treatment via biota – if waste is intentionally released into the sea as a form of treatment, or flood protection – if a saltmarsh is intentionally left undeveloped for this purpose).

Many of these services could be understood to be intermediate (rather than final) services **under certain contexts** (e.g. *Seed and gamete dispersal*, *Maintaining nursery populations and habitats*, *Gene pool protection*, *Sediment nutrient cycling*, etc.) because their possible direct human use (and benefit) is not very obvious. Thus, many of these services do act as supporting services for other (final) services, and their direct human benefit is less obvious than their supporting role. For example, *Waste and toxicant treatment via biota* and *Disease control* support the seafood services (such as for producing safe shellfish), and *Recreation and leisure* (providing a safe/clean environment to carry out activities such as surfing and scuba diving). Nevertheless, **in other contexts**, these services may be considered as final services, including through the avoidance of a human intervention and related costs (e.g. gene pool protection allows the avoidance of keeping a 'gene bank', or of keeping animals in captivity for genetic insurance). Examples of where services can be intermediate or final are provided for some of the Regulation and Maintenance services below, but it is considered here that all of the services listed below can be final **in at least one context** (see Section 1.4.2 of this Report).

[92] https://cleantechnica.com/2013/03/26/biofuel-made-from-marine-filter-feeders-tunicates-usable-as-source-of-biofuels/

10. Waste and Toxicant Treatment via Biota

This service involves the *in-situ* processing or break-down (i.e. bioremediation) of waste and toxicants (e.g. anthropogenic additions of oil, sewage, heavy metals), which may cause undesirable impacts in the environment, into another product or products that are less harmful to the ecosystem and humans. 'Waste' here is considered to be anthropogenic (as many substances that may be waste can also come from natural sources, see services 21 and 22 – *Sediment nutrient cycling* and *Chemical condition of seawater*). This service can be considered intermediate in the context of providing good water quality necessary for the sustainable supply of other services, such as those related to seafood production and aquaculture, and many cultural services. However, it can also be considered a final service since, despite the existence of relevant EU legislation, the sea is still actively, or accidentally and passively, used as a place to deposit waste for treatment and/or partially treated waste. This can be, for example, the case for sewage and/or wastewater (cf., e.g., EEA, 2013a[93], EEA2016b and EEA2016c), thus saving costs on other treatment options (such as building waste water treatment plants or providing the most adequate level of treatment in existing plants in the case of wastewater). Nevertheless, marine capacity for treating some wastes, such as raw or partially treated sewage, can be overcome rather fast leading to eutrophication and other negative impacts.

Regarding service linkages:

- **Bacteria** can process waste through detoxification, decomposition, degradation and mineralisation. These processes occur in the sediments as well as in the water column, e.g., oil degraded by bacteria. For example, ships carrying crude oil can leak their consignment into the sea and bacteria such as *Marionobacter* can break the oil down into simple monomers, which are less harmful (Wang et al. 2010; Dash et al. 2013).
- Photosynthetic organisms (**macroalgae**, **macrophytes**, **microphytobenthos** and **phytoplankton**) can process contaminants through phytodegradation (Susarla et al. 2002).
- **Zooplankton** (detritivores) can also contribute to waste treatment through feeding on particulate organic matter (POM) (Lalli and Parsons, 1993). The breakdown of these particulates, which could otherwise lead to smothering and anoxia on the seabed, can facilitate the sequestration of nutrients (see Service 11 – *Waste and toxicant removal and storage*) as well as reduce the survival of pathogenic viruses, which are more persistent when attached to particulates (Griffin et al. 2003).
- **Infauna** and **epifauna** can consume organic matter waste originating on land, e.g., mussels filtering particulate organic matter (POM). The breakdown of particulate or solid waste, which could otherwise lead to smothering and anoxia on the seabed, can facilitate the sequestration of nutrients (see Service 11 – *Waste and toxicant removal and storage*) as well as reduce the survival of pathogenic viruses, which are more persistent when attached to particulates (Griffin et al. 2003).

11. Waste and Toxicant Removal and Storage

This service involves the *in-situ* removal of toxicants (e.g. heavy metals, which may become toxic at certain concentrations, synthetic hazardous substances) and waste (e.g. excess dissolved nutrients from agriculture) from circulation in the environment, without changing the waste/toxicant into a new product, through the processes of filtration, sequestration, storage and accumulation. 'Waste and toxicants' here are considered to be derived from anthropogenic inputs. The waste/toxicants end up packaged somewhere in the ecosystem (e.g. stored in the body tissues of fish), but could re-enter circulation at some point in the future (if the animal dies) and could also enter the food chain

[93] http://www.eea.europa.eu/data-and-maps/indicators/urban-waste-water-treatment/urban-waste-water-treatment-assessment-3

(if the animal gets eaten, including by humans). This service can be considered intermediate in the context of providing good water quality necessary for the sustainable supply of other services, such as the chemical condition of seawater. However, it can also be considered a final service since, despite the existence of relevant EU legislation, the sea is still actively, or accidentally and passively, used as a place to deposit waste for removal, thus saving costs on other removal options (see also limitations of this option in Service 10 **–** *Waste and Toxicant Treatment via Biota*).

Regarding service linkages:

- **Bacteria** can sequester wastes from the environment (Dash et al., 2013).
- All photosynthetic organisms (**phytoplankton**, **macroalgae**, **microphytobenthos**, and **macrophytes**) can sequester dissolved wastes, such as nutrients, or hazardous substances (Sung et al. 2013).
- Invertebrates (including **zooplankton**, **epifauna** and **infauna**) can directly absorb hazardous substances, such as heavy metals, from the water column and store them in biologically inert forms or simply dissolved in the tissues as a body burden (Martincic et al. 1984).
- **Macrophytes,** for example salt marsh grass, can trap particles in their roots, sequestering wastes/toxicants in the sediment (Govers et al. 2014).
- Higher organisms also accumulate hazardous substances in their tissues (e.g. **fish**, **seals**, **reptiles**, **whales** and **birds** (Méndez-Fernandez, et al. 2014).

There is a lot of overlap between this service and *Waste and toxicant treatment via biota* (service 10 above) as the waste inputs and relevant ecosystem processes can occur concurrently or consecutively, e.g. bacteria may process solid organic waste into dissolved nutrients (service 10 above), which are then sequestered by phytoplankton (this service). Thus, the processes involved in waste treatment and waste removal and storage are inherently linked and separating them practically, in order to carry out an assessment, is problematic. A more natural split would be to have one 'Waste/toxicant treatment' service including several service types based on the types of material/substances that are treated. Then, the removal/treatment/storage of waste could be considered one main benefit. This suggestion is in line with recent research e.g. Watson et al. (2016).

Additionally, as stated in Section 2, note also that the distinction between the CICES service group: *Mediation by biota*, class: *Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants and animals* and the CICES service group: *Mediation by ecosystems*, class: *Filtration/sequestration/storage/accumulation by ecosystem*s is not clear. As biota are part of ecosystems and the waste etc. treated is the same in both cases, making these two separate services (classes) seems unnecessary. Thus, these service classes were merged into the one service class *Waste and Toxicant Removal and Storage* in this assessment approach (see Section 2).

12. Mediation of smell/visual Impacts

This service involves the *in-situ* removal of anything that may cause a smell or a visual impact on people using the marine environment, and is passively used. It can be considered intermediate in the context of providing a nuisance-free environment necessary for the sustainable supply of other services, such as many cultural services (e.g. scavenging seabirds may remove smelly or visually unappealing debris from beaches allowing enhancement of *recreation and leisure* activities there). However, the prevention of unpleasant views and bad smells can also be considered a final service as this is directly, though passively, preventing impacts on people's well-being. A further context where this service can be considered final is that this service allows the avoidance of costs associated with needing to clean areas used by people, such as a local authority needing to clean a beach in order for it to become more aesthetically pleasing (e.g. by removing rotting algae from the strandline or from the adjacent water column) and attract more visitors.

Regarding service linkages:

- All scavengers and detritivores including **birds**, **epifauna**, **infauna** and **bacterial** communities contribute to this service by removing material, such as rotting algal mats, which are in littoral habitats or offshore but could potentially wash up on shore and produce olfactory and visual impacts. Another example is **bacterial** communities breaking down oil slicks, which can cause olfactory impacts and visual impacts on surface waters and can also wash up (as tar) onshore.

Note that the CICES interpretation of this service refers to green infrastructure such as trees screening transport corridors and reducing noise, smells and visual impacts. The interpretation for the marine environment in this assessment approach deviates from the CICES interpretation, in particular because the mediation of noise is excluded, but we consider that marine ecosystems do contribute to this service, such as through the examples included in the text above. This interpretation also overlaps with the services dealing with waste (Services 10 and 11), but the beneficiaries of these services may be different.

13. Erosion Prevention and Sediment Retention

This service refers to the *in-situ* stabilisation of sediments, accumulation of sediment, and attenuation of wave energy, which all help to prevent erosion. Stabilisation can occur through biological/ecological structures (e.g. macrophyte roots, which may be part of a saltmarsh) *holding* sediment in place. Accumulation can occur through sediment becoming *trapped* in structures (e.g. biogenic reefs). Attenuation of wave energy can occur through structures (e.g. a kelp forest) being in place and breaking the energy of waves before they reach the shore. This is a final service as it provides safety for people and protects man-made structures through the prevention of erosion in coastal areas (so limited to littoral and shallow sublittoral habitats). This service is normally used passively by people, but can also be actively used, such as through the restoration of habitats specifically to provide erosion prevention.

Regarding service linkages:

- **Macroalgae**, **microphytobenthos**, **macrophytes** and **epifauna** and **infauna** all contribute through sediment stabilisation, accumulation and/or wave attenuation (Hu et al. 2014, Spalding et al. 2014, Yallop et al. 1994).
- Macrophytes above littoral habitats (*sensu* the MECSA habitat typology, e.g. in dunes) may also be relevant for this service. However, they do not currently fit within our typology, which is restricted to marine habitats (as defined in Section 3) (this is also true for Service 14 – *Flood protection*), and thus would be captured in a terrestrial ecosystem service assessment.

As explained in Section 2, under the *Mediation of flows* division and the *Mass flows* group, CICES (version 4.3) considers the service class *Mass stabilisation and control of erosion rates*, which corresponds to the description above, and also the service class *Buffering and attenuation of mass flows*. This latter class is taken to mean the prevention of sediment movement, or the retention of sediment, which could be carried out through the stabilisation of sediments, accumulation of sediment and attenuation of wave energy. It, therefore, has a lot of overlap with the *Erosion prevention* service above, as would be supplied by the same ecosystem structures. In fact, these two service classes, along with *Flood protection* (Service 14 below) have been collectively referred to as *Coastal protection* in existing services assessments (e.g. Liquete et al 2013b). Thus, indices have been developed to assess them as a single service as opposed to individually (see the marine pilot exercise in Maes et al (2014)).

As a result, we consider that the mediation of mass flows resulting in erosion prevention and sediment retention could be grouped together as a single service class as the differences in the way the ecosystem supplies each of these services are not clear (see Section 2). Flood protection could be considered separately as the way the ecosystem supplies this services has a clear difference to erosion prevention and sediment retention. While erosion prevention and sediment retention can be carried out by the stabilisation of sediments, e.g., by microphytobenthos, this does not lead to flood protection, which relies on the attenuation of wave energy, thus this (latter) service should be considered separately.

14. Flood Protection

This service refers to the *in-situ* attenuation of wave energy through ecosystem structures breaking the energy of waves before they reach the shore (e.g. in a kelp forest, the wave energy is transferred to movement in the kelp fronds, Spalding et al. 2014) and, thus minimising, or even preventing, sea flooding, which could be in an *ex-situ* environment. This is a final service through the avoidance of having to develop artificial flood barriers to provide safety to people and protect man-made structures from sea floods. This service is passively used by people, but could be actively used when habitats that provide flood protection are restored for this purpose. It is only relevant for intertidal and shallow sub tidal habitats.

Regarding service linkages:

- **Macroalgae** beds, such as a kelp forest, **macrophytes** and biogenic reefs (**epifauna** and **infauna**) contribute to attenuation of wave energy and, thus, flood protection via prevention (Spalding et al. 2014).

15. Oxygen Production

This service refers to the production of atmospheric oxygen by the photosynthesising components of the marine ecosystem (Hader & Schafer, 1994; Murray & Wetzel, 1987). It is a commonly cited statistic that marine algae provide 70 % of the world's oxygen, although more conservative estimates state this is around 50 % (Nadis, 2003). The actual contribution is unknown; nevertheless, the oxygen produced in situ by the photosynthesising components of the ocean and released into the atmosphere is an important marine ecosystem service as it provides part of the air that we breathe. This is an example of where human demand for an ecosystem output to become a service is not active but passive, as our respiration normally is, and where the service is only used outside of the marine environment (*ex-situ*).

Regarding service linkages:

- All photosynthesising components contribute (**macroalgae, macrophytes, microphyto-benthos** and **phytoplankton**) to this service.

It is noteworthy that this service comes under the CICES (version 4.3) group *Gaseous/air flows*, while another group is called *Atmospheric composition and climate regulation*, where, actually, the description of this oxygen production service would seem to fit better under the latter group, but only climate regulation services are included there. The production of oxygen could also refer to the oxygenation of the water column but, in this assessment approach, this function is included under the service *Chemical condition of seawater* (Service 22), which includes balancing the natural conditions of the water column.

16. Seed and gamete dispersal

This service refers to the *in-situ* biotic dispersal of seeds (e.g. from seagrasses) and gametes (reproductive cells). While generally the dispersal of seeds and gametes in the marine environment is largely driven by abiotic processes (e.g. currents, see Section 2), there are smaller scale examples where the biotic contribution is significant or essential, in particular for seagrasses and isolated coastal lagoons (see examples below).

The service can be considered intermediate as it supports the growth of populations of biotic groups that contribute to the supply of other services. However, in the context of societal efforts for the restoration of, for example, seagrass beds[94], or other fragmented or isolated populations of marine species, it can be considered a final, but passively used, service. This is because seed (or gamete) dispersal can occur through this service rather than requiring artificial reintroduction of juvenile or adult individuals.

Regarding service linkages:

- Modes of seed and gamete dispersal may include transport of seagrass seeds by benthic (feeding) **fish, reptiles** and **birds.** Although this is probably not essential for seagrass communities in general, the rates of biotic dispersal have been found to be significant and to disperse seed to isolated areas (Sumoski and Orth, 2012). Furthermore, seagrass meadows, for example in the Mediterranean, are becoming increasingly isolated due to degradation, and so the contribution to seed dispersal by relevant biotic groups may become even more important[95].
- Dispersal of gametes may be important for coastal lagoons that are isolated and this may occur through water droplets transported by **birds** (Carlquist, 1981).

17. Maintenance of nursery populations and habitats

Maintenance of nursery populations involves providing the habitat and refuge from predation for juveniles of migratory and/or commercially important species (Tuya et al. 2014), as well as providing the food resources needed to sustain them *in-situ*. Nursery habitats are those that are more important than surrounding areas for the juveniles of populations of those species. The definition here, considering also the prey or food source of the juvenile species, goes beyond the meaning of this service in some other assessments (and in CICES version 4.3), where only the physical habitat structure is considered, but is in line with other assessments (e.g. Hattam et al., 2015). This aspect has been added in order to capture important nursery grounds, which may lack significant physical structures (e.g. a rocky reef), but, nevertheless, support nursery populations, such as plaice nursery grounds in soft sediments in the North Sea (Seitz et al., 2013).

This service can be considered intermediate in the context of supporting juvenile populations of biotic groups that contribute to the supply of other services, such as the supply of *Seafood from wild animals* and *Recreation and leisure* linked to sports fishing. Note, however, that there has been some debate about whether this service can also be final. The reason intermediate services should not be included in CICES is to avoid the 'double counting' of service benefits (i.e. the benefit of the final and that/those of the intermediate service/s making it possible) in, e.g., a potential subsequent economic valuation

[94] http://eu.oceana.org/sites/default/files/reports/OCEANA_Restoration_of_seagrass_meadows.pdf, http://ec.europa.eu/environment/integration/research/newsalert/pdf/361na4_en.pdf

[95] *Posidonia oceanica* is slow growing and highly vulnerable, which is why it is protected by the EU Habitats Directive and other EU, global and national regulations (Pergent et al., 2016). Following historical decline, it now covers about 2 % of the area of the Mediterranean Sea and the population trend is decreasing according to the IUCN red list of threatened species (Pergent et al., 2016). Research predicts further decline of *Posidonia oceanica* due to increased sea surface temperature as a result of anthropogenic climate change (Jorda et al., 2012).

exercise (see Section 1). Nevertheless, Liquete et al (2016) argued that the nursery function should be considered an ecosystem service in its own right when it is linked to a concrete human benefit (e.g. spillover effects from a protected nursery habitat to fishing grounds, leading to enhanced fishing, increased recreational activities, etc.). These authors did not find existing economic valuation studies that included both the monetary value from the *Seafood from wild animals* provisioning service and the nursery function role towards that, i.e. the studies had not double-counted the same benefit, because the indicators used to characterize the delivery and benefit from the nursery function were different from those used to assess seafood provisioning. They concluded that, when it came to economic valuation, the results from the nursery service should only be used to estimate what share of the total fishing value ultimately depended on specific nursery habitats.

Additionally, Hattam et al. (2015) stressed that pressures on the nursery service can be managed in their own right through, e.g., seasonal, spatial closures to fisheries (under the Common Fisheries Policy), which would make it an actively and directly used (final) service. In this context, we propose that it can also be argued that there are avoidance costs associated here, since without recognising this service (and the associated spill over effects), broader (potentially more expensive) fisheries' management measures may be required. Hattam et al. (2015) also concluded that the service could be final over different temporal scales, where juvenile populations contribute now directly to the supply of (final) services in the future, and where management has changed in intervening years (to allow for that potential to be realised). We agree with the conclusion of Hattam et al. (2015) that the nursery function may be counted as a final service, actively or passively used, in some situations, but an intermediate service in others, which would vary according to the temporal and spatial boundaries of the assessment approach.

Important nursery habitats include estuaries, seagrass beds, kelp forests and wetlands, as well as soft sediment, hard bottom, shell bottom and water column habitats[96] (Seitz et al., 2013). In addition, biogenic reefs such as oyster beds, maerl and glass sponge reefs are also important nursery habitats. Overall, nearshore and coastal areas are much better understood for the roles they play in nursery functions (e.g. Seitz et al. 2013). However, some knowledge exists for offshore areas, e.g., oceanic soft bottom habitats are an important spawning ground for summer flounder in the North Western Atlantic[97]. For this reason, linkages identified in this study include most habitats, even for offshore habitats where direct evidence of nursey function roles may not be available. Despite this, habitats deeper than the deepest commercial fishery operations (i.e. abyssal) were not included as these habitats are unlikely to play significant roles in maintaining juveniles of the populations of commercial or migratory species.

Some essential nursery function features are abiotically mediated, such as rocky reef structures in hard bottom habitats, and salinity or temperature of water column habitats, and these are not included based on the definition of ecosystem services used in this assessment. However, there are also ecologically mediated contributions to the maintenance of habitats from a range of biotic groups. Links are included only where the contributions from biotic groups are known to maintain nursery habitats in a consistent way. Thus, other interactions of biotic groups with potential nursery habitats, such as intermittent natural disturbance due to foraging activities of whales, turtles, birds and fish in soft sediment benthic habitats, are not considered to contribute to this service. Biotic groups which contribute to this service through providing a bio-physical habitat structure include:

- **Macrophytes** such as seagrass beds (Tuya et al. 2014) and saltmarsh wetlands (Seitz et al. 2013); and **macroalgae** such as kelp forests (Ara et al. 2013) in all shallow sublittoral and littoral habitats.
- Deeper habitats, such as deep water corals, biogenic reefs and glass sponges, etc. (**infauna** and **epifauna**).

[96] http://portal.ncdenr.org/web/mf/habitat/nc-habitat
[97] http://portal.ncdenr.org/web/mf/habitat/soft-bottom

- Floating seaweed clumps (**macroalgae**) form rafts under which juvenile fish aggregate e.g., in the North Sea (Vandendriessche et al. 2007) in pelagic habitats.
- **Reptiles** can also contribute to this service. Green Sea Turtles 'crop' and maintain distinct seagrass beds (Godley et al. 2002) in shallow sublittoral habitats.
- **Infauna** and **epifauna** maintain benthic habitats of commercially important species of demersal fish in soft sediment habitats (Peterson et al. 2000, Thrush and Dayton, 2002). Thus, all soft sediment benthic habitats are included from littoral to lower bathyal (down to deepest fishing depth there, 2000 m).

Nursery populations of migratory and/or commercially important species can also be maintained through the other species acting as prey species. Biotic groups which contribute to the service in this way include:

- In pelagic habitats, **phytoplankton** and **zooplankton** are likely to make the largest contribution; however, **fish** and **cephalopods** may also contribute.
- In benthic habitats, **epifauna**, **infauna** and **microphytobenthos** are likely to make a large contribution, while **fish** and **cephalopods** may also contribute.
- No link for bacteria is given in this assessment approach since, even if it is known that fish can feed on bacteria, the exact role bacteria may play in providing nutrition for commercial or migratory species is currently unclear.

18. Gene Pool Protection

This service involves the *in-situ* protection of genes and species and, essentially, biodiversity. As such, it can be considered intermediate and passive in the context of maintaining the genetic diversity necessary for the sustainable supply of other services such as genetic resources. However, it can also be considered a final, but passively used, service in the context of avoiding the cost of maintaining gene banks, or zoos, or reserves, as needed to protect marine genetic diversity for future generations and for genetic insurance purposes. Where conservation policy/measures are explicitly set up to protect genetic diversity, this would be considered an active use.

Regarding service linkages:

- **All components** contribute to this service by simply existing and reproducing; some organisms will also contribute by providing biogenic habitat, or symbiotic relationships, which other organisms may be dependent on.

Note that *Gene Pool Protection* as a service class was not included in the CICES version 4.3 classification table (Table 2.1, Section 2); this is believed to have been an oversight, as the words 'gene pool protection' are included in the name of the service group, and so the service has been included here, in the MECSA approach, as a service class (see Section 2).

19. Pest control

This service involves the *in-situ* control of pest species in the marine environment, including non-indigenous, invasive species; proliferating native species; nuisance algae; and any species that can become a nuisance for humans. Thus, where natural pest control mechanisms fail, there can be a cost in controlling these pests to maintain desired environmental conditions or to prevent or minimise losses of valuable stock. This would be the case, for example, in *in-situ* aquaculture when invasions of jellyfish small enough to enter cages can damage or destroy stocks of farmed salmon[98]. A further example of costs due to pests include proliferation of jellyfish on beaches, which can shorten the bathing season[99] and deter tourists (and their local investment). Costs can be incurred by local authorities in trying to offset jellyfish presence using anti-jellyfish nets[100], and there can be costs to local health systems from having to treat jellyfish stings (De Donno et al, 2014) (which could also be considered under the *Disease control* service, 20, see below). In this context, this service can be considered final as natural pest control leads to the avoidance of these costs. Otherwise, this service can be considered a supporting service, such as through maintaining good conditions for the supply of the *Seafood from wild animals* or *Recreation and leisure* services.

The service is mainly used passively in the marine environment (*in situ*), but an example of an active use would be if a 'biological control' species were intentionally released as a pest control. For example, wild wrasse fish are used to control sea lice in farmed salmon pens[101]. In this context, this is a final service for the salmon farmer.

Regarding service linkages:

- Control of pest species is underpinned by a balanced foodweb; hence, **all components** are relevant to the supply of this service. When thinking of specific examples of pest species in a specific location, it may be possible to identify key species that contribute to their control. For example, in the Black Sea, the recovery of fish populations and an alien invader, the Beroe comb jelly (both of which predate nuisance alien comb jellies, Finenko et al. 2009), may have been the most important contributing factors for the control of the *Mnemiopsis leidyi* alien comb jelly, which caused an ecosystem shift in the late 80s.

There could be some overlap between with this service and Service 20, *Disease control*, as mentioned above. Thus, some species, such as algae or jellyfish, could be mere nuisances or pests in some contexts, but become harmful in other contexts. When they are nuisances, we consider them under this service, but when they are bringing harm to people's health, we consider them under *the Disease control* service.

20. Disease control

This service involves the *in-situ* control of human disease and maintenance of safe waters and marine products, and it is passively used by people. Human illnesses caused by unsafe marine products include the 'Red Tide', which can be contracted by the ingestion of neurotoxins contained within infected fish and shellfish that have been contaminated with the toxins from toxic algal blooms (Abbott et al. 2009). Toxic or harmful cyanobacteria or algal blooms can also poison people through direct contact (such as from swimming), or through inhalation of toxic aerosols carried by the air/wind (Leftley and Hannah, 2009). Although EU legislation on the protection of shellfish waters, the marketing of shellfish products, and on bathing waters (and even on the ecological state of transitional and coastal waters) is in place to prevent people becoming ill, the natural occurrence of harmful toxic substances or organisms in the sea means that there is always a risk of illness present. Where these illnesses occur, this may incur costs to the healthcare industry and hence, in this context, this service is final.

[98] http://www.bbc.com/news/uk-scotland-highlands-islands-30493457
[99] http://www.telegraph.co.uk/news/earth/wildlife/7922422/Jellyfish-invasion-closes-beaches-across-Spain.html
[100] https://www.lavanguardia.com/local/20130606/54375406690/instalan-43-kilometros-de-redes-en-las-playas-del-mar-menor-para-evitar-la-entrada-de-medusas-a-las.html
[101] https://www.theguardian.com/environment/2017/jun/10/salmon-farmers-put-wild-wrasse-at-risk--sea-lice-scotland-anglers

Regarding service linkages:

- For disease control it is hard to constrain its delivery to specific ecosystem components, and so we apply the rationale that, although perhaps directly influenced by primary consumers, toxic blooms etc. are underpinned by a balanced food web and hence, **all components** are relevant to the supply of this service. Again, as described for Service 19 – *Pest control*, for particular diseases, it would be possible to pinpoint a subset of biodiversity that is most relevant in terms of its prevention.

21. Sediment nutrient cycling

This service concerns all ecosystem components involved in sediment nutrient cycling, and refers to 'natural' nutrients, i.e. those that are not the result of anthropogenic waste inputs (such as in Services 10 and 11, where the (waste and toxic) substances being processed are considered to come from anthropogenic inputs). Nutrient cycling occurs *in-situ*, through ecosystem processes such as death, decay, consumption, production, etc., in all habitats. Pelagic components, which die or defecate, can sink to the seabed and contribute to nutrient cycling in sediments, and keep the cycle going. Thus, nutrients are transferred to the sediments, such as in the form of animal waste or dead organisms, and processed by the benthic infauna, epifauna, and bacteria through their living habits (such as burrowing, filtering, deposit feeding, etc.), so that the nutrients can become available in different forms and enter the cycle again (through, e.g., the predation on benthic organisms).

This service is mostly considered an intermediate service and is passively used. There may be contexts, however, where it can be considered final. For example, as described under *Materials for agriculture and aquaculture*, sheep reared and grazed on saltmarsh can produce lamb that is sold at a premium, and there are other specialist products, such as sea lavender honey produced from saltmarsh plants. The beneficiaries of these products include the producers or farmers, who actively choose to use these locations to produce their stock, and directly benefit from the avoidance of having to maintain the ideal sediment nutrient conditions to support the macrophytes contributing to the production of these products. Thus, in this example, sediment nutrient cycling is one of several intermediate services to someone who obtains nutrition from lamb or honey, but is a final service to the farmer producing the food. However, it should be noted that 'double counting' of service benefits in, e.g., a potential subsequent economic valuation exercise would occur if the benefit is counted under both the *Materials for agriculture and aquaculture* service and this service here. Sediment nutrient cycling can also be considered final in the context of the avoidance costs of restoring degraded sediment conditions.

Regarding service linkages:

- The main contribution to this service comes from the benthic habitats; however death and defecation of pelagic species that subsequently sinks to the benthos will also contribute. Thus, **all components** are relevant.

There is some overlap between this service and waste (in the form of nutrients) treatment and removal/storage (Services 10 and 11); all three services are underpinned by similar ecosystem processes (i.e. degradation, decomposition, bioturbation). However, they differ in that the waste services deal with anthropogenically introduced elements; they have different beneficiaries; and the relative contribution of the different components involved in service supply capacity is different. Therefore, they have been kept separate (as per Table 2.2, Section 2). This service is also linked to the *Chemical composition of seawater* (Service 22) because many of the ecosystem processes that underpin them are the same, and the links between the benthic and the pelagic realms are important for the regulation and maintenance of the conditions of both the *sediment* and the water column (*seawater*). However, they have also been kept as separate services because the relative contribution of relevant components to service supply capacity is likely to be different, and the beneficiaries are different.

22. Chemical condition of seawater

This service involves the *in-situ* maintaining and buffering of the natural balance of all chemicals naturally present in seawater, such as oxygen, carbon, nutrients and minerals, as a result of ecosystem processes and functions e.g., respiration, photosynthesis, calcification. This service can act as a supporting service for others, such as maintaining ambient water conditions suitable for seafood production. However, seawater is directly used and marketed for health and cosmetic purposes because of its chemical quality. It is used in seawater-based products and thalassotherapy. When directly marketed as, e.g., a spray (such as Sinomarin[102]), some specific chemical compositions (i.e. seawater of a certain quality) are more sought after than others (e.g. those in Brittany, France, or from upwelling areas[103]). Since the producers of this, and similar products made fully of seawater, which may favour specific chemical compositions would not need to manipulate the seawater they collect, such as removing excess nutrients (although in some cases changes are made), this service could be considered as final in this context. This service can be passively used *in-situ* in most contexts. In the examples of using seawater-based products, the service is considered actively used, i.e. actively sought *in-situ* by the producers of these products, and would be used *ex-situ* by the people buying the products.

Regarding service linkages:

- **All components** contribute to this service via localised changes in concentrations caused by ecosystem processes and functions, such as respiration, photosynthesis, calcification, defecation, nitrification etc., although the relative contributions to service supply capacity will vary between components.

There is some overlap between this service and waste (in the form of nutrients) treatment and removal/storage (Services 10 and 11); all three services are underpinned by similar ecosystem processes (i.e. degradation, decomposition, bioturbation). However, they differ in that the waste services deal with anthropogenically introduced elements; they have different beneficiaries; and the relative contribution of the different components involved in service supply capacity is different. Therefore, they have been kept separate (as per Table 2.2, Section 2). This service is also linked to *Sediment nutrient cycling* (Service 21) because many of the ecosystem processes that underpin them are the same, and the links between the benthic and the pelagic realms are important for the regulation and maintenance of the conditions of both the *sediment* and the water column (*seawater*). However, they have also been kept as two separate services because the relative contribution of relevant components to service supply capacity is likely to be different, and the beneficiaries are different.

23. Global climate regulation

Global climate can be regulated by marine ecosystem components through the uptake of greenhouse gases. Carbon dioxide is the major gas driving anthropogenically caused climate change; however, greenhouse gases can be released from both natural and anthropogenic sources and other gases, such as water vapour and methane, have a greenhouse effect. Regulation of carbon dioxide (CO_2) is underpinned by energy flows within the climate system, e.g., the atmosphere and the oceans. The ocean can act as a sink of CO_2 and this is underpinned by physical and biological processes. Calcifying organisms in the marine environment contribute to the carbonate pump, whereby calcium carbonate can be locked away at the sea floor effectively removing CO_2 from the ocean, and allowing further drawdown of atmospheric CO_2. Similarly, photosynthesising organisms remove CO_2 leading to carbon burial

[102] https://www.sinomarin.com/hypertonic-nasal-sprays-vials/
[103] https://www.totumsport.com/product/

in the form of primary producers but also via consumption and subsequent death/defection of higher organisms (see also Figure 1.3 and EEA, 2015). Bacteria can also reduce the level of methane gases originating from the ocean floor that are released into the atmosphere. This final service is an example of where human demand for an ecosystem output to become a service is not active but passive and used *ex-situ*, as living in a habitable ambient climate is.

Regarding service linkages:

- **All components** store carbon in some form or other; thus all components contribute to this service, although the relative contributions of components to service supply capacity will differ.
- **Bacteria** can sequester methane released from the ocean floor (Ruff et al., 2015).

4.3.3 Cultural services

Cultural services include all non-material marine ecosystem outputs that have physical, experiential, intellectual, representational, spiritual, emblematic, or other cultural significance (Box 2.1), and are always final services. However, demand for them may sometimes be passive and, in those cases, the benefits from the services could, in principle, be free flowing (not requiring human input) (see Section 1). These services can be supplied *in-situ*, or *ex-situ*, or both. The names of these services tend to reflect the benefits people get from them or the activities via which these benefits are obtained, rather than the services providing those benefits (see Section 2 for issues with the 'blurring' of services names in CICES). Considering the kinds of ecosystem structures, processes or functions that cultural services can be underpinned by, these can range from the abundance, distribution and behaviour of animals (e.g. on which wildlife watching is based); the decomposition of microalgae (producing the sea smell people enjoy when being at the seaside); or simply the existence of ecosystem components (for aesthetic benefit, existence, bequest, etc.). Thus, cultural services are, in principle, linked to the state of ecosystem components and the capacity of the ecosystem to supply them, but the way in which they are linked can vary, ranging from a tight link to being fully decoupled in some cases (see below).

The ecosystem capacity to supply some cultural services can indeed be actually fully decoupled from the *current* state of the ecosystem itself, i.e. a 'state to capacity' decoupling. This first aspect of decoupling would be problematic for an approach such as the MECSA, which assesses current (and future) service supply capacity on the basis of current (and future) ecosystem state (see Section 5), and this is further discussed in sections 6 and 7. Beyond this, the use of some other cultural services can be partially decoupled from the capacity of the ecosystem to supply them, i.e. a 'capacity to actual supply/use' decoupling. This second aspect of decoupling needs acknowledging but can only be taken into account in the context of a '*demand*-side' approach to assess marine ecosystem services, rather than in a '*supply*-side' approach like the MECSA.

On the first aspect of decoupling ('state to capacity'), consider the example whereby the current state and (associated) presence of whale populations would not have any bearing on the traditional/heritage *ex-situ* use of whales, or the capacity of whales to supply other services *ex-situ*, when this is only based on/reflects the presence of whales in the *past* (see Service 27 – *Heritage*).

On the second aspect of decoupling ('capacity to actual supply/use'), consider the example whereby the current capacity of fish populations to supply recreational fishing may have not have a one to one relationship with the practice (use) of recreational fishing, where recreational fishing users may decrease less than expected with decreased catch rates (Prayaga et al. 2010). Here other factors, such as availability of conveniences like car parks, or good weather, can also be as, or more, important than the capacity (based on the state) of the underpinning ecosystem components to supply the service (O'Higgins et al., 2010). Thus, users do not necessarily set out to use the service at its optimal capacity because other factors are also important to them (see Service 24 – *Recreation and leisure*). Another example of 'capacity to actual supply/use' decoupling, would be certain activities that users actively choose to carry out in marine ecosystems, such as swimming, surfing, kayaking, coasteering, where the presence of ecosystem components (linked to their state), e.g., seabirds or dolphins, adds to or can enhance the experience of the user. However, the components are, in themselves, not essential to that experience (see the *Recreation and leisure* service types identified as having a 'moderate' or 'low' dependence on marine ecosystem components in Table 5.9, Section 5 and Annex II). Thus, the user may have prioritised carrying out the activity rather than using the relevant cultural ecosystem service – notwithstanding such an enhancement. Therefore, the capacity of the ecosystem to supply the service is only partially realised through the actual use of the service (see Service 24 – *Recreation and leisure*).

Carrying out a single activity to interact with marine biota/ecosystems in a 'cultural' manner can lead to simultaneous physical, intellectual and other cultural experiences, and benefits. Thus, there is a degree of potential overlap between many cultural services for several reasons:

- Firstly, there is a general overlap of the ultimate physical and mental health and wellbeing benefits, e.g., relaxation and peace of mind, which can be provided by many cultural services, e.g., *Recreation and leisure*, *Entertainment* and *Sacred/religious*. However, the categorisation of services here can still be used to explore the different ways in which those benefits are reached.
- Secondly, there is potential overlap in the sensorial use of ecosystem components. For example, viewing a seascape, which includes marine biota (e.g. seabirds) or their outputs (e.g. sea smell), from the beach could be considered a way of using the *Recreation and leisure* service because it is a physical experience in the marine environment, but it could also be considered a way of using the *Aesthetic* service because that is a visually pleasing view. To avoid, or minimise, this overlap, we distinguish *Recreation and leisure* as an active, *in-situ* service (see below) and separate it from intellectual services, such as *Aesthetic*, which are mainly used passively and ex-situ, or actively and *in-situ* only in certain contexts (see below under each service).
- Thirdly, some activities or uses are associated to multiple services and do not fit neatly under any one. For example, recreational wildfowling is linked to the *Recreation and leisure* service through the activity, to the *Seafood from wild animals* service through the birds hunted and consumed, and to the *Raw materials* service through the birds' feathers. An individual hunter may have different primary reasons for carrying out the activity. In other examples, a cartoon or advertisement featuring marine biota could be linked to the *Entertainment*, *Aesthetic* and *Education* services at the same time.

Nevertheless, we do not consider that these types of overlap would lead to 'double counting' of service benefits (in, e.g., a potential subsequent economic valuation exercise) because the benefits would differ for each service, and an activity or use that is associated with multiple services could be more valuable culturally than an activity or use associated with one service. In addition, different users may prioritise different benefits.

24. Recreation and leisure

This service entails a range of physical and experiential interactions with marine biota/ecosystems, where the service is enhancing or underpinning these interactions through the relevant ecosystem components. These interactions are achieved through a series of *in-situ* activities, such as wildlife watching, diving, swimming, boating, angling, etc. (see Table 5.9, Section 5).

As explained in Section 2, despite the *Physical* use of plants, animals and land-/seascapes in different environmental settings and the *Experiential* use of the same aspects being two separate services (classes) in the CICES classification system, it was considered impossible to disentangle physical from experiential interactions. For example, although swimming in the marine environment may be a purely physical activity (and thus not a biologically mediated ecosystem service), it will be influenced by the associated experiences, such as water quality, presence of jellyfish or bioluminescence, and these are all reliant on marine biota. Thus, a higher level of the CICES hierarchy has been used here, i.e. 'group', although this group of physical and experiential interactions has been named *Recreation and leisure* and considered, de facto, a service 'class' in this assessment approach (see Table 2.2, Section 2). In addition, and although the CICES description of this service also includes the land-/seascape environmental settings (see Table 2.1, Section 2), the MECSA approach is set up in a way that does not allow for the potential contribution to service supply capacity from physical environmental settings on their own to be accounted for. Thus, links to these settings can only be made through biotic groups occurring there (as we have defined services to be biologically/ecologically mediated). The possibility to incorporate environmental settings in themselves explicitly and their contribution to the ecosystem's capacity of supply of cultural services could be explored in future assessment approaches.

The experiential interactions covered under the *Recreation and leisure* service are always associated with some kind of ***in-situ*, active** physical activity, leading to several service 'types'. These activities distinguish experiential interaction from intellectual, representative and spiritual interactions, as provided through other cultural services, although these may lead to attaining the same benefits in terms of enhanced mental health and wellbeing, e.g., relaxation. For example, the activity of going to see a natural marine seascape would be a way of using the *Recreation and leisure* service as it is physical and takes place *in-situ*. However, this activity could also be a way of using the *Aesthetic* service given that some of the benefits gained would be the same, e.g. sensorial enjoyment. Thus, there could be an overlap between the *Recreation and leisure* and *Aesthetic* services. In order to avoid that and, thus, 'double counting' of service benefits (in, e.g., a potential subsequent economic valuation exercise), we have (also) specified which are the interactions linked to the *Aesthetic* service. In brief, these are passive, *in-situ* aesthetic experiences and 'sense of place'; artistic inspiration (*in-situ* or *ex-situ*, active or passive), and active or passive *ex-situ* aesthetic experiences (see Service 29). There are also overlaps between the *Recreation and leisure* service and other cultural services in terms of the sensorial enjoyment or amusement people would get from, e.g., being entertained by whale watching. In this case the overlap with the *Entertainment* service (see Service 28) is avoided because, as stated, all *in-situ* active pursuits are included under the *Recreation and leisure* service, so being entertained by whale watching comes under this service; while the *Entertainment* service covers any *ex-situ* entertainment.

Different activities associated with the *Recreation and leisure* service rely in different ways on the presence (linked to the state) of ecosystem components due to a range of factors, including both the type of activity as well as factors affecting human behaviour. As noted already, these factors may result in a partial decoupling between the ecosystem capacity to supply the service and the actual use of the service. Therefore, the ecosystem capacity to supply the service may not being fully realised into an actual service. For example, a study of recreational clam digging found that most activity occurred at easily accessible sites, even though more valuable stocks were present in other locations, which were less accessible (O'Higgins et al., 2010).

See also Annex II of this Report for a test case assessment of the *Recreation and leisure* service class, through a specific example that explored how the state of the underpinning biota affected the ecosystem capacity to supply the *Recreation and leisure from whale watching* service class *type*. This Annex also includes a ranking of the dependency of human activities in marine environmental settings on marine ecosystem components (which is also included as Table 5.9 in Section 5). Thus, showing where the presence of ecosystem components (and/or their state) would add to, or enhance, the user's experience while carrying out these activities, but may not be what the user has prioritised. However, we argue that such an enhancement has been actively sought by the user; otherwise he/she would be carrying out these activities in another feasible setting. Nevertheless, once again the ecosystem capacity to supply the service may not be fully realised into an actual service, which would depend on the actual service class *type* being assessed.

Regarding service linkages:

- Most biotic groups were considered to contribute to this service via enhancing or underpinning physical and experiential interactions associated to activities such as diving, swimming, hunting, boating, wildlife-watching, recreational angling, horse riding and yachting. Some of these activities (such as visiting a scenic area and picnicking there) may actually take place further inland than the habitats covered in the MECSA habitat typology (see Section 3) but, given that the interaction is still underpinned by marine ecosystem components, it has thus been included.

  Most biota underpin or enhance recreation and leisure-type interactions; however not all ecosystem components may be relevant. For example, it is unlikely that epifauna in areas beyond the shelf have a link as divers will not be found there. In contrast, birds, dolphins and phytoplankton (bioluminescence) have the potential to be experienced by people further offshore (oceanic waters), e.g., on cruises. Benthic bacteria and microphytobenthos are not considered to underpin recreation and leisure-type interactions.

  Examples for each biotic group are given below:
    - **Whales**, **birds**, **seals** and **reptiles** can be enjoyed by wildlife watchers
    - **Birds** and **seals** can be hunted under certain conditions
    - **Infauna** can be collected by bait diggers
    - **Fish** and **cephalopods** can be recreationally fished
    - **Epifauna** can be enjoyed as part of rock-pooling, crabbing or diving
    - **Macrophytes** could be enjoyed on coastal walks
    - **Bacteria** and **phytoplankton** can produce bioluminescence
    - **Zooplankton,** e.g., jellyfish can be enjoyed by divers
    - **Macroalgae,** e.g., kelp forest can be enjoyed by divers and snorkelers

25. Scientific

Marine biota/ecosystems supply this service when they are used as a subject matter within scientific research activities, e.g. the ODEMM EU RTD project (http://www.liv.ac.uk/odemm/); this can be in both the field and other forms of media, and so including the *ex-situ* use of marine ecosystems. Research into certain marine ecosystem constituents could also lead to providing inspiration for technological or scientific innovation. However, research does not necessarily depend on the current state of the relevant biotic groups, which would be the case for *ex-situ* uses of the service, or *in-situ* research surveys on, e.g., deep sediments. As a result, the meaning of the links may be different for this cultural service than for other services, where the current state of the ecosystem may not reflect its service supply capacity. Thus, the ecosystem capacity to supply the service could be based on/reflect the *past* (or other[104]) state of the relevant biotic groups, and so be decoupled from their *current* state and (associated) presence. Nevertheless, identifying a depleted natural resource, such as a species threatened by extinction, or simply raising awareness of certain marine species through research can result in efforts to maintain, reintroduce or increase its/their population/s. For example, a large investment has been made in the Baltic Sea to reintroduce wild salmon (HELCOM, 2007; 2011) because it had been documented to be near extinction (cf., e.g., Karlsson and Karlstrårn, 1994).

Regarding service linkages:

- **All components** contribute to this service as they have all been considered in various scientific research activities (e.g. this current study, research into the development of liquid biofuels, medical/pharmaceutical research, etc.).

[104] Scientific research can be based on past or theoretical ecosystem states

Research providing inspiration for technological or scientific innovation could lead to overlaps with other cultural services; where inspiration for designs and inventions[105], or the applications of such designs into relevant media[106,107,108,109], could also come under *Entertainment* or *Aesthetic* services. However, 'double counting' of service benefits (in, e.g., an economic valuation exercise) is avoided because there is a different benefit for each service.

26. Educational

Marine biota/ecosystems supply this service when they are used use as a subject matter for educational activities, including *ex-situ* use. These activities can range from third level scientific education to coastal discovery centres that provide information about the surrounding habitat and species[110]. However, educational material or some educational *in-situ* experiences do not necessarily depend on the current state of the relevant biotic groups, e.g., using University marine biology and ecology textbooks. As a result, the meaning of the links may be different for this cultural service from other services, where the current state of the ecosystem may not reflect its service supply capacity. Thus, the ecosystem capacity to supply the service could be based on/reflect the *past* (or other[111]) state of the relevant biotic groups, and so be decoupled from their *current* state and (associated) presence. Nevertheless, as per the Baltic salmon example above, identifying a depleted natural resource, such as a species threatened by extinction, or simply raising awareness of marine species through, in this case, educational material can result in efforts to maintain, reintroduce or increase its/their population/s.

Regarding service linkages:

- **All components** contribute to this service, as they are all studied at higher education institutes.

27. Heritage

Marine biota/ecosystems supply this service when they feature in historical records and are part of our cultural heritage. This service is actively used by people, and this use can be *ex-situ* (e.g. historical records) or *in-situ* (e.g. old cultural practices which carry on nowadays). Ecosystem components occurring deeper than the shelf are considered unlikely to contribute to cultural heritage (unless from a connected population, e.g., whales).

Regarding service linkages:

- **Seals**, **birds**, **fish**, **cephalopods**, **whales, reptiles, infauna and epifauna** are/were important to the culture of some communities. Examples include traditional tuna fishing in the Mediterranean; traditional whale and seal hunting. Thus, there is a link anywhere there is a historical cultural record. However, the use of historical records would always be *ex-situ* and, by being historical, this use

[105] http://webecoist.momtastic.com/2011/03/21/marine-muse-12-more-sea-inspired-designs-inventions/
[106] http://www.vogue.com/article/ocean-inspired-fashion-spring-trends and https://edelscope.com/2012/02/11/fashion-inspiration-sea-creatures-in-alexander-mcqueens-springsummer-2012/
[107] https://www.adsoftheworld.com/taxonomy/brand/surfrider_foundation
[108] https://www.salondeauville.com/ocean-inspired-collection-by-costis-aims-to-bring-the-marine-world-to-life/
[109] https://www.etsy.com/dk-en/listing/270652089/octopus-print-blue-9-octopus-wall-art?ga_order=most_relevant&ga_search_type=all&ga_view_type=gallery&ga_search_query=&ref=sr_gallery_10
[110] http://www.oceanexplorercentre.org/
[111] Education can be based on past or theoretical ecosystem states

does not necessarily depend on/reflect the current state and (associated) presence of these biotic groups. For example, traditional whale hunting does currently not take place in the EU due to regulations for the protection of whales, and traditional (and other) bluefin tuna fishing has been kept low for years (up until 2014[112]) due to quite stringent fishing quotas for all bluefin tuna fisheries (aiming at reversing the overexploitation of stocks, which is currently improving[113]). Therefore, historical records would have only reflected the past condition of whale and bluefin tuna populations. Thus, the ecosystem capacity to supply the service would be based on the *past* state of the relevant biotic groups and so be decoupled from their *current* state and (associated) presence. Nevertheless, identifying a depleted natural resource, such as a species threatened by extinction, through following historic records can result in efforts to reintroduce or increase its populations.

In contrast, seal-hunting (Northern Europe)[114], gannet chick harvesting (Scotland), and gull egg harvesting (England) (Wood et al. 2009) are three examples of the heritage service, which take place nowadays. They are tightly linked with the current state and (associated) presence of the relevant ecosystem components. Because these species are consumed, they are also considered under the provisioning of seafood, although this allocation is dependent on the scale of this consumption. Thus, if enough animals are consumed, then such consumption may displace other meat purchasing, although if very small amounts are consumed, purely for heritage reasons, then the provisioning aspects are marginal. In any case, seals (considerably bigger organisms), gannets and bird eggs have been considered in the supply of both services for completeness. This would not lead to 'double-counting' of service benefits (in, e.g., an economic valuation exercise) because the benefit would differ for each service (although the components contributing to it are the same).

Wildfowling (hunting of wetland birds on estuaries and coastal marshes[115]) is another activity that could be considered to come under several services – nutrition, recreation and heritage.

- Samphire (*Salicornia* sp.) and intertidal **macrophytes**, as currently being collected for human consumption, have traditionally been used for soap and glass making (giving the common name 'glasswort') in the 14th century in England[116]. Furthermore, Rock Samphire (*Crithmum* sp.) is mentioned in the Shakespearean play *King Lear*[117]. There is a rich history of harvesting seagrass for many traditional uses, such as thatching roofs, for animal food, and for cushion and mattress stuffing[118].
- **Macroalgae**, such as kelp, has been traditionally harvested in coastal communities in Europe (e.g. in the Highlands and Islands of Scotland)[119]. Harvested kelp has been used as a source of soda, potash and iodine. Crofters (small-scale landholders who use traditional agricultural methods) in the Western Isles and Orkney continue to make use of wild kelp[120].
- There are no known examples of phytoplankton, zooplankton, microphytobenthos and bacteria contributing to this service.

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[112] http://www.pewtrusts.org/en/research-and-analysis/analysis/2014/11/20/iccat-ignores-science-and-increases-quota-for-atlantic-bluefin-tuna
[113] https://www.fishsource.org/stock_page/679
[114] www.aland.com/en/see_and_do/sportfishing_and_hunting/experience_unique_seal_hunting_on_aland
[115] https://www.shootinguk.co.uk/shooting/wildfowling
[116] http://en.wikipedia.org/wiki/Glasswort
[117] http://en.wikipedia.org/wiki/Samphire
[118] http://www.iucnredlist.org/details/153534/0
[119] https://www.nature.scot/professional-advice/land-and-sea-management/managing-coasts-and-seas/seaweed-harvesting
[120] http://marine.gov.scot/sites/default/files/r3007_wild_seaweed_harvesting_scoping_report_17july2018lr_0.pdf

28. Entertainment

Marine biota/ecosystems supply this service when marine wild species, wilderness, ecosystems and seascapes are subject to *ex-situ* viewing/experiencing through different forms of media, e.g., documentaries, magazines, museums, aquariums, films, books, etc. This service is actively (e.g. going to the cinema to watch a documentary on the marine environment) and also passively (e.g. accidentally seeing an advertisement featuring marine biota when walking on the street[121]) used by people.

To note, however, the media above do not necessarily reflect the current state of the relevant biotic groups because the service is supplied *ex-situ,* e.g., a film including shots/stories on threats to the marine environment and threatened marine species such as the 2009 Disney docu-film 'Oceans'. As a result, the meaning of the links may be different for this cultural service than for other services, where the current state of the ecosystem may not reflect its service supply capacity. Thus, the ecosystem capacity to supply the service could be based on/reflect the *past,* or other, states of the relevant biotic groups and so be decoupled from their *current* state and (associated) presence. Nevertheless, identifying a depleted natural resource, such as a species threatened by extinction, or simply raising awareness of marine species through various media, can, as said already, result in efforts to maintain, reintroduce or increase its/their population/s.

This service does not overlap with the *Recreation and leisure* service (see Service 24) because only *in-situ* uses are included there, while we only consider *ex-situ* uses here – even if some *in-situ* uses may also provide 'entertainment'. For example, listening to a whale song *in-situ* would come under the *Recreation and leisure* service, while listening to a whale song *ex-situ* would come under the *Entertainment* service. This service could also overlap with other services where some representations of the marine ecosystem are also a way of using the *Scientific, Aesthetic* and *Educational* services (see Services 25, 26 and 29). This would not lead to 'double counting' of service benefits (in, e.g., a potential subsequent economic valuation exercise) because the benefits would differ for each service.

Regarding service linkages:

- **All components** contribute to this service, as they are all represented in, for example, marine wildlife documentaries.

29. Aesthetic

Marine biota/ecosystems supply this service when they convey a 'sense of place'[122] and through the artistic representations of marine wild species, wilderness, ecosystems and seascapes (e.g. art works using marine wildlife as inspiration[123]). People can use this service:

1) passively *in-situ*, both through a sense of place and by being in an aesthetically pleasing setting without having actively sought that out; thus, distinguishing it from the *Recreation and leisure* service, which is only actively used;
2) where an artistic inspiration or representation is made – this could be actively or passively *in-situ* or *ex-situ*, e.g., an artist finding a subject matter within marine ecosystems; and
3) actively or passively *ex-situ* through artistic representations that are sought out, or not, and which provide sensorial enjoyment, e.g., a marine art exhibition.

[121] https://www.adsoftheworld.com/taxonomy/brand/surfrider_foundation

[122] "…*the meaning attached to a spatial setting by a person or group*" Jorgensen, B.S. & Stedman, R.C. (2001) Sense of place as an attitude: Lakeshore owners attitudes toward their properties. *Journal of Environmental Psychology*, 21, 233–248.

[123] http://www.livinginthebalticsea.com/

The Aesthetic service and associated benefits can, thus, be experienced broadly – by those directly experiencing the marine ecosystem, i.e. *in-situ* use, and by those experiencing any shared representations of the marine ecosystem (Rodwell, 2013), i.e. *ex-situ* use.

Regarding service linkages:

- **All components** have the potential to contribute to this service. However, it depends on where (which habitats) people take their inspiration from. For this service, we may need to consider whether the component needs to be directly used, e.g., someone drawing a rocky shore in the field, or whether it is just the representation that matters, e.g., someone drawing a dolphin from an image on the Internet who has never actually seen a dolphin in the wild, or someone seeing a drawing of a dolphin in an art exhibition, i.e., an *ex-situ* use. For this assessment approach, all of these uses are included. In the latter case (*ex-situ* use), however, such a representation does not necessarily reflect the current state of the relevant biotic groups. As a result, the meaning of the links may be different for this cultural service than for other services, where the current state of the ecosystem may not reflect its service supply capacity. Thus, the ecosystem capacity to supply the service could be based on/reflect the *past* or imagined state of the relevant biotic groups and so decoupled from their *current* state and (associated) presence. Although, as mentioned already, identifying a depleted natural resource, such as a species threatened by extinction, or simply raising awareness of marine species through, in this case, its/their aesthetic representation can result in efforts to maintain, reintroduce or increase its/their population/s.

As mentioned, this service could overlap with the *Recreation and leisure* service (see Service 24) because aesthetic benefits, e.g. sensorial enjoyment, can be obtained through carrying out recreational activities, which are also a way of using that service. We avoid this by specifying the contexts under which the uses of this service (see above) and the *Recreation and leisure* service (*in-situ* and active only) fall. There are also potential overlaps with *Scientific* and *Entertainment* services (see Services 25 and 28), where a single activity, such as gaining inspiration for a design, can be associated with multiple services. This would not lead to 'double counting' of service benefits (in, e.g., a potential subsequent economic valuation exercise) because the benefits would differ for each service and different users may prioritise these benefits differently.

30. Symbolic

Marine biota/ecosystems supply this service through emblematic plants and animals featuring as, for example, national symbols, such as the dolphin in Greece[124]. This service can be used *ex-situ*, actively (intentional symbolic representation) or *ex-situ*, passively (e.g. unintentional feeling of unity or enhancement of well-being resulting from symbolic use of a marine representation). However, the use of these symbols does not necessarily depend on the current state and (associated) presence of these biotic groups. As a result, the meaning of the links could be different for this cultural service than for other services, where the current state of the ecosystem may not reflect its service supply capacity. Thus, the ecosystem capacity to supply the service could be based on/reflect the *past* state of the relevant biotic groups and so decoupled from their *current* state and (associated) presence. Nevertheless, identifying a depleted natural resource, such as a species threatened by extinction through, in this case, its/their symbolic representation, or simply raising awareness of marine species, can, as said already, result in efforts to maintain, reintroduce or increase its/their population/s. For example, the now extinct marine bird Great Auk is used as a symbol by conservation or other organisations through

[124] http://en.wikipedia.org/wiki/List_of_national_animals

ceremonies[125], logos and paintings/drawings[126], etc. when raising awareness of the high rate of extinction of marine and other biota. This type of efforts can give rise to plans for the reintroduction of the extinct species, such as the UK-led considerations to bring back the Great Auk[127].

Regarding service linkages:

- Charismatic megafauna (**whales**, **seals**, **birds**, and **reptiles**) are often important symbols; however, other components like **fish**, invertebrates (**cephalopods**, **epifauna**, **zooplankton** – jellyfish) and seaweeds (**macroalgae – benthic only**), or **macrophytes**, are also used as symbols for conservation societies, environmental NGOs, etc.
- Components found deeper than the shelf are considered unlikely to contribute to this service (unless from a connected population, e.g., whales).
- Infauna, microphytobenthos and bacteria are not considered to contribute to this service.

31. Sacred and/or Religious

Marine biota/ecosystems supply this service when they form part of, or enhance, spiritual and ritual identity or experiences (e.g. holy places, sacred marine plants and animals and their parts). Use of this service can be active (see examples below) or passive (e.g. unintentional feeling or enhancement of spiritual well-being from the marine environment or representations of it). Organised religious, sacred or spiritual practices can occur *in-situ* (see examples below) or *ex-situ*, for example the storytelling or parables employed for religious or spiritual purposes (Rodwell, 2013).

An EU example would be the Spanish religious marine festival and procession (including on boats in the sea, and so *in-situ*) for the 'Virgen del Carmen', the patron of fishermen and divers, on 16 July. Thus, there are links to all biotic components relevant for fishing and scuba diving. These components would include the biotic groups **fish**, **cephalopods**, **infauna** and **epifauna** for fisherfolk (in the relevant fished areas – see footnote under Service 2 – *Seafood from wild animals*); and for divers they could include **birds**, **whales**, **seals**, **reptiles**, **fish**, **cephalopods**, **zooplankton**, **infauna**, **epifauna**, **macroalgae** and **macrophytes** in areas used for diving.

Other EU examples of this service are the Sami people of Finland and Sweden and their possible use of the Baltic Sea, including sea ice, for sacred/religious practices. Elements of Sami sacred beliefs include that all animals and plants have souls, and the veneration of animal spirits is part of their religion[128]. Such practices also comprise rituals involving marine biota, such as fish and fish parts, for the success of those people going hunting and fishing[129]. Whether these rituals are still practiced in this way is unclear as, in more recent times, other valuables, such as alcohol, tobacco and money, have also been used[130]. It is likely that at least the charismatic marine animals and other animals important for food have a spiritual significance to people in these regions. To represent this, links with **birds**, **seals** and **fish** have been included in sea-ice habitats.

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[125] 'Remembrance day for Lost Species' https://www.lostspeciesday.org/?page_id=25

[126] 'Ghosts of the gone birds' http://www.independent.co.uk/environment/nature/the-dodo-flies-again-as-do-the-great-auk-giant-moa-6255853.html

[127] http://www.telegraph.co.uk/science/2016/08/19/plot-hatched-to-reintroduce-extinct-great-auk-to-british-shores/ and 'Revive & Restore' http://reviverestore.org/?s=great+auk

[128] https://en.wikipedia.org/wiki/Sami_shamanism

[129] From a review in Nationalparks.fi (https://www.nationalparks.fi/inari/sights/mythology), see original references there

[130] From a review in Nationalparks.fi (https://www.nationalparks.fi/inari/sights/mythology), see original references there

There are likely to be other EU examples of sacred associations with the marine ecosystem, but these have not been found and are, therefore, not included here.

In any event, as noted above this service can be used *ex-situ* through, e.g., sacred/spiritual representations and so it does not necessarily reflect the current state of the relevant biotic groups. This would be, e.g., when sacred places for fishermen, who may be struggling due to fish stocks being depleted such as in the Mediterranean Sea (FAO, 2018; EEA, 2019a), have a marine religious aim but are inland, such as the churches hosting the above-mentioned Spanish Virgen del Carmen. As a result, the meaning of the links may be different for this cultural service than for other services, where the current state of the ecosystem may not reflect its service supply capacity. Thus, the ecosystem capacity to supply the service could be based on the *past* state of the relevant biotic groups and so decoupled from their *current* state and (associated) presence. Although, as mentioned already, identifying a depleted natural resource, such as a species threatened by extinction, or simply raising awareness of marine species through, in this case, its/their sacred and/or religious representation can result in efforts to maintain, reintroduce or increase its/their population/s.

32. Existence

Marine biota/ecosystems supply this service by virtue of the potential enjoyment intrinsically supplied by marine wild species, wilderness, ecosystems and seascapes. People benefit from this service by simply knowing or appreciating that marine biota/ecosystems exist, even if they would never see them or use them for any other purpose. This service is thus used *ex-situ* and actively because people do not need to be in the marine environment to actively realise they are enjoying its existence. Thus, an artistic or other representation could trigger such existential thoughts. This service could overlap with the *Entertainment*, *Aesthetic* or *Symbolic* services (see Services 28, 29 and 30) but this would not lead to 'double counting' of service benefits (in a potential subsequent economic valuation exercise) because the benefits would differ for each service. The meaning of the links may be different for this cultural service than for other services, where the current state of the ecosystem may not reflect its service supply capacity. Thus, the ecosystem capacity to supply the service could be based on the *past* state of the relevant biotic groups and so decoupled from their *current* state and (associated) presence.

Regarding service linkages:

- **All components** contribute to this service.

33. Bequest

Marine biota/ecosystems supply this service when people are willing and/or acting to preserve plants, animals, ecosystems, seascapes for the experience and use of future generations, moral/ethical perspective, or belief. This service is considered to be actively used, for example through implementing legislation to protect species and habitats, or the setting up and of running environmental NGOs for the protection of the sea (e.g. Oceana EU[131] or Seas at Risk[132]) and associated campaigns, such as beach and sea (marine litter) clean ups[133]. No passive use is considered because an active decision needs to be made by a user to want to protect an ecosystem component so that it is available for future generations. People use this service *ex-situ*, e.g., through the implementation of legislation to protect a species or habitat, and *in-situ*,

[131] http://eu.oceana.org/en/home
[132] http://www.seas-at-risk.org/
[133] By Surfers against sewage https://www.sas.org.uk/campaign/beach-cleans/ or Surfrider Foundation Europe http://www.initiativesoceanes.org/en/

e.g., through active on-site restoration of a habitat. This service could overlap with the *Entertainment*, *Aesthetic* or *Symbolic* services (see Services 28, 29 and 30) when images, or other media, may be used as part of campaigns; although this would not lead to 'double counting' of service benefits (in a potential subsequent economic valuation exercise) because the benefits would differ for each service. The meaning of the links may be different for this cultural service than for other services, where the current state of the ecosystem may not reflect its service supply capacity. Thus, the ecosystem capacity to supply the service could be based on the *past* state of the relevant biotic groups and so decoupled from their *current* state and (associated) presence. Nevertheless, identifying a depleted natural resource, such as a species threatened by extinction through, in this case, campaigning for its reintroductions, or simply raising awareness of marine species, can, as said already, result in efforts to maintain, reintroduce or increase its/their population/s.

Regarding service linkages:

- **All components** contribute to this service.

4.3.4 *Lessons learnt from establishing linkages between marine ecosystem components and ecosystem services in an EU context*

As described under Section 2 of this Report, a number of ecosystem service classes included under CICES (version 4.3) were excluded going forward in this assessment approach in order to make the typology fully applicable to marine ecosystems. This section here aimed at describing the linkages between this relatively reduced list of 33 marine-relevant ecosystem services (as summarised in Table 2.2) and the marine ecosystem components identified in Section 3. These are summarised for each biotic group in Table 4.3 here and for each habitat type in Annex I. In addition, and following the general definition of ecosystem services in Section 1, this section has provided descriptions of the different marine ecosystem service classes within CICES.

Once the links with ecosystem components were established for each service, a number of services were found to have no links to all the ecosystem components. The absence of some linkages was determined *a priori* and resulted from having placed some constraints regarding whether a link to a service would be realised or not. These constraints were due to operating in an EU context and having to respect EU policy and follow cultural practices within the EU. People's access to the services (to service supply capacity) – either directly or indirectly, through the technology used to exploit them – was also considered in the identification of links. These, therefore, show where a service would not be supplied by a particular habitat due to its inaccessibility, e.g., abyssal habitats would not underpin the *Recreation and leisure* service or the *Seafood from wild animals* service. Alternatively, the lack of linkages was due to lack of evidence on the use of some services in EU marine waters. Nevertheless, all the original 33 services in list detailed under Section 2 have been retained as they could be applicable in other marine regions than the EU's (e.g. whaling for seafood in Norway[134]) or in the future in the EU (e.g. use of liquid biofuels from marine biota). In this way, some aspects of the (possible) use of marine ecosystem services are taken into account in this assessment approach, where services that are not currently used in the EU (for any of the above reasons) show no links with ecosystem components.

The process of identifying linkages also highlighted some services that were found to require further consideration in moving forward with a generic marine ecosystem service typology as the one used to serve the approach here. These are summarised in Table 4.2.

[134] http://www.ifaw.org/united-states/our-work/whales/which-countries-are-still-whaling

A more general issue relates to the services names (from the CICES version 4.3 'division' to the 'class' names). It has not been possible to achieve consistency because the name can relate to an ecosystem function and/or a process (i.e., an intermediate service), a final service, a human activity drawing on the service, a service benefit, or a good, *sensu* the ecosystem services 'cascade model' (see Figure 1.3), as has been explained in Section 2. In many cases, there is no clear way to disentangle these different parts of this cascade in the service names. For example, CICES uses 'Nutrition' as the name for the provisioning service division relating to wild or *in situ* cultured seafood (see also Table 4.2). 'Nutrition' is the benefit obtained from eating, e.g., fish, rather than the service. Noting also that this assessment approach does not consider, e.g., fish as a 'good', but considers fish to be both: one of the biotic groups holding the capacity to supply the *Seafood from wild animals* service and (part of) the *Seafood from wild animal*s service itself (which would be the fish biomass). This has been noted under Section 4.3.1 and would be the case for all wild and cultured biota that can be eaten. The 'good' versus 'service', i.e. final ecosystem output, discussion is an issue relating to the general definition of ecosystem services, see Section 1).

Nevertheless, given that the intention of this assessment approach was to capture the full capacity of the marine ecosystem to supply services:

- It does not attempt to reclassify and rename services in order to develop a consistent typology since service typologies are not an exact science and tend to evolve[135] (see also discussion under Section 1.4.2). We simply acknowledge issues relating to this lack of consistency in the service names (and/or other typological issues) and show how we have overcome them in part or in full, or not at all, while developing our approach.
- Services were not excluded on the basis of being considered to be intermediate, as done under some (other) classifications in order to avoid 'double counting' of service benefits (in a potential subsequent economic valuation exercise) (or for other reasons, see also discussion under Section 1.4.2). In contrast, examples were highlighted where services defined by CICES as final can act as intermediate services for other final services (e.g. genetic materials and in situ aquaculture), as well as services that could appear to be intermediate (e.g. pest control) but were actually found to be final under certain conditions. This demonstrated the context dependency of when a service can be considered to be intermediate or final (see Section 1.4.2). Thus, many of the Regulation and maintenance services included under the scope of our assessment approach could be interpreted as being intermediate services under other classifications (e.g. waste and toxicant treatment by biota, maintenance of nursery populations and habitats, see Box 4.1 for a full list), or under different contexts.

  In fact, there are many examples where, *a priori*, it is difficult to identify the final service application, i.e., the final ecosystem output that is directly consumed, used (actively or passively) or enjoyed by people, but where under a very specific context it is actually possible to do so. Our assessment approach considered that excluding services on the basis of being defined as intermediate under some contexts could result in missing important aspects of how the marine ecosystem provides benefits to people and has, thus, avoided to do so.

[135] CICES version 4.3 underwent a review during 2016/2018 resulting in CICES version 5.1 (see Haines-Young & Potschin, 2018). See Section 7 and Annex VI.

Box 4.1 Regulation and Maintenance marine ecosystem services that could be deemed to be 'intermediate' services but which in certain contexts can all be considered 'final'

- Waste and toxicant treatment via biota
- Waste and toxicant removal and storage
- Mediation of smell and visual impacts
- Seed and gamete dispersal
- Maintaining nursery populations and habitats
- Gene pool protection
- Pest control
- Sediment nutrient cycling
- Chemical condition of seawater

Establishing the linkages between ecosystem components and ecosystem service has also shown that services differ in how they are supplied by the different components. As mentioned already, people's access to the services (to service supply capacity) determines where some of these are supplied. In this context, some services are supplied by very specific parts of the ecosystem – certain biotic groups in certain habitats the, e.g., *Erosion prevention and sediment retention* service is only supplied by benthic flora and fauna in littoral and shallow sublittoral habitats because it is only relevant there. Leaving aside issues of access, some services would be supplied by different biotic groups, or by different species within the same group, in different habitats. For example, the service *Waste and toxicant treatment via biota* would be supplied in all habitats but by different biotic groups, because, e.g., relevant groups include photosynthesising biota and these do not occur in aphotic habitats. Another reason for such differences is that specific species within a biotic group supply different services from others in that group. This means that, at the wide biotic group level, a service is supplied by the group in a different way in different habitats. Thus, the group, e.g. birds, may occur in a given habitat but not have the capacity to supply a service, e.g., *Raw materials*, there, which they can supply in another habitat. This is because of the different species involved where, e.g., only wildfowl species could provide feathers as a raw material and these species do not occur in all the habitats that are relevant for the birds biotic group. In contrast, other services are supplied more generically, where the same (relevant) biotic groups supply the service in the same way everywhere they occur. For example, all biotic groups contribute to the *Global climate regulation* service in all of the habitats that they are associated with. The additional full linkages matrices per habitat (in Annex I) show, specifically, which ecosystem components (biotic groups linked to specific habitats) hold the capacity to supply which services.

Another way services differ in how they are supplied is whether it is the biota themselves that hold the capacity to supply the service as ecosystem structures; or if it is the processes and functions the biota carry out within the ecosystem that hold such capacity. The former tends to be the case for Provisioning services, e.g., a fish, as an ecosystem structure in itself, holds the capacity to supply the *Seafood from wild animals* service. The same with Cultural services although, in a few cases, these are also underpinned by ecological processes or functions involving certain biotic groups, e.g., the sea smell that can enhance recreation and leisure-type interactions is a by-product of the metabolism of phytoplankton, under certain conditions, or of bacteria when these degrade phytoplankton[136]. The capacity to supply Regulation and maintenance tends to also be held in this way, e.g., filtration by benthic infauna leading to the *Waste and toxicant treatment via biota* service.

[136] Phytoplankton (and other algae) produce dimethylsulfoniopropionate (DMSP), which is then converted to dimethyl sulfide (DMS), which is the actual sea smell. Bacteria also produce DMS by feeding on dead phytoplankton (and other dead algae) (Dodd, 2008).

Additionally, in identifying linkages between ecosystem components and cultural ecosystem services, it was clear that there can be a full or partial decoupling between them, which affects all cultural services. In some cases, this decoupling is between the current state of the ecosystem components and their capacity to supply cultural services, and this would be a full decoupling. In other cases, this decoupling is between the capacity of the ecosystem components to supply cultural services and the actual use of these services, and this would be a partial decoupling (see section 4.3.3 and Box 4.2 for a summary of the services affected).

The first decoupling, i.e. 'state to capacity', can be due to the *ex-situ* use of some cultural services when this is based on the past state of the relevant components, such as for the *Heritage* service. Thus, the *current* ecosystem capacity to supply the service would be based on the *past* state of the relevant biotic groups/components and so be decoupled from their *current* state and (associated) presence. This has implications for the approach developed here, where we rely on an assessment of current (and future) ecosystem state to inform us about its current (and future) capacity to supply services (see Section 5). If there is a decoupling between current ecosystem state and current service supply capacity, the latter cannot be assessed using our approach. However, highlighting the past state of a culturally and historically important species could lead to measures to improve its current state. The implications from the 'state to capacity' decoupling are further discussed in Section 6, where Section 7 puts forward alternative ways to assess the cultural services affected.

The second decoupling, i.e. 'capacity to actual supply/use', can relate to how dependent different human activities linked to the use of cultural services are on the capacity of the ecosystem to supply these services (and this dependence can be ranked see Annex II). Thus, the decoupling is due to the fact that people prioritise carrying out certain activity types in marine environmental settings, such as sports/water sports, rather than using the relevant cultural services there. This is notwithstanding the fact that there would be an enhancement of the user's experience by the presence/functioning of marine biota/ecosystems, e.g., by enjoying the above-mentioned sea smell produced by phytoplankton and bacteria, and by the sighting of charismatic marine species. In fact, this enhancement is actively sought as the user of the marine ecosystem as a 'physical' setting still chooses to be there, in, e.g., seascape, rather than in another feasible setting. This 'capacity to actual supply/use' decoupling can also relate to users not necessarily setting out to use the service at its optimal capacity because other factors are also important to them. Other factors would be the availability of conveniences, like car parks, or good weather, which can also be as, or more, important than the capacity (based on the state) of the underpinning ecosystem components to supply a service (O'Higgins et al., 2010). An example would be the *Recreation and leisure from fishing* service, where recreational fishing users may decrease less than expected with decreased catch rates (Prayaga et al. 2010).

The consequence from the 'capacity to actual supply/use' decoupling is that the capacity of the ecosystem to supply the service is only partially realised through the actual use of the service, i.e. that service supply capacity will not be used in full. To note however, that it is limited to the *Recreation and leisure* service class and would not affect all the service class *types* within it. As explained in point 1.4.4 and applied in Section 4.1, the MECSA approach does not consider the ecosystem capacity to supply ecosystem services in isolation but also whether this capacity can be realised into actual services, or not. In as much as it does that, however, the approach is based on the *supply* of services from marine ecosystems and does not account for human behaviour in realising the ecosystem capacity for such a supply. Thus, services only exist because people use them; it is people who transform the ecosystem capacity to supply services into an actual supply through their use (see Section 1). Nevertheless, we can only note the possibility of a 'capacity to actual supply/use' decoupling for several *Recreation and leisure* service types here. Taking this decoupling into account is not within the remit of the MECSA approach. Thus, it would need to be taken into account when quantifying the amount of services used and/or valuing the benefits from this use in the context of a '*demand*-side' approach to assess marine ecosystem services.

Box 4.2 Cultural marine ecosystem services that can have either decoupling between 'state to capacity' (~) or between 'capacity to actual supply/use' (*) in relation to the relevant ecosystem components holding the capacity to supply them.

- Recreation and leisure (*)
- Scientific (~)
- Educational (~)
- Heritage (~)
- Entertainment (~)
- Aesthetic (~)
- Symbolic (~)
- Sacred/Religious (~)
- Existence (~)
- Bequest (~)

Finally, linking ecosystem components to ecosystem services also highlighted that some services will be used actively and others passively, or both, and that some services can be used *in-situ*, or *ex-situ*, or both. Provisioning services are always used actively, i.e. there is an active human demand for them, and where an active human intervention is required to get the benefit of the service. They all can have *in-situ* users – the people gathering the biota, and *ex-situ* users – the people who buy and use the biota for nutrition, materials or energy. Many of the Regulation and maintenance services can be used passively, i.e. there is a passive human demand for them, such as breathing oxygen produced by photosynthesising marine biotic groups, whilst others can be used both actively and passively. Some Regulation and maintenance services are only used *in-situ*, e.g., *Waste and toxicant treatment via biota*, and others only *ex-situ*, e.g., *Oxygen production*, while a couple can be used both *in-situ* and *ex-situ*, e.g., *Chemical condition of seawater*. Cultural services can be actively and passively used, and, while many are used *ex-situ*, *in-situ* cultural experiences are also possible.

For cultural services, it was found that they provide a series of 'ultimate benefits', which generally relate to physical and mental health and wellbeing, or the broad enjoyment that people get from the sea and marine biota/ecosystems, and which overlap across all, or most, cultural services. In some cases, a single 'activity' could be associated with the use of multiple cultural ecosystem services. For example, watching a marine documentary could be associated with the *Entertainment*, *Aesthetic* and *Educational* services; and recreational hunting can be associated with the *Recreation and leisure*, *Seafood from wild animals* and *Raw materials* services. These, and other, potential overlaps are not considered to lead to 'double counting' of service benefits at the valuation stage of an 'end-to-end' services assessment (from 'supply' to 'demand'), or in the monetary accounting of ecosystem services. They just show that multiple benefits can be obtained from carrying out a single activity associated to a cultural interaction with marine biota/ecosystems, increasing the cultural value of that activity, or allowing a user to prioritise between different benefits

Table 4.2 Services that require further consideration in moving forward with an EU-generic marine ecosystem service typology, or were found to have no links to ecosystem components in an EU (policy) context

Service	Outcome	Recommended Action
Seafood from in-situ Aquaculture (from Plants and Algae and from Animals) (Services 3 and 4)	The classification of outputs from agriculture or (in situ) aquaculture, including for seafood, has been the subject of debate in terms of whether these are final services in themselves or whether there are 'goods' supported by (other) final services. In the production of seafood from (in-situ) aquaculture, the animals or algae harvested are sometimes interpreted as the 'good', while the services contributing to their growth would include waste treatment, chemical condition of seawater, etc. However, the cultured algae or animals would not be there without (some degree of) human intervention. Nevertheless, this assessment approach considers that the actual biota being cultured in-situ are what holds the capacity to supply the service. This is because these biota biologically mediate (i.e. produce/accumulate) the biomass that is used/consumed by people, and which is what people value because it holds the benefit (e.g. nutrition). These biota are also considered to be the service, given that they constitute the final ecosystem output (holding the biomass) that is directly harvested and used, in part or in full, by people because it provides them with the benefit. The biota's growth (i.e. accumulation of biomass) results from their interaction with their surrounding environment through different ecosystem processes. These include feeding, which is natural in the case of algae and molluscs and still happens to some degree in the case of fish.	Further discussion with the wider ecosystem services or CICES community[137] required to reach consensus on the definition of this service in the context of the general definition of ecosystem services, and the placement of the 'production boundary'.
Seafood from in-situ Aquaculture (from Plants and Algae and from Animals) (services 3 and 4), Materials for Agriculture and Aquaculture and Genetic Materials (Services 6 and 7)	When wild seed, e.g. young fish or algal spores, or wild spat[138] from, e.g., mussels, is collected and used to stock in situ aquaculture, there are potential overlaps between the services *Animal seafood from in-situ aquaculture*, *Plant and algal seafood from in-situ aquaculture*, *Materials for agriculture and aquaculture* and *Genetic materials*. This is because there are a number of possible pathways linking groupings of these services as follows: (2) Removal of seed/spat from the wild and its direct transfer to an *in-situ* aquaculture farm with no other treatment. This pathway is common to three of these services: *Materials for agriculture and aquaculture*, *Animal seafood from in-situ aquaculture* and *Plant and algal seafood from in-situ aquaculture*. However, there are some small differences in the benefits/beneficiaries along this service use pathway. For the aquaculture materials, the beneficiary can be the person collecting the seed/spat (and selling it for an economic profit to, e.g., an aquaculture farmer), or the aquaculture farmer (if he/she collects the seed/spat and does not have to buy it). For the cultured seafood, which results from the accumulation of biomass by the seed/spat (see above), the aquaculture farmer is a beneficiary (economic profit from selling it), but there are also others, including those eating the seafood (nutrition).	Marine ecosystem services assessments to provide clarification of the affiliation of specific examples of biotic material that arguably fall under either category because of the shared pathways. This is to ensure no 'double counting' of service benefits at the valuation stage of an 'end-to-end' services assessment (from 'supply' to 'demand'), or in the monetary accounting of ecosystem services

[137] CICES version 4.3 underwent a review during 2016/2018 resulting in CICES version 5.1 (see Haines-Young & Potschin, 2018). This version of CICES does not take this approach and considers the crop to be a 'good' and not a service in itself. In the case of marine biota cultured in situ, CICES v5.1 considers that the service is, indeed, the ecological contribution to the growth of these biota. However, the actual biota are used as a proxy for the service and are, in fact, taken to represent the service because, in line with our thinking, they are what is harvested (Potschin and Haines-Young, 2018) and can, thus, be assessed, counted, etc. See also Section 7 and Annex VI.

[138] Juvenile shellfish recently settled on a substrate following the end of their planktonic larval life stage (Ifremer, 2011) http://en.aquaculture.ifremer.fr/Informations/Glossary/Spat

Service	Outcome	Recommended Action
	(2) Removal of seed/spat from the wild, its culture in an artificial environment, and its later transfer to an in-situ aquaculture. This pathway is common to all four services: *Genetic materials* (any culturing of biota in an artificial environment), *Materials for agriculture and aquaculture*, *Animal seafood from in-situ aquaculture* and *Plant and algal seafood from in-situ aquaculture*. However, there are some small differences in the benefits/beneficiaries along this service use pathway. Thus, for the genetic materials, the beneficiaries are the person collecting the seed/spat, such as algal spores, and those doing the culturing (and selling the, e.g., cultured spores for an economic profit to, e.g., an aquaculture farmer). The beneficiaries of the aquaculture materials and the cultured seafood have been listed in (1) above.	
Plant and Algal- and Animal-based Biofuels (Services 8 and 9)	No links were found for these services as the liquid biofuel industry is currently in experimental stages and no evidence was found for current harvesting of species for solid fuel. This could change in the future. The current experimental use of algal or animal biomass for biofuels has been counted as scientific research and so under the *Scientific* service.	No links identified. Future marine ecosystem services assessments to check for links as this industry is developing.
Waste and Toxicant Treatment via biota and Waste and Toxicant Removal and Storage (Services 10 and 11)	The CICES equivalents for the services called *Waste and toxicant treatment via biota* and *Waste and toxicant removal and storage* here appear, in a marine context, to be artificially divided. The processes involved in waste treatment and waste removal and storage are inherently linked, and separating them practically, in order to carry out an assessment, is problematic, although we have kept the original separation in CICES. However, a more natural split would be to have one 'Waste/toxicant treatment' service including several service types based on the types of material/substances that are treated. The removal/treatment/storage of waste could be considered to be one main benefit. This suggestion is in line with recent research e.g. Watson et al. (2016).	Marine ecosystem services assessments to consider including just one 'waste and toxicant treatment' service comprising all uses separated per the type of waste/toxicant being dealt with.
Waste and Toxicant Treatment via biota and Waste and Toxicant Removal and Storage, Mediation of smell/visual impacts (Services 10, 11, 12)	Examples found for the mediation of smell/visual impacts also relate to the services where waste is treated and removed as this involves the removal of nuisance material, although for the mediation of smell/visual impacts the material could be anthropogenic or natural in origin. We consider that even where there is an overlap, e.g., an oil spill treated by bacteria, the beneficiaries of all these services are different, and we have kept them separate.	No action needed
Oxygen Production (Service 15)	This service comes under the CICES group *Gaseous/air flow*s (as the equivalent to the *Ventilation and transpiration* terrestrial name) while another group is called *Atmospheric composition and climate regulation*. Our description of this service as the production of atmospheric oxygen would seem to fit better under the group of *Atmospheric composition and climate regulation* but only climate regulation services are included in that group. Therefore, we have, left the service under the CICES *Gaseous/airflows* group. This means that the maintenance of oxygenated seawater, which could have been another interpretation of this service, is now considered to be accounted for under the *Chemical condition of seawater* service (22).	Clarification needed of where service fits in CICES hierarchy[139].

[139] CICES version 4.3 underwent a review during 2016/2018 resulting in CICES version 5.1 (see Haines-Young & Potschin, 2018). This new version of CICES has kept the situation as per version 4.3, so what is described in the 'Outcome' here has not changed. See also Section 7 and Annex VI.

Service	Outcome	Recommended Action
Seed and Gamete Dispersal (Service 16)	While, generally, the dispersal of seeds and gametes in the marine environment is largely driven by abiotic processes, there are smaller scale examples where the biotic contribution is significant or essential, in particular for seagrass habitats and isolated coastal lagoons. This service was, therefore, included in the services typology used in our assessment approach, as although the biotic contribution is small overall, it can be significant in specific circumstances.	Marine ecosystem services assessments to include this service due to essential biologically mediated role for the capacity to supply/use of this service in a marine context.
Maintenance of nursery populations and habitats (Service 17)	Maintenance of nursery populations and habitats involves providing the physical habitat, i.e. refuge from predation for juveniles of migratory and/or commercially important species, as well as providing prey needed to sustain populations. This definition goes beyond the meaning of this service in some other assessment approaches, where only the physical habitat structure is considered (but not all, see Hattam et al. 2015). Here, the prey or food source of the juvenile species was considered in order to capture important nursery grounds, which lack significant physical structures but nevertheless, support nursery populations, e.g., plaice nursery grounds in soft sediments in the North Sea. We agree with the conclusion of Hattam et al. (2015) that the nursery function may be counted as a final service, actively or passively used, in some situations, but an intermediate service in others, which would vary according to the temporal and spatial boundaries of the assessment approach. This service can be final because: (1) pressures on the nursery service can be managed in their own right through, e.g., seasonal, spatial closures to fisheries (under the Common Fisheries Policy); thus there are potentially avoidance costs for broader (potentially more expensive) fisheries' management measures may be required; and (2) the service could be final over different temporal scales, where juvenile populations contribute now directly to the supply of (final) services in the future and where management has changed in intervening years.	Marine ecosystem services assessments to include provision of prey species as part of this service and consider it as a final service.
Waste and Toxicant Treatment via biota and Waste and Toxicant Removal and Storage, Sediment Nutrient Cycling, Chemical Condition of Seawater (Services 10, 11, 21, 22)	There is overlap in the services that are involved in processing or cycling nutrients and other elements throughout the system. While *Waste and toxicant treatment via biota* and *Waste and toxicant removal and storage* deal with those that are anthropogenically introduced, *Sediment nutrient cycling* and *Chemical condition of seawater* involve those that are present naturally at background levels in the system. However, many of the elements can be the same, e.g., heavy metals such as copper can be found naturally in marine systems but can also be introduced by anthropogenic activities. In addition, many of the ecosystem processes that underpin all these services are the same. Furthermore, for *Sediment nutrient cycling* and *Chemical condition of seawater,* the links between the benthic and the pelagic realms are important for the regulation and maintenance of the conditions of both the sediment and the water column (seawater). Nevertheless, all these services have been kept separate because the relative contribution of components to service supply capacity is likely to be different and the service beneficiaries are different.	Marine ecosystem services assessments to establish the source of each substance/element/waste product– natural or anthropogenic.

Service	Outcome	Recommended Action
Recreation and leisure (Service 24)	Although the CICES description of this service includes the environmental settings (Table 2.1, Section 2), the way this assessment is set up does not allow for the potential contribution to service supply capacity from physical environmental settings on their own to be accounted for, where links to these settings can only be made through biotic groups (as we have defined services to be biologically/ecologically mediated) occurring there.	In future marine ecosystem services assessments, to explore explicit incorporation of environmental settings in themselves and their contribution to the ecosystem's capacity to supply cultural services
Recreation and leisure, Aesthetic (Services 24 and 29) as well as other cultural services	There could be an overlap between *Recreation and leisure* and *Aesthetic* cultural services. In order to avoid that, and so the 'double counting' of service benefits (in a potential subsequent economic valuation exercise), we have defined the experiential interactions covered under *Recreation and leisure* to be always associated with some kind of *in-situ*, active physical activity. This would distinguish them from intellectual and representative interactions that may lead to similar benefits (e.g. relaxation) as attained through other cultural services. For example, we consider that the activity of going to see a natural marine seascape is a way of using the *Recreation and leisure service*. However, the activity also results in aesthetic benefit and in order to avoid the overlap, we also specify the interactions falling under the *Aesthetic* service. In brief, these are passive *in-situ* aesthetic interactions and sense of place, artistic inspiration (*in-situ* or *ex-situ*, active or passive), and active or passive *ex-situ* aesthetic experiences. In addition, in some cases, a single 'activity' could be associated with the use of multiple cultural ecosystem services. For example, watching a marine documentary could be associated with the *Entertainment*, *Aesthetic* and *Educational* services. This, and other, potential overlaps are not considered to lead to 'double counting' as the benefits attained can be different	Marine ecosystem services assessments to specify conditions for *Aesthetic* and *Recreation and leisure* services, and keep other potential overlap in mind, to avoid 'double counting' of service benefits (in, e.g., a potential subsequent economic valuation exercise).

As outlined above, each biotic group holds the capacity to supply several services, and this has been summarised in Table 4.3. This table also indicates, using colours, the confidence in the links (see Section 4.2). Confidence is based on the source of information used for identifying the link. Where this is the literature, the confidence is based on a three-tier scale with the greatest confidence in peer-reviewed material and the least in information from websites. Expert opinion is not included in the confidence assessment and is shown as a separate category. The confidence for many links is high as the sources of information have relied on peer-reviewed literature, but there are also many links that were reliant on expert judgement and for many services, especially the cultural services, there is a lack of peer-reviewed literature available to consult.

Table 4.3 Overview of all the linkages (*) between the MECSA biotic groups and marine ecosystem services with an indication (colour) of the confidence in the link based on the source of information used to establish it

Legend of Table	
	High confidence
	Moderate confidence
	Low confidence
	No confidence assessment (expert judgement)
*	Link
	No link

Marine Ecosystem Service	Biotic Group													
	Birds	Whales	Seals	Reptiles	Fish	Cephalo-pods	Epi-fauna	In-fauna	Phyto-plankton	Zoo-plankton	Macro-phytes	Macro-algae	Microphyto-benthos	Bacteria
1. Seafood from Wild Plants and Algae											*	*		
2. Seafood from Wild Animals	*		*		*	*	*	*		*				
3. Plants and Algal Seafood from *in-situ* Aquaculture												*		
4. Animal Seafood from *in-situ* Aquaculture					*		*	*						
5. Raw Materials	*	*	*		*	*	*	*		*	*	*		
6. Materials for Agriculture and Aquaculture					*	*	*	*			*	*		
7. Genetic Materials	*				*	*	*	*	*	*	*	*	*	*
8. Plant and Algal-based Biofuels														
9. Animal-based Biofuels														
10. Waste and Toxicant Treatment via Biota							*	*	*	*	*	*	*	*
11. Waste and Toxicant Removal and Storage	*	*	*	*	*	*	*	*	*	*	*	*	*	*
12. Mediation of smell/visual impacts	*						*	*			*	*		*
13. Erosion Prevention and Sediment Retention							*	*			*	*	*	
14. Flood Protection							*	*			*	*		

Marine Ecosystem Service	Biotic Group													
	Birds	Whales	Seals	Reptiles	Fish	Cephalo-pods	Epi-fauna	In-fauna	Phyto-plankton	Zoo-plankton	Macro-phytes	Macro-algae	Microphyto-benthos	Bacteria
15. Oxygen Production									*		*	*	*	
16. Seed and Gamete Dispersal	*			*	*									
17. Maintaining Nursery Populations and Habitats				*	*	*	*	*	*	*	*	*		
18. Gene Pool Protection	*	*	*	*	*	*	*	*	*	*	*	*	*	*
19. Pest Control	*	*	*	*	*	*	*	*	*	*	*	*	*	*
20. Disease Control	*	*	*	*	*	*	*	*	*	*	*	*	*	*
21. Sediment Nutrient Cycling	*	*	*	*	*	*	*	*	*	*	*	*	*	*
22. Chemical Condition of Seawater	*	*	*	*	*	*	*	*	*	*	*	*	*	*
23. Global Climate Regulation	*	*	*	*	*	*	*	*	*	*	*	*	*	*
24. Recreation and Leisure	*	*	*	*	*	*	*	*	*	*	*	*	*	*
25. Scientific	*	*	*	*	*	*	*	*	*	*	*	*	*	*
26. Educational	*	*	*	*	*	*	*	*	*	*	*	*	*	*
27. Heritage	*	*	*	*	*	*	*	*			*	*		
28. Entertainment	*	*	*	*	*	*	*	*	*	*	*	*	*	*
29. Aesthetic	*	*	*	*	*	*	*	*	*	*	*	*	*	*
30. Symbolic	*	*	*	*	*	*	*		*	*	*	*		
31. Sacred and/or religious	*	*	*	*	*	*	*	*	*	*	*	*		
32. Existence	*	*	*	*	*	*	*	*	*	*	*	*	*	*
33. Bequest	*	*	*	*	*	*	*	*	*	*	*	*	*	*

Notes: Published literature has the greatest confidence and websites have the least. Expert opinion was considered to be separate from the confidence assessment (see Section 4.2 for details on the confidence assessment).

The linkages matrices provide a starting point for the assessment part of the MECSA approach by identifying the ecosystem components that potentially hold the capacity to supply each service. Links connect services to biotic groups to start with, since they ultimately deliver the service (Table 4.3). The biotic group – habitat links (i.e. ecosystem components, see Section 3) are then the basis for determining all the services that are potentially supplied by a given habitat (Annex I). These two types of linkages facilitate the service supply capacity assessment, which may be focussed on particular biotic group(s) (or habitat/s). They allow a link to be established between the services, the ecosystem capacity to supply them as held by a given biotic group(s), and the information on the state of that group(s), and of other parts of the ecosystem where relevant, reported at the EU level from the implementation of relevant EU environmental legislation and related EU and other policy (see Section 5).

4.3.5 Next steps

The identification of these generic linkages forms Stage 1 of the MECSA methodological development. Biotic groups and their habitats (i.e. ecosystem components) have the potential to deliver multiple services. Often there is high confidence that an ecosystem component supplies a service but how it does this is less well understood. This is further explored in this Report through test case assessments (Annex II–IV) and in Stage 2 of the MECSA methodological development in Section 5, where weighting of the links between ecosystem components and services will facilitate a critical pathway analysis approach (although this is only illustrated for the tested services). In Section 5, the critical ecosystem components (in terms of their relative contribution to service supply capacity) are identified and assessed, together with other parts of the ecosystem where relevant, providing information on (the state of) the capacity of the ecosystem to supply a given service. The services described above have been considered at the CICES 'class' level; moving to the assessments, it is often necessary to identify a more specific level of service to work with, the CICES service 'type' (see Section 2). This is described in Step 1.1 of Stage 2 of the MECSA approach (Section 5).

5 Operational steps for the MECSA – the assessment method

This section sets out the method for the marine ecosystem capacity for service supply assessment (MECSA), which can be made operational using currently available policy-relevant data/information, such as that available at the EU-level from, e.g., the implementation of EU water, marine and nature directives. The overall MECSA approach aims to assess the capacity of the ecosystem to supply services now and in the future based on its current and predicted future state (see Section 1.1. of this Report for definitions of ecosystem capacity for service supply, and how ecosystem state relates to this).

Stage 1 of the assessment, described in Section 4 of this Report, utilises a holistic approach which considers all possible interactions between ecosystem components and the ecosystem capacity to supply services in a qualitative way. Stage 2 here takes these linkages as a starting point and applies a focused approach, based around critical ecosystem component(s), to assess the state of the ecosystem's capacity to supply a given service and the direction of change in this capacity. This focused approach makes use of the best available understanding and reported information on the status (i.e. a classified state) of marine ecosystems to deliver outputs relating to the current and future state of their capacity to supply ecosystem services (see Figure 5.1). A key feature of this approach is the consideration of the (ecosystem) state-service (generation) relationship. This captures how a change in ecosystem state is translated into a change (or not) in its capacity to generate and, thus, supply ecosystem services. This relationship is considered in detail here, in Stage 2 of the assessment, but is important throughout all parts, from identifying relevant ecosystem components in Stage 1 to completing several steps for Stage 2.

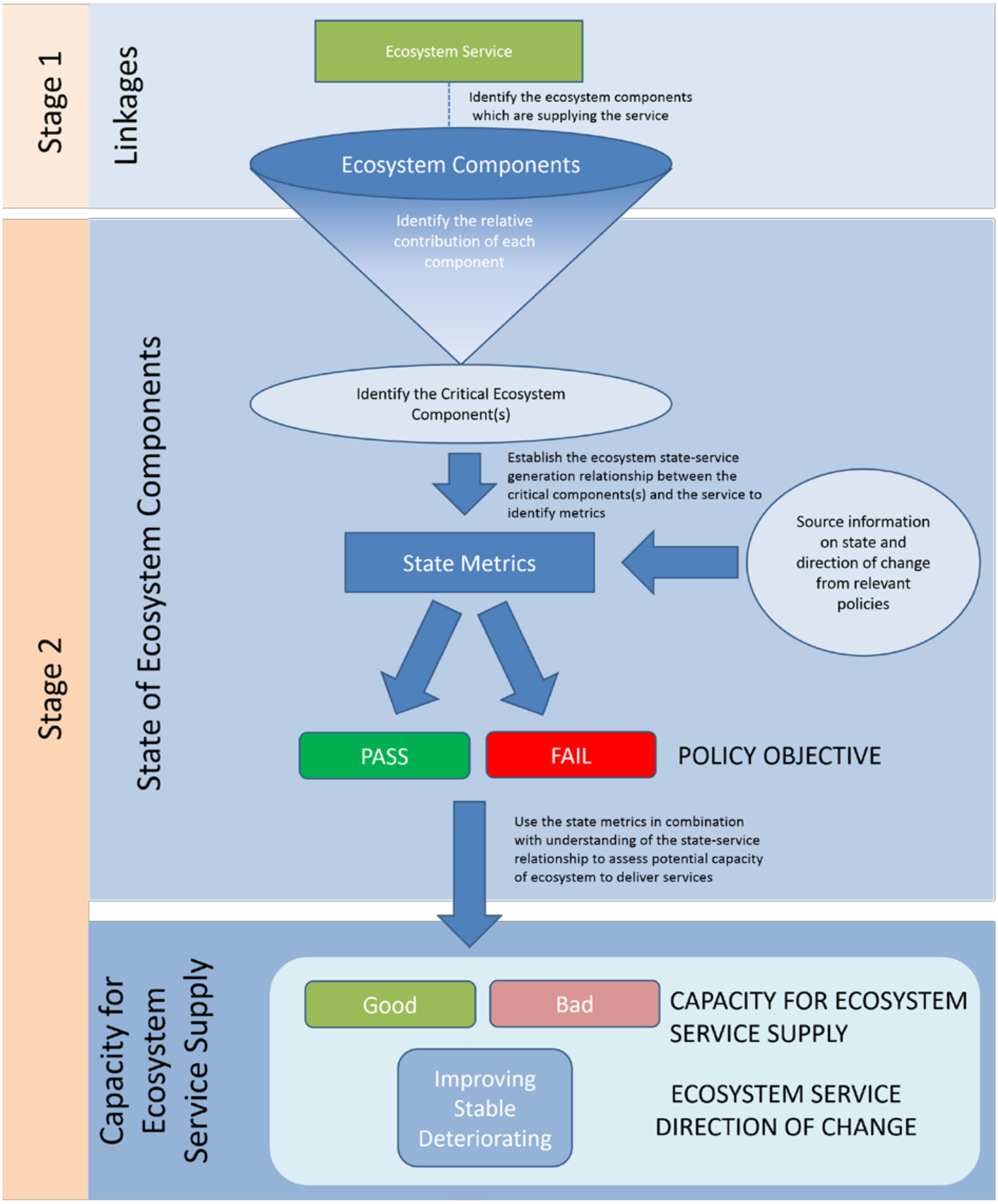
This second stage of the assessment is broken down into a number of steps as described in detail under Section 5.1. In brief:

- In Step 1, the ecosystem components that are critical for the marine ecosystem capacity to supply a given service class or type are identified. This requires establishing the relative contribution of each of the component(s) contributing to such capacity first, which is done using quantitative information, where available, or ecological knowledge from the literature. Some knowledge of the (ecosystem) state-service (generation) relationship is also required at this stage. The critical component(s) are then identified from those with the highest relative contribution to service supply capacity. The critical path analysis undertaken here allows the best use of the, limited, available assessment information at the EU level. It is also a more manageable approach as it removes the need to consider a large number of contributing ecosystem components, which may be less important than others dependent on the scale of the assessment; thereby allowing a systematic prioritisation of information to deliver assessment results (see Step 1 under Section 5.1).
- In Step 2, the relationship between the critical ecosystem component(s) and the service class or type is established in detail using best available knowledge/information, and metric(s) are identified to describe this relationship in terms of the critical ecosystem component(s) and other parts of the ecosystem, where relevant, for service supply capacity.
- In Step 3, appropriate marine ecosystem state and trend information (collected as part of reporting for laws/policies, e.g., at the EU level) is selected to assess the current state and direction of change in the state of the metrics of the critical ecosystem component(s), and other parts of the ecosystem where relevant, as identified in Step 2. If no information on ecosystem state and state trends is available to do so, the trends in pressures may need to be used to infer the direction of change in ecosystem state (but not the state itself, which cannot be assessed in this case) (see Figure 5.2).

- In Step 4, the assessment of the state and direction of change in the state of the metrics of the critical ecosystem component(s), and other parts of the ecosystem where relevant, is used in conjunction with knowledge of the (ecosystem) state – service (generation) relationship from Step 2, and expert judgement, to interpret the consequences for the current state of the ecosystem capacity to supply the service class or type (i.e. 'good', 'bad)' and likely direction of change in current capacity ('improving', 'stable' or 'deteriorating') (see Figure 5.2). An assumption of the information used in this step, is that if current trends in a critical pressure(s) are used as a proxy for the trends in ecosystem state, it is assumed that the pressure-state relationship is understood.
- In Step 5, the future state and direction of change in the state of the metrics of the critical ecosystem component(s), and other parts of the ecosystem where relevant, are assessed – in as much as available information allows – and the outcomes used to determine the future state of and direction of change in the capacity of the ecosystem to supply the service class or type (see Figure 5.2). The input information required to make the assessment has some key assumptions associated with it. If current or future trends in a critical pressure(s) are used as a proxy for the future trends in ecosystem state, it is assumed that the pressure-state relationship is understood. In the case of current pressure trends being used to assess future trends in ecosystem state, it is assumed that the pressure will continue in the same direction in the future. Future state of service supply capacity can only be forecasted in specific scenarios, e.g., if the current state of service supply capacity is 'good' and the future direction of change in this capacity is 'increasing', its future state must also be 'good'. However, if the current state of service supply capacity is 'good' and the future direction of change in this capacity is 'decreasing', we do not know how much the state will decrease in the future and cannot forecast the future state of service supply capacity (see Step 5 of the method for further details).

The approach can be used to assess the current (state of the) marine ecosystem capacity for service supply, based on the current state of ecosystem components, and the future (state of the) marine ecosystem capacity for service supply, based on the forecasted future state of ecosystem components (see expansion of this in Figure 5.2).

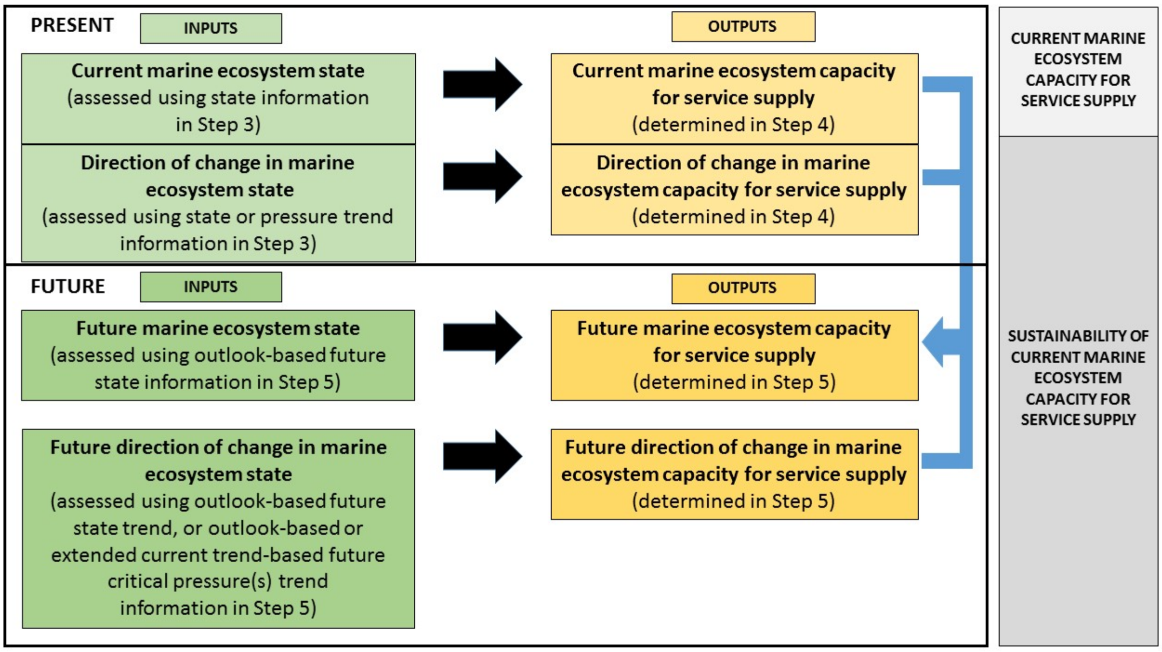
Figure 5.1: The two stages of assessment in the Marine Ecosystem Capacity for Service supply Assessment (MECSA) approach



Notes:

- 'State of ecosystem components' refers to the physical, chemical and biological condition of an ecosystem component at a particular point in time (see Section 1)
- 'Marine ecosystem capacity for service supply' refers to the effective capacity (potential) of an ecosystem (i.e. ecosystem component(s)) to supply ecosystem services, which is that based on its state and linked to its functioning (see Section 1).

Figure 5.2: Inputs and outputs in Stage 2 of the MECSA



Notes: Black arrows represent an understanding of the (ecosystem) state-service (generation) relationship. The blue arrow indicates an alternative route to assessing the future ecosystem capacity for service supply, based on first assessing the other three outputs, and then using these to do so. The grey box on the right-hand side represents the outputs linked simply to the current ecosystem capacity for service supply, and those that are relevant for considering the sustainability of that supply.

The MECSA approach can provide an assessment of the ecosystem capacity to supply a single service based on the state of the ecosystem components that contribute to, or solely hold, that capacity (i.e. a service-by-service approach, see Figure 5.1) (Section 5.1). Alternatively, it can be applied starting from the ecosystem components (taking each component) and considering the multiple services to which these components may contribute supply capacity to (i.e. a component-by-component approach) (Section 5.2). Only the service-by-service option has been explored at this stage in the development of the MECSA approach, and this is the focus of this section of the Report. The component-by-component approach has only been outlined at this stage and consists of repeating the service-by-service approach multiple times. The reason for only including an outline of this other assessment option is because it was not feasible at the time the MECSA method (Section 5.1) was developed (2014). This was due to not only insufficient knowledge on cause and effect within marine ecosystems, but also, and most importantly, because the particular information required to run such a component-based assessment was not available at the EU level.

Service supply capacity will vary from service to service, depending on which biotic groups are involved in generating a given service. To illustrate this, this sections includes examples of final outcomes of the application of the MECSA method to three test case assessments. Examples are shown for both a common EU-level approach (i.e. applicable to each of the four EU marine regions, *sensu* the MSFD in geographical scope but slightly modified in physical terms following the MECSA habitat typology, see Section 3), which is achievable in a data poor situation (using information from, e.g., Member States' EU-level reporting on the 1st implementation cycle of the WFD and MFD, and the 2nd implementation cycle for the HD), as well as giving examples of the best possible approach for a given step (using best available information at the time of the assessment, which in this case was 2014, see Section 5.1). The steps outlined provide the framework for the assessment approach; within this framework a degree of flexibility remains to accommodate the large range and variety of ecosystem services.

5.1 Approach to assess the marine ecosystem capacity to supply a single marine ecosystem service

Three test case assessments (one for a cultural, one for a regulation and maintenance, and one for a provisioning service type, see Table 5.1) were carried out to test and further develop the MECSA method to assess the capacity of the marine ecosystem to supply a single ecosystem service outlined here. The test case assessments were developed in 2014 and have not been updated since then, while certain elements of the main Report here have been updated since 2014[140]. These assessments were 'pilots', rather than full assessments, because *inter alia* it was not possible to identify, or incorporate, all the information relevant for the assessment at the global/EU/regional level available at the time, and not all the EU marine regions were covered in each of the cases tested (see Section 6 for further detail on the limitations of the test case assessments). The assessment is completed following a number of steps (Table 5.2), each of which is described and illustrated below using material from the test case assessments. There are a number of points throughout the process where it is important to document the confidence associated with the outcome of a step, or sub-step. These confidence assessments are each mentioned in the description of the method steps below, and fully detailed in Annex V (as well as Annexes II–III where relevant), following the description of the method steps. The fully documented test case assessments can be found in Annexes II, III and IV, although, because these remain untouched since 2014, there may be some inconsistencies between the main Report here and these annexes.

Table 5.1 Test case assessments carried out to develop and test the operational steps making up the MECSA method

Service section and type		Test case assessment
Cultural	*Recreation and leisure from whale (and dolphin) watching*	Annex II
Regulation and maintenance	*Waste nutrient removal and storage*	Annex III
Provisioning	*Seafood (commercial fish and shellfish) from wild animals*	Annex IV

[140] The majority of the work described in this Report, including its Annexes with the test case assessments, was carried out and completed in 2014 as Culhane et al. (2014), with a small refinement of the original Report, but not of the test case assessment Annexes, in 2016 and a more substantial one in 2017 and into 2018 leading to this updated version. These refinements have been limited to specific issues around the 'structural elements' of the assessment approach, such as the characterisation and classification of marine ecosystems and ecosystem services. To note that ongoing reviews of key EU legislation and policy, including associated classifications, in 2016/2018 mean that, in order to keep the approach one-to-one EU policy-relevant, elements of our assessment approach (including some of those 'structural elements' and the information used to test the approach) will need to be updated when used for future/other work. A more detailed discussion on this is given in Section 7.

Table 5.2 The steps involved in the MECSA method to assess marine ecosystem capacity to supply a single ecosystem service, based on the state of the critical ecosystem components for such capacity, indicating the points at which a confidence assessment is carried out

	Step	Aspects that are relevant for determining the overall confidence in the assessment
Step 1	**Identify the critical ecosystem components for service supply capacity**	
1.1	Identify the service class or type to be assessed	
1.2	Determine the relative contribution of all components to the ecosystem capacity to supply the service class or type	• Developing criteria to assign relative contribution • Assigning relative contribution
1.3	Identify the component(s) critical for the ecosystem capacity to supply the service class or type	• Deciding on the critical components
Step 2	**Establish the relationship between the critical ecosystem component(s) and the service class or type, and identify metric(s) describing this relationship**	
2.1	Establish the (ecosystem) state-service (generation) relationship	• Establishing the type of relationship
2.2	Identify metric(s) describing the (ecosystem) state-service (generation) relationship, including of the critical ecosystem component(s) and other parts of the ecosystem if relevant	
Step 3	**Assess the current state and direction of change in the state of the critical ecosystem component(s) and other parts of the ecosystem where relevant**	
3.1	Identify EU (and other) legislation and policy generating ecosystem state and trend information to assess the metric(s) of the critical ecosystem component(s) and other parts of the ecosystem, where relevant, identified in Step 2	
3.2	Synthesise the ecosystem state and trend information from the different pieces of EU (and other) legislation and policy used to assess the metric(s)	• Information sources used
3.3	Establish the quality classifications for the ecosystem state ('pass'/'fail') and trend ('increasing'/'decreasing'/'stable') information from each piece of EU (and other) legislation/policy used to assess each metric(s)	
3.4	Aggregate the quality classifications for the ecosystem state and trend information across all pieces of EU (and other) legislation and policy used to assess each metric(s), and determine the overall current state and direction of change in the state of the critical ecosystem component(s) and other parts of the ecosystem where relevant	• Confidence in the aggregation of different policy outcomes
Step 4	**Assess the current state of and direction of change in the capacity of the ecosystem to supply the service class or type**	• Translating ecosystem state into the capacity to supply a service
Step 5	**Assess the future state and direction of change in the state of the critical ecosystem component(s), and other parts of the ecosystem where relevant, and use that to determine the future state of and direction of change in the capacity of the ecosystem to supply the service class or type**	There are several points in Step 5 where confidence is assessed. These depend on the method used and are fully described under Step 5 and in Annex V

Step 1 Identify the critical ecosystem components for service supply capacity

Step 1	Identify the critical ecosystem components for service supply capacity

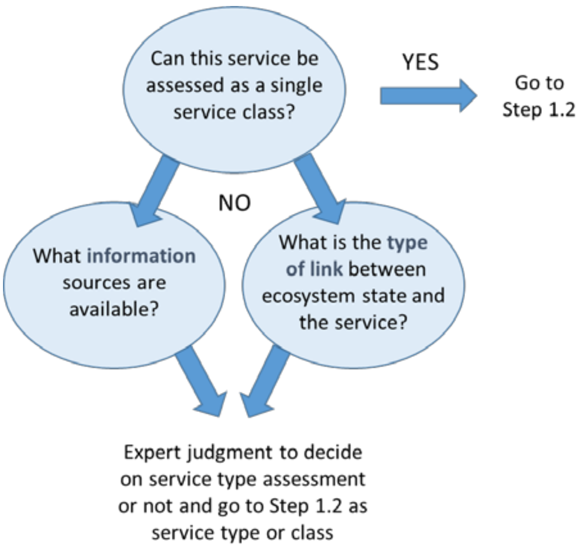
For any given ecosystem service, the Stage 1 linkages matrix identifies the ecosystem components that have the capacity to contribute to its supply (Section 4; here Figure 5.1). The linkages matrix identifies the links between ecosystem components and ecosystem services at the service 'class' hierarchical level (or higher) of the CICES typology (version 4.3, see Section 2). The aim of the first step of this assessment is to focus on each single service that can be assessed, and this would normally be at the lower 'type' level of the CICES hierarchy, as well as to select the ecosystem components that need to be carried through to the assessment, which is done using a critical path analysis.

<u>Step 1.1</u> Identify the service class or type to be assessed

Step 1	Identify the critical ecosystem components for service supply capacity
1.1	Identify the service class or type to be assessed

Many of the services at the 'class' hierarchical level of the CICES typology (as listed in Table 2.2, Section 2) encompass a large range of service 'types', and these are delivered by a variety of processes, by various biotic groups and may provide a range of benefits. This first sub-step (of Step 1) is to identify whether the service can be assessed at the higher hierarchical 'class' level (e.g. *Flood protection*) or whether a more specific service 'type' level needs to be identified (e.g. *Recreation and Leisure* would need to be assessed by the particular type of recreation or leisure supported by the ecosystem, e.g. by activity type). If the service can easily be assessed at the 'class' level the process can move to Step 1.2. If the service 'class' level cannot be easily assessed as such and clear service types can be identified an expert judgement decision is required to determine if the latter is the appropriate service 'level' for the assessment. This needs to take into account what information is available and how the ecosystem components are linked to the service (Figure 5.3) in order to decide on the service type as the 'level' at which the (ecosystem capacity to supply the) service can be assessed; otherwise the service is still assessed as a 'class'. *Nevertheless, to note that, in order to simplify, both the service 'classes' and the service (class) 'types' used as examples throughout this Report tend to have just been referred to as 'service(s)'.*

Figure 5.3: Determining if, and how, to assess marine ecosystem capacity for service supply at the service 'class' level or service 'type' level



Identifying a service 'type' may be directed by the **information** available to carry out the assessment – for example, for the *Waste and toxicant removal and storage* service class, the information available differs depending on the type of waste (nutrients, synthetic substances, etc.). For ease of assessment, it is, therefore, helpful to consider each of these wastes separately as a service type.

Identifying a service 'type' can also depend on the **type of links** between ecosystem state and service generation. For example, the *Waste and toxicant removal and storage* service involves the storage and removal of many different types of waste/toxicants, and each of these may enter the system in different ways as well as have a different fate within the system. Thus, one waste type is nutrients of anthropogenic origin and, hence, one waste service type within this services class is *Waste nutrient removal and storage* (see Annex III for a complete test case assessment of the *Waste nutrient removal and storage* service type). Another example would be the cultural service *Recreation and leisure*; where, within this service 'class' (see Section 2), the ecosystem provides for physical and experiential interactions to people, which constitute the service and are underpinned by the relevant ecosystem components. The service can be used through different human activities, which depend or rely on the state of these ecosystem components in different ways (see Table 5.3 for a categorisation of these relationships). For example, the state of the relevant ecosystem components is essential for wildlife watching, which is one way of using the *Recreation and leisure* service, but for other activities in marine environmental settings (such as sailing), the activity can be experienced and enjoyed regardless of the state of the relevant ecosystem components. Nevertheless, a good state of these components (linked to the presence of wildlife) could be considered an enhancement of the activity, rather than something essential (see further discussion of these issues in Section 4 and in the introduction to the test case assessment for the *Recreation and leisure from whale watching* service type in Annex II). Thus, separate supply capacity assessments for service 'types' with different degrees of dependence on the ecosystem should be carried out within this service 'class'.

Table 5.3 Different categories of activities using the Recreation and leisure cultural marine ecosystem service according to their dependence on the marine ecosystem

Dependence of Activity on Ecosystem Components (Category and Score)	**Description of Category**
Essential (3)	The activity is completely dependent on the state (e.g. population size and abundance, which determine the presence of relevant biota) of ecosystem components, e.g. wildlife watching
Moderate-High (2)	The activity has some, or considerable, elements that can be carried out without ecosystem components but is otherwise enhanced by the (good) state of ecosystem components, e.g. scuba-diving and visiting scenic areas
Low (1)	The activity, normally a type of sport, could be carried out completely in the absence of ecosystem components (is only dependent on the abiotic system) but is enhanced by the (good) state of ecosystem components, e.g. sailing

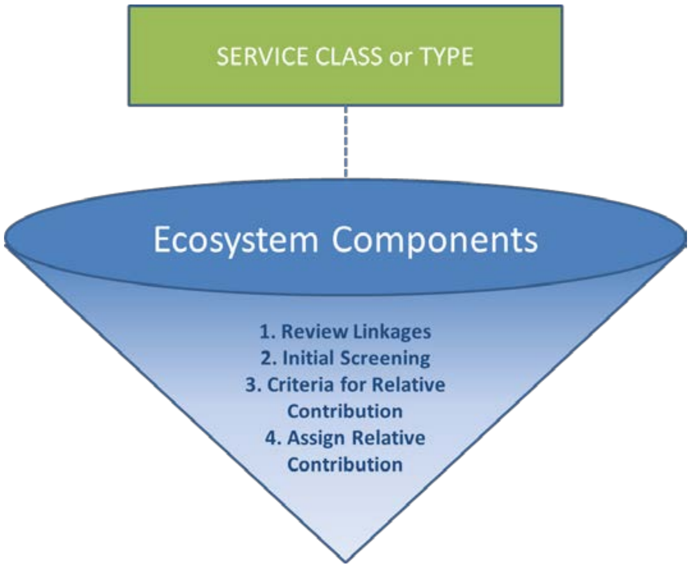
Notes: Taken from Table AII.1 in Annex II

Step 1.2 Determine the relative contribution of all components to the ecosystem capacity to supply the service class or type

Step 1	Identify the critical ecosystem components for service supply capacity
1.1	Identify the service class or type to be assessed
1.2	Determine the relative contribution of all components to the ecosystem capacity to supply the service class or type

This sub-step involves refining the ecosystem component-ecosystem service linkages that were identified in Stage 1 (Section 4) for the specific service type to be assessed (if applicable); carrying out an initial screening of these components to identify those with most relevant contribution to the ecosystem capacity to supply the service (type or class); and assigning a weighting to the contribution of each component to the supply of the service (type or class) (Figure 5.4). More detail on these actions is provided below Figure 5.4.

Figure 5.4: Assigning the relative contribution of marine ecosystem components to the supply of a marine ecosystem service class or type



Notes:

- Action 1. Review linkages between ecosystem components and the ecosystem service (this could be a service 'class' or a service 'type')
- Action 2. Carry out an initial screening of ecosystem components and disregard any that make a very small contribution (to the capacity for the supply of the service class or type)
- Action 3. For the remaining ecosystem components, develop criteria to assign relative contribution of ecosystem components (to the capacity for the supply of the service class or type)
- Action 4. Assign the relative contribution of ecosystem components to the capacity for the supply of the service (class or type).
- See text for full description of each action.

1. Review of the linkages between marine ecosystem components and marine ecosystem services (when a service type is identified)

Once the service type has been identified, the components contributing to the ecosystem capacity to supply it can be identified by refining the linkages that were established for the broad service class in Stage 1 (see Section 4), which need to be made more specific for the service type (if applicable). For example, for the service type *Waste nutrient removal and storage* (under the *Waste and toxicant removal and storage* class), higher biotic groups, such as seals, have links for the storage of toxicants, because they may bioaccumulate, e.g., heavy metals, but they cannot absorb nutrients from the water column. Thus, links to seals are not applicable for this service type. The relative contribution of components may also differ depending on the geographic region, since different marine regions may have different distributions of biotic groups or habitats; thus, this part of the assessment should be location-specific.

2. Initial screening of components to determine the ones critical to the ecosystem capacity for the supply of the service class or type

At this stage, an initial 'screening' of the ecosystem components to determine the ones critical to the ecosystem capacity for the supply of a service class or type can also be carried out, using expert judgement and ecological knowledge, to remove any links that do not make a substantial contribution to such capacity. For example, plants and algae require phosphorus to photosynthesise (i.e. convert carbon dioxide and water into sugar and oxygen, using light) and nitrogen for growth. Aquatic plants and algae can absorb nutrients directly from the water column. Thus, for the service type *Waste nutrient removal and storage* (under the *Waste and toxicant storage and removal* class), the photosynthesising ecosystem components were identified as the most relevant contributing components. Other components, such as invertebrates, may absorb dissolved nutrients directly from the water column (Uchida et al. 2010), but only do so to a very small degree compared to plants and algae; thus, only the photosynthesising components were carried forward for the assessment. This initial 'screening' is only carried out where there is high confidence that components do not contribute substantially to the ecosystem capacity for the supply of the service being assessed (using expert judgement).

3. Develop criteria to assign the relative contribution of ecosystem components (to the ecosystem capacity for the supply of the service class or type)

In order to assess the relative contribution made by a component to the ecosystem capacity for the supply of a service class or type, the approach has to take into account *how* the contributing components can supply the service (i.e. the (ecosystem) state-service (generation) relationship). Ultimately, the ecological processes and functions underpinning ecosystem services are delivered by individual organisms carrying out their activities; or the services are underpinned by these biota acting as ecosystem structures (see Sections 1 and 4). So, whilst services may be delivered by a variety of mechanisms, they are described here as being supplied by the biotic groups (existing within specific habitats), or by habitats (which support a collection of biotic groups). Both terms, biotic group and habitat, are used in this assessment and which one is used reflects the specific context; in this case the criteria used to assign the relative contribution of biotic groups/habitats/components to the ecosystem capacity for service supply. However, whether we refer to a biotic group or a habitat explicitly, it is always implicit that a biotic group is associated with a habitat, or habitats, and that a habitat is associated with a collection of biotic groups, and that these are not independent of each other. In other words, we are considering the *ecosystem components* and their contributions.

Provisioning services generally have a direct link with the biotic group that is exploited, i.e. the ecosystem structure. For example, wild fish provide the *Seafood from wild animals* service, where different fish species may have a greater relative contribution to commercial fisheries than others may, and the criteria used to assign the relative contribution of wild fish to the *Seafood from wild animals* service may be based on what species contribute most to the catches or are considered of significant socio-economic importance.

About half of all Regulation and maintenance services are also delivered by biotic groups, or collections of biotic groups, acting as ecosystem structures, e.g., marine plants and algae contribute to the capacity to supply *Waste nutrient removal and storage*, and the criteria used could be how efficient each of these biotic groups is at absorbing nutrients in combination with the spatial extent of their habitats.

Many cultural services are supplied by habitats, or in certain environmental settings (e.g. a seascape), where many biotic groups live. For example, one way of using the *Recreation and leisure* service is by walking along the coast, which allows experiential interactions with the presence of relevant habitats, and all of their biotic groups, and gaining benefits such as sensorial enjoyment or relaxation (see Section 4). In this context, the habitats which are closer to the coast have a greater contribution to the ecosystem capacity to supply this service than those further away.

This step, therefore, requires the use of ecological knowledge and expert judgment as well as an assumption to be made that the criteria chosen to assign the relative contribution of a component to the ecosystem capacity for the supply of a service will be a good representation of such capacity. This decision has an associated level of confidence that should be assessed here (see Annex V).

4. Assigning the relative contribution of ecosystem components to the ecosystem capacity for the supply of the service (class or type)

The relative contribution, i.e. how much each component contributes to the ecosystem capacity for the supply of the service (class or type) being assessed, is obtained by applying quantitative, semi-quantitative or qualitative information to the criteria developed to assign the relative contribution. This depends on the level of information available, with quantitative information (data) providing a more robust outcome and expert judgement providing the least robust outcome (Table 5.4). Confidence in assigning the relative contribution should also be assessed (see Annex V).

Table 5.4 The types of information that can be used to assign the relative contributions of marine ecosystem components to the ecosystem capacity to supply a service

Information source for assigning components' relative contribution to service supply capacity	
Best Source (Most Robust)	A *quantitative* analysis of how much each relevant component contributes to the supply of a given service relative to the other components using data, such as mapped spatial extent of components in combination with their efficiency at supplying a service.
First alternative (Less Robust)	Information from the literature that may indicate a general estimation of the relative contribution of different components to the supply of a service. This could be *quantitative or semi-quantitative.*
Second alternative (Least Robust)	*Qualitative* assignment of relative contribution based on information from the literature or expert judgement.

Some examples of different criteria used to assign the relative contribution of ecosystem components to the capacity for the supply the service (type or class) are included in the test case assessments in Annex II–IV and also provided below.

Example 1: Using spatially supported (mapped) habitat data and ecological knowledge for a detailed and robust estimation of the relative contribution of marine plants and algae to the capacity to supply the Waste nutrient removal and storage service type

Spatially supported (mapped) habitat data, where available, can be used to estimate the spatial extent of ecosystem components contributing to the capacity to supply a given service. For example, for assessing the service type *Waste nutrient removal and storage* (under the *Waste and toxicant removal and storage* service class) in the Irish Sea, the photosynthesising ecosystem components, which were identified as the contributing components, were mapped using EUSeaMap data (full details in Annex III). The spatial extents of these components were combined with an estimation of the rate of primary productivity of each of the components to give an estimated overall contribution to primary productivity for each component (where primary productivity was assumed to be representative of the capacity of the component to sequester nutrients) (Table 5.5).

Table 5.5 Primary production of Irish Sea photic habitats

Broadscale habitat type (dominant primary producer)	Primary Productivity (kg m^{-2} yr^{-1} dry weight)	Contribution to primary productivity in the Irish Sea (10^6 kg yr^{-1} dry weight) (^)
EUNIS A1.1 (Fucoid)	0.19	3.22
EUNIS A1.2 (Fucoid)	0.75	81.03
EUNIS A1.3 (Fucoid)	1.50	116.40
EUNIS A3.1 (Kelp)	7.50	4307.30
EUNIS A3.2 (Kelp)	11.25	2518.13
EUNIS A3.3 (Kelp)	7.50	6.04
EUNIS A2.5 (Saltmarsh Macrophytes)	0.48	148.03
Water Column: Irish Sea (Phytoplankton)	0.19	19665.50
Irish Sea Total Primary Productivity		**26845.65**
Macroalgae Proportional Contribution		**26 %**
Macrophyte Proportional Contribution		**< 1 %**
Phytoplankton Proportional Contribution		**73 %**

Notes:

- Analysis includes the dominant primary producers, the contribution of each primary producer to total primary production, and the percentage contribution of each primary producer grouped according to the biotic group typology used in the MECSA approach (in bold at end).
- (^) Productivity was estimated based on primary productivity of the habitat type and the area of each habitat
- EUNIS refers to the 2004 marine classification
- Taken from Table AIII.4 in Annex III

Example 2: Using information from the literature for a general estimation of the relative contribution of marine plants and algae to the ecosystem capacity to supply the Waste nutrient removal and storage service type

For the service type *Waste nutrient removal and storage* (under the *Waste and toxicant storage and removal* service class), the photosynthesising ecosystem components were identified as the ones contributing to the ecosystem capacity to supply this service. From the literature, an estimation of the relative primary production of each of these components was found. The contribution that each of these component makes to the overall removal of nutrients was assumed to be reflected in their relative contribution to primary productivity. Thus, their contribution to total primary production was taken as the relative contribution of each of the components to the ecosystem capacity to supply this service (Table 5.6).

Table 5.6 Primary production in seas and oceans (reproduced from De Vooys, 1979(*))

Ecosystem component (with production category used in De Vooys, 1979)	Contribution to Total Primary Production (%)
Macroalgae (Kelp, Other weeds)	0.07
Macrophytes (Angiosperms)	1.09
Microphytobenthos	Unknown
Phytoplankton (Seas and oceans)	96.80
Other (Estuaries)	2.05

Notes:

- (*) Although this reference is old, more recent literature indicates that phytoplankton are the dominant primary producers in the ocean (Field et al. 1998; Cloern et al. 2014) but as these sources do not estimate the production of other biotic groups, the De Vooys (1979) paper was used to give a cross biotic group comparison.
- Taken from Table AIII.2 in Annex III

The implication for using a general estimation, such as in this example, is that a less robust assessment is carried out and, unlike in Example 1, it is not specific to a particular geographic location. Furthermore, there were missing data as no proportion was given for microphytobenthos. However, this does not necessarily mean that the overall outcome will differ between more and less robust assessments. As seen in Examples 1 and 2 here, where a much more detailed assessment was carried out in Example 1, the overall outcome showed – in both cases – that phytoplankton made the greatest relative contribution to the *Waste nutrient removal and storage* service, based on primary productivity.

Example 3: Identifying the relative contribution of whale (and dolphin) species to the ecosystem capacity to supply the Recreation and leisure from whale watching (cultural) service type

Within a biotic group, some species may be more important and provide a greater relative contribution than others. For the cultural service type *Recreation and leisure from whale watching*, not all whale species occurring in a marine region were considered to contribute to ecosystem capacity to supply this service, but only the species which were actually reported as being seen on whale watching tours were used as the contributing components. The whale species which are spotted on whale watching trips were identified by searching the websites of several whale watching operators in a region and listing the species which the operators claim can potentially be seen (Table 5.7). The likelihood of seeing particular whale species (whether they are common or rare) is only available as a qualitative description on websites of tour operators, and the information is patchy. Therefore, a quantitative relative contribution was not assigned for each individual whale species. Each whale species listed on the tour operators' websites was given an equal weighting, i.e. assigned an equal relative contribution. This is justified because while spotting several individuals of a more common species may guarantee a successful whale watching trip, spotting one individual of a rare species may be a special experience and, therefore, as valuable culturally as being more certain of seeing common species.

Table 5.7 List of whale (and dolphin) species advertised for likelihood of sighting by whale watching tour operators in the Mediterranean Sea

Species	Advertised likelihood of sightings	Country
The Fin whale *Balaenoptera physalus*	Not indicated	France
	Not indicated	Spain (Gibraltar)
	Rare	Spain
	Not indicated	Italy (Ligurian)
	Not indicated	France
	Rare	Spain
Short-beaked common dolphin *Delphinus delphis*	Not indicated	Spain (Gibraltar)
	Common	Spain
	Not indicated	France
	Not indicated	Spain
Pilot whale *Globucephala sp.* (probably the long-finned (*))	Not indicated	France
	Not indicated	Spain (Gibraltar)
	Common	Spain
	Not indicated	France
	Not indicated	Spain
Risso's dolphin *Grampus griseus*	Not indicated	France
	Not indicated	France
The killer whale *Orcinus orca*	Not indicated	Spain (Gibraltar)
	Rare	Spain
	Not indicated	Spain
The sperm whale *Physeter catodon*	Not indicated	France
	Not indicated	Spain (Gibraltar)
	Occasional	Spain
	Not indicated	Italy (Ligurian)
	Not indicated	France
	Not indicated	Spain
	Not indicated	Greece (Crete)
Striped dolphin *Stenella coeruleoalba*	Not indicated	France
	Not indicated	Spain (Gibraltar)
	Common	Spain
	Not indicated	France
	Not indicated	Spain
	Not indicated	Greece (Crete)
Common bottlenose dolphin *Tursiops truncates*	Not indicated	France
	Not indicated	Spain (Gibraltar)
	Common	Spain
	Not indicated	Italy (Ligurian)
	Not indicated	France
	Not indicated	Spain
Cuvier's Beaked Whale *Stenella coeruleoalba*	Not indicated	Greece (Crete)
Dolphins (species not indicated)	Not indicated	Italy (Ligurian)
Rorquals (Balaenopteridae) (species not indicated)	Not indicated	Italy (Ligurian)

Notes:

- A total of 8 sources were used (in 2014), see Annex II, Table AII.5, for list of sources
- (*) This is expected to be the long-finned pilot whale because this is the species recorded for the Mediterranean Sea in publications such as ACCOBAMS (Notarbartolo di Sciara and Birkun, 2010).

Example 4: Using distance from the shore and habitat type to assign the relative contribution of different habitats to the ecosystem capacity to supply the Recreation and leisure (cultural) service class

This example does not estimate a relative contribution of ecosystem components for any particular cultural service but describes an approach that could potentially be used to determine which habitat types are more or less important for carrying out those activities using the *Recreation and leisure* (cultural) service class, or the service types therein.

To assess the relative contribution of different habitat types (with their assemblages of biotic groups) to the ecosystem capacity to supply the *Recreation and leisure* service, ideally actual distance from shore would be used with mapped habitat data of where activities take place. For example, information such as that found in the Scottish Marine Atlas[141], which maps rates of activities in different locations, could be used. An alternative to this would be to assign habitat types to (scored) distance categories, based on their likelihood of distance from the shore in a particular region (Table 5.8). For example, shallow sublittoral habitat types are more likely to be closer to the shore while shelf sublittoral habitat types are further away in some areas; while in other areas, shelf sublittoral habitat types may be much closer to the shore. The scored distance categories could be used to assign a semi-quantitative relative contribution to different habitat types. This could then be combined with an assessment of where activities using the *Recreation and leisure* service take place, and how dependent these activities are on the state of the marine ecosystem (Table 5.9).

Table 5.8 Habitat types within the MECSA habitat typology (*) directly providing opportunities to use the *Recreation and leisure* service, which have been assigned to categories of distance from shore

Distance from Shore: Category (Score)	Description of Category
Zero (4)	Included here are some variable salinity habitats (a coastal lagoon in the supralittoral may be surrounded almost fully by land); littoral habitats; and ice-associated habitats
Low (3) – easy to reach with low effort	Included here are some variable salinity habitats, some coastal water habitats, and shallow sublittoral habitats
Moderate (2) – still easy to reach but requires some more effort	Included here are some coastal water habitats, some shelf water habitats, and some shelf sublittoral habitats
High (1) – requires considerable effort to reach	Included here are some shelf water habitats, oceanic water habitats, and some shelf sublittoral habitats

Notes:

- The MECSA habitat typology is found in Section 3
- (*) Habitats types below shelf sublittoral habitat types are not considered to directly supply the *Recreation and leisure* service (see Section 4)
- Taken from Table AII.3 in Annex II

141 https://www2.gov.scot/Topics/marine/science/atlas

Table 5.9 Different activities using the *Recreation and leisure* cultural marine ecosystem service according to their dependence on the marine ecosystem

Activity	Can take place in habitat types	Dependence on ecosystem components	Note
Recreational fishing/hunting/ wildfowling/ crabbing/bait collecting/ clam digging	Variable salinity waters Coastal waters Shelf waters Oceanic waters Ice-associated Littoral Shallow sublittoral Shelf sublittoral	**Essential**	Leisure fishing and hunting can include angling, foraging for shellfish and deep-sea fishing, amongst others. These activities can occur in all pelagic habitats, ice habitats and benthic habitats out to the shelf.
Wildlife watching (whales, dolphins, birds, seals) and enjoying nature (e.g. spotting saltmarsh plants)	Variable salinity waters Coastal waters Shelf waters Oceanic waters Ice-associated Littoral	**Essential**	Wildlife watching can occur anywhere the animals or plants are visible. Whales can be spotted from habitats close to the shore, or from boats in habitats further from the shore. Although even whale-watching boats are unlikely to go as far as oceanic waters, spotters may see whales from cruise ships in these habitats. Birds and seals can be watched in littoral or ice habitats and plants can be spotted in littoral habitats.
Rock pooling (looking at rock pool algae and animals)	Littoral	**Essential**	Rock pools can be found in rocky littoral habitats.
Snorkelling (to look at wildlife)	Variable salinity waters Coastal waters Shallow sublittoral Shelf sublittoral	**Essential**	Snorkelling can be carried out in any type of water body. Snorkelers can benefit from both pelagic and benthic elements of the ecosystem. Although snorkelling in deeper waters off a boat (shelf) is possible, it is considered that most snorkelling occurs in shallower areas.
Enjoying bioluminescence (of phytoplankton)	Variable salinity waters Coastal waters Shelf waters Oceanic waters	**Essential**	Bioluminescence can be seen in all pelagic habitats such as at the shore line on the beach or in the open ocean from a cruise ship.
Scuba-diving	Variable salinity waters Coastal waters Ice-associated Shallow sublittoral Shelf sublittoral	**Moderate – High**: scuba diving can be carried out regardless of biotic elements (e.g. wreck diving), but is enhanced by biotic elements and in areas with no wrecks is greatly enhanced by biotic elements	Scuba-diving can be carried out in any type of water body and ice diving can also be carried out. Recreational divers dive to a maximum of around 40 m (e.g. PADI). Divers can benefit from both pelagic and benthic elements of the ecosystem.
Visiting scenic areas/land- and seascapes (where the ecosystem components contribute to the scenery)	Variable salinity waters Coastal waters Shelf waters Oceanic waters Ice-associated Littoral	**Moderate**: abiotic scenery (e.g. a sandy beach, sea cliffs) could be enjoyed as much as biotic elements but is enhanced by ecosystem components e.g. the presence of wildlife in the scenery	In this case, the activity occurs in the littoral habitat (or further inland) but all habitats within sight can contribute to the experience. It can also occur in other habitats from a boat.

Table 5.9 Cont.

Activity	Can take place in habitat types	Dependence on ecosystem components	Note
Walking, cycling or horse riding along the coast (where the ecosystem components add to the experience)	Variable salinity waters Coastal waters Ice-associated Littoral	**Low**: these activities could be carried out completely in the absence of ecosystem components where the abiotic elements can be enjoyed but can be enhanced by their presence, e.g. enjoying the smell of the sea air (dimethyl sulphide produced directly by phytoplankton or by bacteria degrading phytoplankton).	In this case, these activities occur in the littoral habitat (or further inland) but all habitats within site can contribute to the experience.
Sailing and Boat trips (where the ecosystem components add to the experience)	Variable salinity waters Coastal waters Shelf waters Oceanic waters	**Low**: these activities could be carried out completely in the absence of ecosystem components where the abiotic elements can be enjoyed but can be enhanced by their presence, e.g. enjoying the smell of the sea air (dimethyl sulphide produced directly by phytoplankton or by bacteria degrading phytoplankton), and seeing whales, turtles, dolphins, fish and birds	The state and presence of ecological components in pelagic waters can contribute to the experience.
Other sports/water sports (where the ecological components adds to the experience) – swimming, surfing, kayaking, coasteering.	Variable salinity waters Coastal waters Ice-associated Littoral Shallow sublittoral	**Low**: these activities could be carried out completely in the absence of ecosystem components but can be enhanced by their presence, e.g. kayaking with whales or seals.	Water sports such swimming, surfing and kayaking take place in the pelagic waters. Beyond the coastal area, these activities are less likely to occur due to the distance from the shore and also the experience is less likely to be influenced by the ecological components in the open water further from the coast. Coasteering makes use of pelagic, littoral and shallow sublittoral habitats. Ice-skating can take place on sea ice.
Going to the beach/seaside (where the ecosystem components add to the experience)	Variable salinity waters Coastal waters Littoral Shallow sublittoral	**Low**: activity has considerable elements which can be carried out without ecosystem components such as sun bathing but is enhanced by ecosystem components, e.g. enjoying the smell of the sea air (dimethyl sulphide produced directly by phytoplankton or by bacteria degrading phytoplankton), and seeing different marine animals out in the water from the beach, e.g., fish, birds	In this case, the activity occurs in the littoral habitat (or further inland) but all habitats within site can contribute to the experience.

Notes: Taken from Table AII.2 in Annex II

Step 1.3 Identify the component(s) critical for the ecosystem capacity to supply the service class or type

Step 1	Identify the critical ecosystem components for service supply capacity
1.1	Identify the service class or type to be assessed
1.2	Determine the relative contribution of all components to the ecosystem capacity to supply the service class or type
1.3	Identify the component(s) critical for the ecosystem capacity to supply the service class or type

Once the relative contributions of the different components to the ecosystem capacity to supply the service, type or class, have been assigned, the critical component(s) for this capacity need to be identified. This allows the assessment to be carried out without the need for consideration of a large number of lower contributing ecosystem components. For example, three components may contribute equally to the ecosystem capacity to supply a service and all three should be carried through to the next step of the assessment. On the other hand, one component may contribute vastly more than any other components and, in this case, only this component may be taken forward through the next steps of the assessment. Use of expert judgement is required to decide how many components to carry forward, and confidence in this decision should be estimated (see Annex V).

To stress that identifying the critical components to the ecosystem capacity for the supply of a given service, on the basis of their higher relative contribution, does not mean that other components do not have a service generation role within the ecosystem; they just would not have a critical role in relation to that service. It should also be noted that, although in this approach some components are considered to make a less substantial contribution than others do to the ecosystem capacity for the supply of a service, relative contributions are dependent on the scale that the assessment is carried out at. For example, in the assessment of the *Waste nutrient removal and storage* service, phytoplankton was found to make a much greater relative contribution than other components at the regional scale (EU marine regions and at the Irish Sea scale) (Annex III). However, at a smaller scale, such as in a sheltered bay, macroalgae may be more than or equally as important as phytoplankton (Kinney and Roman, 1998) and, thus, macroalgae may be one of the critical components when considering eutrophication hotspots.

As explained under the *Recreation and leisure from whale (and dolphin) watching* example (Example 3, Step 1.2), once the species relevant for whale watching were identified, both common and rarer species were assigned equal relative contributions and, thus, all considered critical. As noted there, this is because, to someone carrying out the activity, the cultural value of seeing an individual of a rare species may be equal to the cultural value of seeing several individuals of common species. In addition, it was also due to the fact that the information to assign different relative contributions to different whale species was not available (see Annex II).

In the *Seafood (fish and shellfish) from wild animals* test case assessment (Annex IV), a threshold of > 0.1 % contribution of a species to the total landings was applied to determine whether the species represented a critical contribution to commercial fisheries and so to the service type assessed there.

Step 2 Establish the relationship between the critical ecosystem component(s) and the service class or type, and identify metric(s) describing this relationship

Step 1	**Identify the critical ecosystem components for service supply capacity**
Step 2	**Establish the relationship between the critical ecosystem component(s) and the service class or type, and identify metric(s) describing this relationship**

The (ecosystem) state-service (generation) relationship captures the link between a given state of the parts of the ecosystem that have the capacity to supply a service and what such a state means in terms of that capacity (e.g. does the good state of a critical ecosystem component correspond to good ecosystem capacity for the supply of the service?). A preliminary consideration of this relationship will have been carried out as part of identifying the components contributing to the ecosystem capacity for the supply of a given service (Stage 1, Section 4), and in making decisions throughout Step 1. This step here is a more in-depth consideration of the (ecosystem) state-service (generation) relationship, and focuses on identifying the specific aspects of the state of a component that can affect the supply of a service, e.g., ecological processes, such as rate of growth and response to environmental variables (e.g., nutrient and toxicant inputs); or animal behaviour, which are unique to and need to be specified for each service. These aspects, then lead to the choice of what metrics should be used to describe the (ecosystem) state – service (generation) relationship and thus assess the capacity of the system to deliver a service in subsequent steps. This step is also important to identify the *type of* relationship between the components and the service, which will need to be considered since the information available from the implementation of EU (and other) legislation/policy with which to assess the state of a component may not have a direct relationship with the ecosystem capacity to supply a service (i.e. how can we meaningfully interpret policy-based information on ecosystem state for an assessment of service supply capacity). This is expanded on below.

Step 2.1 Establish the (ecosystem) state-service (generation) relationship

Step 1	**Identify the critical ecosystem components for service supply capacity**
Step 2	**Establish the relationship between the critical ecosystem component(s) and the service class or type, and identify metric(s) describing this relationship**
2.1	Establish the (ecosystem) state-service (generation) relationship

The type of relationship between the state of the critical component/s and the generation of the relevant service can be **strong**, **weak** (i.e. partially decoupled), or fully **decoupled** (Table 5.10). An example of a strong relationship would be the link between the state of wild fish and the generation/supply of the *Seafood from wild animal* service, where an increase in fish (e.g. biomass) would lead to an increase in the capacity of the ecosystem to supply wild animal seafood. Examples of weak links (partial decoupling) could include the relationship between the state of some ecosystem components and some of the *Recreation and leisure* service types. For example, having an estimation of saltmarsh habitat area tells us that these habitats exist and that they, and their resident biotic groups, could potentially be used by people for their enjoyment. But there may be little evidence that the area of available habitat actually affects whether, or how, people choose to use particular *Recreation and leisure* service types, such through as coastal walking in those habitats (see Section 4). There are also links that are fully decoupled from the current state of the ecosystem component/biota (see Section 4). For example, the link between the state of whales and the generation of the *Heritage* service; this link is based on the historical records of whaling in certain communities and the capacity for the supply of this service will not be affected by the current state of whale populations.

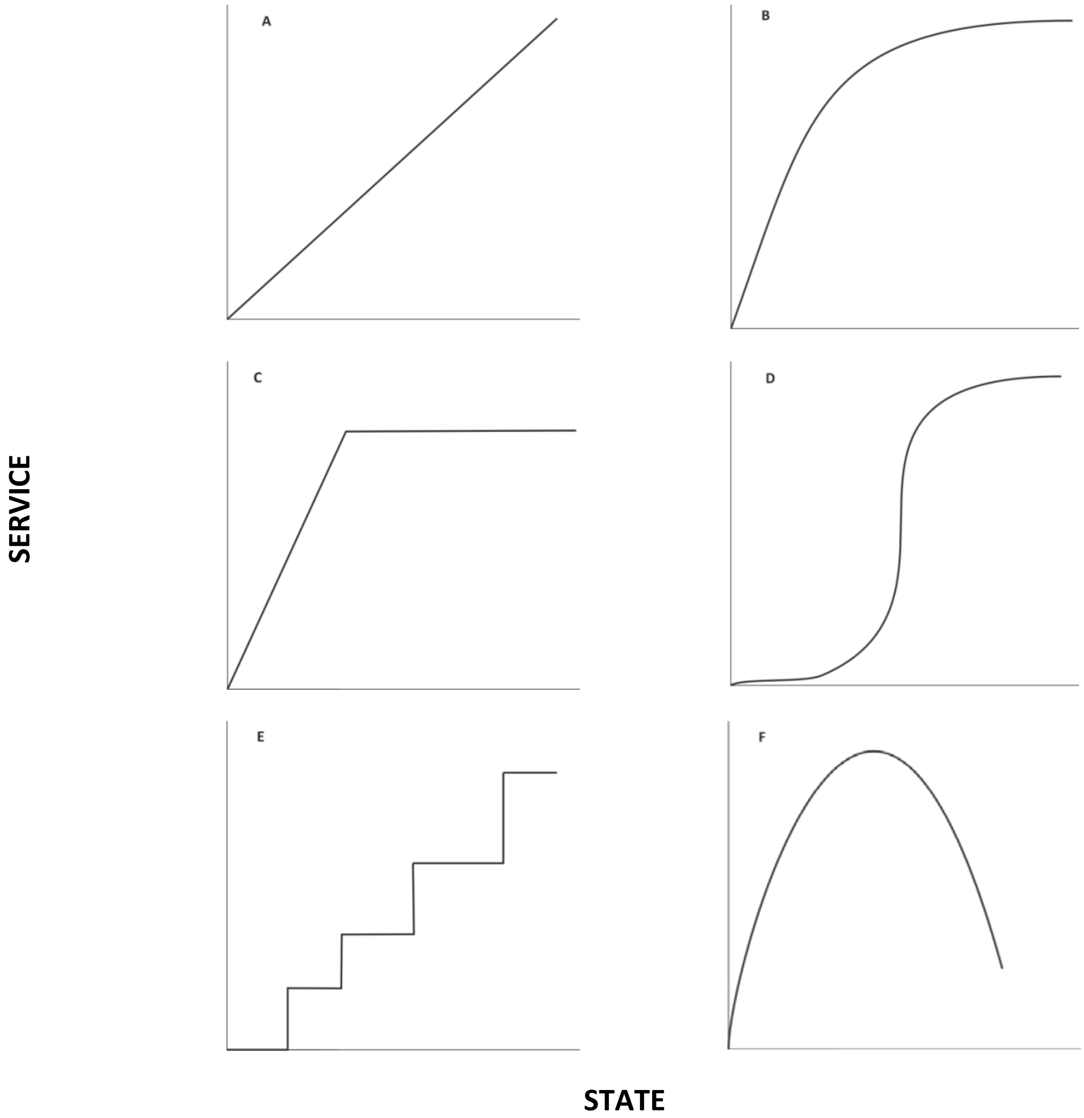
Table 5.10 Types of relationship between the state of ecosystem components and service generation/supply

<table>
<tr><th>Link</th><th>Possible Shape of Relationship</th></tr>
<tr><td>Strong link</td><td rowspan="2">Unbounded linear, plateauing exponential, ogive curve, complex, e.g. step function</td></tr>
<tr><td>Weak link (partial decoupling)</td></tr>
<tr><td>Decoupled link (full decoupling of service supply capacity from current state of ecosystem components)</td><td>Complex, e.g. step function</td></tr>
</table>

The relationship between the state of a component and the generation of the service it can supply, or contribute to, could also be **simple** or **complex**, which would lead them to have different **shapes**. A simple relationship means that the link is one-to-one, such as between the state of whales and dolphins and the generation of the *Recreation and leisure from whale (and dolphin) watching* service (see Step 2.2. below). Simple relationships could have unbounded linear, plateauing exponential or ogive curve shapes (Figure 5.5, Table 5.10). A complex relationship means that the link is not one-to-one as there would normally be some limiting factors to the ecosystem capacity for service supply. It would, thus, have a step function or humped shape (Figure 5.5, Table 5.10). An example of a complex relationship could be that for the *Pest control* service, where there may be several critical components and limiting factors involved in maintaining a balance of organisms as needed for the control of pest species (see service definition in Section 4). For some *Recreation and leisure* service types, even when those activities using the service have an essential dependence on the state of the relevant ecosystem components (see Tables 5.3, 5.9 above), the relationship may be complex. For example, in a study of recreational trips by sea anglers on the Great Barrier Reef, the catch rates were found to have relatively little effect on the demand for angling (Prayaga et al. 2010) because other factors were also involved in people's want to fish (see Section 4).

Finally, the relationship between the state of a component and the generation of the service it can supply, or contribute to, could also be **positive** or **negative**, depending on the service, and not necessarily align with EU legislative or policy objectives for ecosystem state and biodiversity protection. For example, an increase in phytoplankton with increasing nutrients may result in an increase in the supply of the *Waste nutrient removal and storage* service (at least temporarily) but may coincide with a decrease in achieving policy objectives related to preventing eutrophication. This is because a scenario could exist where an increase in waste nutrients discharged into the sea would lead to an increase in the concentration of phytoplankton using those nutrients. This scenario would reflect an increase in the supply of the service (i.e. increasingly more nutrients being removed as more phytoplankton is produced). However, these conditions (i.e. greater nutrient concentration and phytoplankton biomass) concurrently represent those indicating a worsening of ecosystem state through a move towards eutrophication and a failure in achieving policy objectives, such as the MSFD 'Good Environmental Status' (GES) for the Descriptor on 'Eutrophication' (Descriptor 5; EC, 2008) ('though, see discussion below as, at some point, the service becomes degraded as eutrophication increases). A further example would be where human disturbance of the seafloor would compromise achieving the MSFD GES for the Descriptor on 'Seafloor integrity' (Descriptor 6; EC, 2008), but if this disturbance resulted in more small benthic invertebrate organisms, then the system might be able to support more plaice as these invertebrate constitute its food (Rijnsdorp and Vingerhoed 2001, Link et al. 2002, Hiddink et al. 2008). In this way, the seafloor could potentially deliver more of the *Seafood from wild animals* service, in the form of plaice (but not necessarily other seafood species), when not in GES.

Figure 5.5: Possible shapes in the relationship between the state of ecosystem components and the generation/supply of a service



Notes: A Unbounded linear, B Plateauing exponential, C Stepped linear, D Ogive, E Step function, F Humped

The confidence in having adequately identified the relationship between the state of the components and the generation of the relevant service may be 'high', 'moderate' or 'low', and this will depend on scientific knowledge available to identify the relationship as follows:

- **High confidence:** Well understood relationship
- **Moderate confidence:** Less well understood relationship
- **Low confidence:** Poorly understood relationship

For example, for the *Recreation and leisure from whale watching* service, the confidence in the relationship between the state of whales (relevant for whale watching, see Table 5.7) and service generation is 'high' since it is obvious that an increase in the number of whales would increase the people's likelihood of being able to see whales while whale watching. In another example, even though the relationship is complex, the confidence in the relationship between the state of phytoplankton and the generation of the *Waste nutrient removal and storage* service is also high, since the dynamics of phytoplankton, nutrients and impacts of eutrophication are well understood. A poorly understood relationship could include people interacting with coastal habitats through walking in them as a way of using the *Recreation and leisure* service; where people may benefit from many different aspects of the ecosystem through experiencing it in this way, but the nature of the relationship between the state of coastal habitats and the supply of the related experience, and associated benefits such as enjoyment and relaxation, is unclear. See Annex V for more detail in the confidence assessment linked to this step.

Step 2.2 Identify metric(s) describing the (ecosystem) state-service (generation) relationship, including of the critical ecosystem component(s) and other parts of the ecosystem if relevant

Step 1	**Identify the critical ecosystem components for service supply capacity**
Step 2	**Establish the relationship between the critical ecosystem component(s) and the service class or type, and identify metric(s) describing this relationship**
2.1	Establish the (ecosystem) state-service (generation) relationship
2.2	Identify metric(s) describing the (ecosystem) state-service (generation) relationship, including of the critical ecosystem component(s) and other parts of the ecosystem if relevant

In a simple (ecosystem) state-service (generation) relationship, the ecosystem would be represented by just the critical ecosystem component(s) and the assessment of the ecosystem capacity to supply the service would only need to include a metric(s) of the state (and of the state trend) of this component(s). In a complex (ecosystem) state-service (generation) relationship, the ecosystem may need to be represented by not only the critical ecosystem component(s) but also other elements of marine ecosystems (e.g., their physico-chemical attributes), and the assessment of the ecosystem capacity to supply the service would need to include a suite of metrics in order to assess the state (and the state trend) of all these elements.

An example of a simple (ecosystem) state-service (generation) relationship is that between the state of whales and the generation of the *Recreation and leisure from whale watching* service, where it is assumed that whale watching is directly dependent on the populations of those whale species that are relevant for this activity, i.e. the critical ecosystem component (see Table 5.7, Annex II). This is because, as noted already, a decrease in the population of those whale species would result in a decrease in people's likelihood of being able to see whales while whale watching and, thus, in the capacity of the ecosystem to supply the service. Therefore, only the state of the populations of whale species that are relevant for whale watching is needed in order to characterise the (ecosystem) state-service (generation) relationship. The metric to be used in the state assessment needs to relate to their presence, which is dependent on their state and is what determines the ecosystem capacity to supply the service. This metric could be, for example, the population size and abundance of relevant whale species, which is measured (and classified) as part of assessing their status under different policy instruments (e.g. the MSFD). There are two potential 'states' of and two 'directions of change' in the state of the service based on the assessment of the state and direction of change in the state of this metric (where the 'state' of the service refers to the 'state' of the capacity of the ecosystem to supply the service, i.e. whether that is 'good' or 'bad') following the (ecosystem) state-service (generation) relationship:

- **'Good' state of service supply capacity** = 'Good' state of whale populations
- **'Bad' state of service supply capacity** = 'Bad' state of whale populations
- **'Improving' state of service supply capacity** = 'Increasing' (state of) whale populations
- **'Deteriorating' state of service supply capacity** = 'Decreasing' (state of) whale populations

A complex relationship exists for the service *Waste nutrient removal and storage* (Annex III), which is underpinned by the sequestration of nutrients by phytoplankton. In this case, an increase in the capacity of the ecosystem to supply the service does not necessarily coincide with improvements in ecological state, and thus policy objectives (see Step 2.1). For example, as the amount of nutrients and phytoplankton increase, the service may also increase, but there is likely to be a loss in biodiversity of phytoplankton as opportunistic species become dominant, which is one of the effects of eutrophication on phytoplankton. However, in relation to eutrophication, what has been considered here is that the service is compromised when the effects of eutrophication extend beyond just the state of the phytoplankton component. Thus, the (ecosystem) state-service (generation) relationship is represented by phytoplankton, which is the critical ecosystem component, as well as nutrients and benthos, where including the latter aims at capturing the impacts of eutrophication beyond the phytoplankton component[142]. Therefore, a suite of metrics is needed to assess the ecosystem capacity to supply the service, and these metrics should inform on these three elements, e.g., phytoplankton biomass, nutrient concentrations and (eutrophication) impact on the benthos. Again, there are two potential 'states' of and two 'directions of change' in the state of the service based on the assessment of the state and state trend of these metrics (where the 'state' of the service refers to the 'state' of the capacity of the ecosystem to supply the service) following the (ecosystem) state-service (generation) relationship:

- **'Good' state of service supply capacity** = Wider impacts of eutrophication are not apparent and, thus, the system has capacity to assimilate more nutrients (i.e. the benthos is in a 'good' state and phytoplankton sequestration capacity is not compromised) (see Table AIII.5 in Annex III)
- **'Bad' state of service supply capacity** = Wider impacts of eutrophication are apparent and, thus, the (ecosystem capacity to supply the) service is unsustainable (i.e. the benthos is in a 'bad' state and there is low potential for nutrient sequestration by the phytoplankton) (see Table AIII.5 in Annex III)
- **'Improving' state of service supply capacity** = see Table 5.11
- **'Deteriorating' state of service supply capacity** = see Table 5.11

When more than just the critical ecosystem component(s) is involved in the service supply capacity assessment, there can be several potential outcomes for both the state of and the direction of change in this capacity based on the state and the state trends of the various metrics used in the state assessment, respectively. The (classifications for the) state of each of these metrics needs to be considered together in deriving the final outcome for the (state of the) current capacity for service supply (see Table AIII.5 in Annex III). The same with the (classifications for the) trend in the state of the metrics to derive the final outcome for the direction of change in (the state of current) service supply capacity (Table 5.11, see also Example 2 under Step 4 for the difference between the 'direction of change' and the actual trend in the state of the metrics, where the latter is needed to be able to use this table).

[142] We did not consider the effect within the phytoplankton component – such as changes to composition, because the capacity for service supply (what we are concerned with here) would continue, with phytoplankton species more tolerant of nutrients carrying out nutrient removal in increasing nutrient conditions. This is until the system's capacity collapses because nutrients (phosphorus) and/or light eventually become limiting.

Table 5.11 Possible outcomes for the direction of change in the ecosystem capacity to supply the *Waste nutrient removal and storage* service

A	Increasing	Decreasing	Service		E	Increasing	Decreasing	Service
Phytoplankton Concentration	■		**Deteriorating**		Phytoplankton Concentration		■	**Deteriorating**
Nutrient Concentration	■				Nutrient Concentration	■		
Impact on benthos	■				Impact on benthos		■	
B	Increasing	Decreasing	Service		F	Increasing	Decreasing	Service
Phytoplankton Concentration		■	**Improving**		Phytoplankton Concentration	■		**Deteriorating**
Nutrient Concentration		■			Nutrient Concentration		■	
Impact on benthos		■			Impact on benthos	■		
C	Increasing	Decreasing	Service		G	Increasing	Decreasing	Service
Phytoplankton Concentration	■		**Improving**		Phytoplankton Concentration		■	**Deteriorating**
Nutrient Concentration		■			Nutrient Concentration		■	
Impact on benthos		■			Impact on benthos	■		
D	Increasing	Decreasing	Service		H	Increasing	Decreasing	Service
Phytoplankton Concentration		■	**Deteriorating**		Phytoplankton Concentration	■		**Improving**
Nutrient Concentration	■				Nutrient Concentration	■		
Impact on benthos	■				Impact on benthos		■	

Notes:

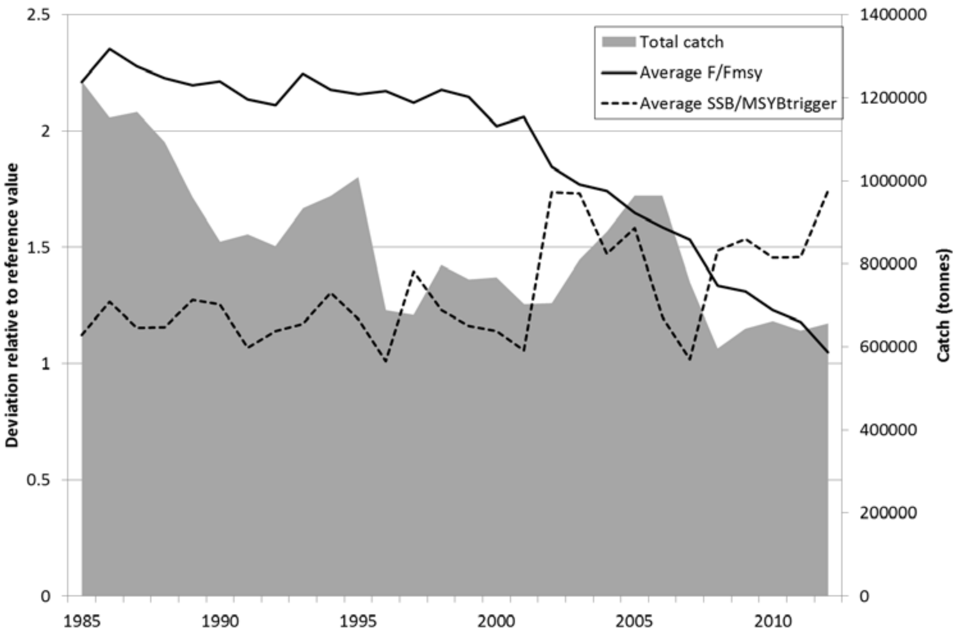
- Possible outcomes for 'stable' state trends not shown
- The actual trend, rather than the direction of change, in the state of the metrics is needed to fuel this table, and this is estimated using the relevant (ecosystem) state trend information directly
- Taken from Table AIII.5 (b) in Annex III

For the *Seafood (fish and shellfish) from wild animals service*, while there is a strong, direct relationship between the state of wild fish and shellfish and the generation of the service, the level of fisheries exploitation also needs to be considered when representing the (ecosystem) state-service (generation) relationship and thus, this service is a further example of a complex relationship. Thus, both the state of the current commercial fish and shellfish populations, plus an indication of the amount of those extracted by fishing need to be considered to assess service supply capacity. Since monitoring of commercial fishing is well established, there are two commonly reported indicators that can reflect these two aspects. The reproductive capacity of the stock (Spawning Stock Biomass, SSB) represents the status of the resource, i.e. fish and shellfish species targeted by fisheries. The level of fishing mortality (F), represents the potential to exploit these species. These indicators have target values (i.e. the greatest fishing mortality that stays at or below maximum sustainable yield (F_{MSY}) and the reproductive capacity required to stay above maximum sustainable yield ($MSY_{Btrigger}$)), which indicate how sustainable the fisheries exploitation is (Figure 5.6, see also Piet et al. 2017), which introduces the idea of using the surplus production to assess the ecosystem capacity to supply the *Seafood (fish and shellfish) from wild animals service*). Once more, there are two potential 'states' of and two 'directions of change' in the state of the service based on the assessment of the state and state trend of the metrics (where the 'state' of the service refers to the 'state' of the capacity of the ecosystem to supply the service) following the (ecosystem) state-service (generation) relationship:

- **'Good' state of service supply capacity** = the reproductive capacity of the stock is greater than $MSY_{Btrigger}$, and the greatest fishing mortality is lower than F_{MSY}.
- **'Bad' state of service supply capacity** = the reproductive capacity of the stock is lower than $MSY_{Btrigger}$, and the greatest fishing mortality is greater than F_{MSY}.
- **'Improving' state of service supply capacity** = the surplus reproductive capacity of the stock is increasing (above levels of fishing mortality).
- **'Deteriorating' state of service supply capacity** = the reproductive capacity of the stock is decreasing.

Figure 5.6 shows how the *Seafood from wild commercial fish and shellfish stocks* service type is related to the average status for North Sea stocks for the period 1985–2012 expressed in fishing mortality and reproductive capacity (on the basis of the 8 main stocks there). For fishing mortality, 1 is considered a target value above which exploitation is unsustainable, while for reproductive capacity, 1 is considered a precautionary limit below which there is a high risk that next year's recruitment is impaired. Figure 5.6 shows how management resulted in a decline in fishing mortality towards F_{MSY}, which, in turn, caused an increase in reproductive capacity further above the limit $MSY_{Btrigger}$. Even though the SSB slightly increased over time, the marked historic trend in F since 1985 resulted in a decrease in total catch of the North Sea stocks by 2012.

Figure 5.6: Status of commercial fish and shellfish stocks in the North Sea over 1985–2012



Notes:

- The status of North Sea commercial fish and shellfish stocks was assessed as part of the assessments of the ICES region comprising the North East Atlantic Ocean and Baltic Sea in 2012.
- The status of these stocks is expressed by two metrics, fishing mortality (F) and reproductive capacity (SSB), reflecting their average deviation relative to the Maximum Sustainable Yield (MSY) policy threshold for the MSFD's 'Good Environmental Status' linked to Descriptor 3 ('Commercial fish'). Note that for fishing mortality, 1 is a target (F_{MSY}) above which exploitation is unsustainable, while for reproductive capacity, 1 is a precautionary limit (SSBpa) below which there is high risk that it is impaired
- From Figure AIV.2 in Annex IV

Step 3 Assess the current state and direction of change in the state of the critical ecosystem component(s) and other parts of the ecosystem where relevant

Step 1	**Identify the critical ecosystem components for service supply capacity**
Step 2	**Establish the relationship between the critical ecosystem component(s) and the service class or type, and identify metric(s) describing this relationship**
Step 3	**Assess the current state and direction of change in the state of the critical ecosystem component(s) and other parts of the ecosystem where relevant**

Step 2 has identified the most appropriate metrics to describe, or represent, the relationship between the ecosystem, in terms of the critical ecosystem component(s) and other elements where relevant, and the service class or type, i.e. the (ecosystem) state-service (generation) relationship. In Step 3, these metrics are assessed as a way to assess the current state and direction of change in the state of the ecosystem, which, in turn, underpins the assessment of the current state of and direction of change in its capacity for service supply (see Figure 5.2). The assessment of these metrics (also called 'state metrics' at times) relies on marine ecosystem state and state trend information that has been reported and interpreted at the EU level from the implementation of EU environmental legislation and other relevant EU (and other) legislation and policy.

In general, the assessments linked to the implementation of EU environmental legislation do not provide sufficient information to apply the MECSA approach, and information generated through the implementation of other EU legislation and policy, or of international and regional policies should be used, where appropriate. The information sources used include EU water, marine and nature directives, e.g. the MSFD; EU policy, e.g., the Common Fisheries Politic; regional policy, e.g. OSPAR; or other policy-related European or global sources, e.g. the IUCN Red List.

All of these 'sources' generate marine ecosystem state and state trend, and other, information as part of the Member State/country reporting on progress in meeting their overall, respective policy objectives, which is done to the EU (or relevant global, or regional organisations). This reporting is then analysed by, e.g., the EEA, becoming a 'pool' of marine information that can be easily accessible and used for EU-level assessment. It can, thus, include information relating to the metrics identified in Step 2.

In this method, the assessment outcomes, or products, from the EU (and other) legislation/policies, i.e. the status quality classifications, are what is used as the input information for the ecosystem (and, thus, the service supply capacity) assessment as opposed to actual data. This is because assessments products are the information that is available at the EU-level from the assessments generated by the implementation of the above-mentioned directives, and which are the priority information streams to use in this (policy-relevant) assessment approach. The method relies on the interpretation of the information made by the reporters of this information at the EU level and, therefore, the associated confidence and uncertainty that goes with that. This also applies to assessment products from other information sources.

Thus, where this assessment approach refers to information on:

- Ecosystem 'state': this information is often in the form of indicators but can also be other types of assessment products from the implementation of EU environmental legislation, or other relevant EU (and other) legislation and policy that are available and interpreted at the EU level. These products usually include/provide status quality classifications expressing ecosystem state in relation to the respective legislation/policy objectives and are used here as such, e.g. 'good ecological status' in the case of the Water Framework Directive. In a few occasions, and mostly relating to fisheries information linked to the implementation of the CFP, state information could also be actual datasets (observations).

- Ecosystem 'state trend': this information is often linked to the above-mentioned EU-level assessment products and so also available and interpreted at the EU level. These products are used here to express the 'direction of change' in ecosystem state towards or away from achieving the respective legislation/policy objectives; i.e. they are interpreted as trends in status (where some pieces of EU environmental legislation already interpret state trends in this way, including the MSFD and HD).

The relevant assessment products can sometimes be based on a number of different measurements (e.g. elements or indicators) aggregated into one overall status quality classification. For example, the Water Framework Directive operates a 'one-out-all-out' aggregation rule on the status of several biological elements to deliver the ecological (and other) status of water bodies. This means that, if the status quality classifications of these elements are not available individually, which tends to be the case at the EU level, the aggregated water body status quality classification could be applied to all relevant elements within it, which would, at worst, overestimate 'bad' status. However, other pieces of legislation/policy do not operate a 'one-out-all-out' approach, and the status quality classifications for the EU-level assessment products they generate cannot be used unless the individual status quality classifications of the relevant elements or indicators within them can be disaggregated somewhat.

Each piece of EU (and other) legislation/policy has its own objective regarding the protection and/or sustainable use of marine ecosystems, which may cover different aspects of marine ecological integrity and different temporal and spatial scales. Policy instruments may also report different products relating to the same ecosystem components or physico-chemical and other attributes of marine systems. We advocate using the best available information (see Step 3.1 below). This, ideally, would come from a single piece of legislation/policy information and no aggregation of the information from different sources would be needed. However, we know that not all of the information required to assess marine ecosystem state (and, thus, its capacity for service supply following the MECSA method) is available for the appropriate spatial and temporal scales in current EU and other legislation and policy (EEA, 2015). Therefore, we take an approach that looks across all relevant information sources (determined as relevant in Step 3.1) and uses them (their status quality classifications for the state of the ecosystems) altogether as sources of complementary information to provide an overall quality classification for the state of each of the metrics used for the assessment. This would then adequately reflect not only the relevant spatial area (i.e. the EU marine regions, *sensu* the MSFD in geographical scope but slightly modified in physical terms following the MECSA habitat typology, see Section 3) but also an as wide as possible interpretation of ecological integrity.

To note, however, that each piece of legislation/policy has a number of quality classifications for status (e.g. the Habitats Directive categorises status into 'Favourable', 'Unfavourable-Inadequate' and 'Unfavourable-Bad') linking to its overall objectives (e.g. the objective of the Habitats Directive is to achieve 'favourable conservation status') (Table 5.12). In order to reach one overall quality classification for the state of each of the metrics used for the assessment, we need to be able to make the classified assessment outcomes of different legislation/policy sources comparable, or to align them in some way. In this assessment approach, the status categories from each piece of legislation/policy have been considered broadly to divide into a 'pass' or 'fail' in achieving its objectives; where the categories which correspond to achieving the respective, overall legislation/policy objective (e.g. 'favourable' for the Habitats Directive) are placed under 'pass', and all other categories are considered to 'fail'. Although within the' pass' or 'fail' category there can be different degrees of disturbance or impact on state indicated, these distinctions are not considered within this assessment approach, where any deviation from achieving the respective, overall legislation/policy objective is considered a 'fail'. This is done in order to align the different assessment outcomes from different pieces of legislation/policy since they cannot be aligned at any other point. If assessment outcomes could be aligned fully, e.g. on a scale of 'bad' to 'high' to correspond to a policy such as the WFD, and not only a 'pass' or 'fail', a greater degree of resolution could be achieved with the assessment. That is, whether (the ecosystem capacity to supply) a service is in 'very bad' or 'moderate' state could be determined, rather than simply being in a 'bad' state as per this approach.

Table 5.12 Examples (1) of the status quality classifications for marine ecosystem state of different EU (and other) legislation/policy grouped under 'pass' (blue and green) or 'fail' (yellow, orange and red) based on the overall objectives of each instrument

Pass or Fail Legislation/Policy Objective	EU environmental legislation and other legislation/policy				
	WFD (2)	**MSFD (3)**	**HD (4)**	**OSPAR (5)**	**IUCN (6)**
Pass	High	Good	Favourable	No problems	Least concern
	Good				
Fail	Moderate	Not Good	Unfavourable – Inadequate	Some Problems	Near threatened
					Vulnerable
	Poor		Unfavourable – Bad	Many Problems	Endangered
	Bad				Critically endangered

Notes:

(1) The table provides a non-exhaustive list of examples. It does not include the Birds Directive and associated status quality classifications; neither those used in the assessments from other regional and international marine conventions, nor from other EU and international organisations covering EU marine regions.

(2) The overall objective of the Water Framework Directive (WFD) is to achieve at least 'good' ecological status and includes five status quality classifications from 'bad' to 'high'

(3) The overall objective of the Marine Strategy Framework Directive (MSFD) is to achieve 'good' environmental status where the status of 11 Descriptors of 'good environmental status' is classified as 'good' or 'not good'

(4) The overall objective of the Habitats Directive (HD) is to achieve 'favourable' conservation status and includes three status quality classifications ranging from 'unfavourable-bad' to 'favourable'.

(5) The objectives in OSPAR depend on the specific assessment; as an example, the eutrophication assessment includes three quality classifications and its objective is to achieve 'no problems'

(6) The IUCN reports on the conservation status of listed species and only considers those of 'least concern' not to be in a threatened status

In some cases, the legislation/policy information identified for use in this assessment method provides/includes state categorisations that do not relate to specific EU (and other) legislation/policy objectives. These categorisations need to be re-categorised into 'pass', 'fail' or 'insufficient information' so they can be used together with the legislation/policy legislation/policy-based classified information. For example, chlorophyll concentrations, which are reported by the EEA using indicators[143], can be used as proxies for phytoplankton biomass but are assigned 'high', 'moderate' and 'low' categories. These categories do not relate to any particular policy objective. If there is a rationale to do so, the categories can also be assigned to a 'pass' or 'fail', using expert judgement. In the EEA example, it is likely that a 'high' chlorophyll concentration would correspond to a 'fail' in the relevant policy objective (e.g. achieving GES for Descriptor 5 on 'Eutrophication' for the MSFD); while a 'low' concentration

[143] EEA indicators are considered part of the EU legislation/policy used as an information source in this assessment approach as their existence is linked to the EU Regulation establishing the EEA (http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32009R0401) and to the role of the EEA as included in several pieces of EU environmental and climate change legislation/policy, e.g. MSFD Article 20.3(b).

would correspond to a 'pass'. However, there is insufficient information to be able to assign a 'moderate' category to either a 'pass' or a 'fail'. This sort of 'moderate' information, although categorised, is not useable in this format for this assessment method.

If the policy/law information cannot be assigned a 'pass' or 'fail' classification, because 'moderate' categories cannot be classified or because it provides an 'unknown' classification, 'insufficient information' is given as the outcome.

Note that the state assessment products/information on the metrics (of the specific critical ecosystem components and physico-chemical or other attributes of marine systems where relevant) that need to be assessed have to provide a status quality classification that can be categorised as 'pass' or 'fail' policy objectives (or be susceptible of being re-categorise as such). However, any relevant datasets could be used to assess the direction of change in the state of the metrics. Thus, providing the datasets measure the state trend of the specific metrics, these can more easily be interpreted and assigned an 'increasing', 'decreasing' or 'stable' trend.

Step 3.1 Identify EU (and other) legislation and policy generating ecosystem state and trend information to assess the metric(s) of the critical ecosystem component(s) and other parts of the ecosystem, where relevant, identified in Step 2

Step 1	**Identify the critical ecosystem components to assess the capacity of the ecosystem to supply a service**
Step 2	**Establish the relationship between the critical ecosystem component(s) and the service class or type, and identify metric(s) describing this relationship**
Step 3	**Assess the current state and direction of change in the state of the critical ecosystem component(s) and other parts of the ecosystem where relevant**
3.1	Identify EU (and other) legislation and policy generating ecosystem state and trend information to assess the metric(s) of the critical ecosystem component(s) and other parts of the ecosystem, where relevant, identified in Step 2

This step identifies information generated by the EU (and other)-level reporting, on the fulfilment of the objectives of relevant legislation/policy, on marine ecosystem state and state trends that can be used to assess the metrics identified in Step 2.2. Thus, these metrics serve to assess the critical ecosystem components and the physico-chemical, and other, attributes of the marine system, where relevant, representing the (ecosystem) state-service (generation) relationship identified in Step 2.1 and, thus, underpinning the ecosystem capacity to supply a given service. Table 5.13 shows potential EU (and other) legislation/policy information sources for the assessment of the (ecosystem capacity to supply the) *Recreation and leisure from whale watching* service in the North East Atlantic Ocean and Mediterranean Sea, and the information reported; where sources collect information on and/or assess whale populations covering part or all of these areas.

Table 5.13 Summary of legislation and policy requiring EU (and other)-level reporting that is relevant to assess the North East Atlantic Ocean and Mediterranean Sea ecosystems' capacity to supply the *Recreation and leisure from whale watching* service

Geographical relevance	Legislation/policy	Information reported
International level	IUCN Red List	Categorisation of status of listed cetacean species and population trends
EU level	MSFD	Reporting for GES Descriptor 1 'Biodiversity', including status and trends in status of 'marine mammals'
	Habitats Directive	Categorisation of status of cetacean species Annex II and Annex IV and trends in status
Regional level	OSPAR Biological Diversity and Ecosystems Strategy (North East Atlantic (NEA))	4 threatened species monitored, pressures on cetaceans recorded
	ASCOBANS[144] (NEA)	Description of known information on cetacean species populations, trends and pressures
	ACCOBAMS[145] (Mediterranean Sea)	Description of known information on cetacean species populations, trends and pressures

In order to select the sources to use from the available information, we consider the following criteria:

(1) relevance to the ecosystem-state service relationship;
(2) relevance to the spatial scale being assessed; and
(3) how up to date the information is.

If one information source fulfils all of these criteria, this can be used, and no further sources of information are required. However, the information available will not have been collected for the purposes of this type of assessment, and it is unlikely that all of these criteria will be filled using what is currently available from just one information source. Therefore, there may be trade-offs in the choosing of different information sources and it may be deemed necessary to use several complementary sources of information to fulfil all criteria. For example, there are only a few species groups under the scope of the WFD and their assessments *tends* to be limited seawards to 1 nm; while the MSFD covers more species groups and fills the WFD gaps within 1 nm and extends, for all species groups, up to 200 nm; i.e., information from more than one piece of legislation may be needed to ensure that the whole spatial range of ecosystem components is covered. We, nevertheless, consider the first criterion to be the most important to fulfil in order to capture an assessment of the ecosystem capacity to supply ecosystem services.

[144] Agreement on the Conservation of Small Cetaceans in the Baltic, North East Atlantic, Irish and North Seas, (http://www.ascobans.org/)

[145] Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and contiguous Atlantic Area (http://www.accobams.org/)

Information reported for different legislation/policy takes a variety of forms, and these will not always be in the form most suitable for the assessment of the services in question (using the metrics identified in Step 2.2) – see Table 5.14 for a hierarchy of best available information to use to fulfil criterion (1) above. In some cases, the reported information will align with state metrics characterising the aspect of the component most relevant to the supply of the service, given the (ecosystem) state – service (generation) relationship established in Step 2.1, e.g. whale species for whale watching (but this is only for the set of species identified as being relevant for whale watching). In other cases, the state of the ecosystem component may need to be inferred from the best available/closest information, e.g. the state of marine mammal populations used to infer the state of whales; or the state of the habitat (*sensu* biotope), rather than the specific biotic group within that habitat, e.g. reporting on 'water column' habitats for the MSFD could be used as a proxy for phytoplankton communities under the proviso that there is a way to infer their individual status from the overall status of those habitats.

If no state information is available relating to the metrics of the critical ecosystem components (and other attributes of the marine system where relevant), the trends in pressures may need to be used to infer the direction of change in ecosystem state (but not the state itself, which cannot be classified in this case). This is the least desirable option when the relationship between the pressure and the state of the ecosystem is not well known but can be a good alternative when this relationship is well understood, as it is in many cases. It is not expected that driver information (e.g. human activities) would need to be used as a proxy for pressure and, hence, change in state and neither is it recommended, as the assumptions required are considered to be too great.

It may be the case that more than one information source is used to fulfil criterion (1), because, for example, different sources cover different aspects of ecological integrity of the same ecosystem component, or different sources have different degrees of stringency in classifying ecosystem condition and there may be greater confidence in the assessment if several information sources are found to agree on the classification.

Once criterion (1) can be fulfilled, we should aim to fulfil criterion (2) above and the information used should, as a first choice, be reported for the appropriate scale (i.e. in this assessment, an EU marine region), or, as a second choice, cover either more than (e.g. global assessments), or a part of (e.g. relevant aspects of sub-regional information), the region being assessed (e.g.an EU marine region for the purpose of the assessment being developed here). Information from the appropriate scale leads to a better quality assessment. In the test case assessments here, we often found that information sources that fulfilled criterion (1) did not cover the appropriate assessment area. Thus, we explored using several different types of information that is available at the EU level together in order to cover the total area. We describe how to aggregate this information in the next steps below.

With the best information available for criteria (1) and (2), the most recent assessments should be used, fulfilling criterion (3). If it has been found that several information sources are already needed to fulfil criteria (1) and (2), it is highly likely that the timings at which the different information used was produced will not overlap due to differences in the timing of reporting of the relevant EU (and other) legislation and policy. Therefore, the information being compared here may not align, with some of it being out of date compared to other parts of it.

If several sources of information are taken forward in the assessment to fulfil all the criteria above, i.e. they are deemed useful and relevant, we do not weight or prioritise these. Expert judgement is used (as part of Steps 3.2 and 3.3) to estimate the confidence in this part of the assessment, taking into account the various factors which may influence the confidence associated with the information sources used (see below and Annex V).

Table 5.14 Classification of the information that could be used to assess the state and direction of change in the state of the component(s) critical to the ecosystem capacity to supply a service, using, as an example, phytoplankton and the *Waste nutrient removal and storage* service

Information		Example	Confidence
Best Available Information	Where state and trend information, e.g. indicators, reported by the legislation/policy align directly with the metrics identified in Step 2. If classified state and trend information is given, these classifications can be used directly as those for the state and direction towards/away from the legislation/policy objective (direction of change) of the metrics assessed.	Phytoplankton biomass (may not actually be available in any legislation) or a proxy of this, such as chlorophyll concentration (e.g. the EEA indicator on chlorophyll-a concentrations, EEA, 2013b))	This information has the highest degree of confidence associated with it.
First alternative	Where state and trend information reported by the legislation/policy align with the metrics identified in Step 2 but are reported in an aggregated form. If aggregated classified state and trend information is given, these classifications can be used as the state and direction towards/away from the legislation/policy objective (direction of change) of the metrics assessed. However, doing this assumes that all measurements (e.g. elements or indicators) specified in the legislation/policy actually make up the aggregated classification, and that their quality is the same as the overall (aggregated) classification across all of these elements/indicators, which would be the case for the WFD through the 'one out-all out' aggregation rule. Thus, in a way, it is implied that the classifications for the individual elements/indicators can be 'disaggregated' from the overall classification somewhat.	Direct effects of nutrient enrichment (aggregated MSFD GES criterion for Descriptor 5), which includes the measurement of chlorophyll-a concentrations (which can be used as a proxy for phyto-plankton biomass)	This information has moderate confidence associated with it.
Second alternative	If no state and trend information is available aligning with the metrics identified in Step 2, i.e. no state assessment products are reported by the legislation/policy, the classification for the trends in pressures on the state of the critical components can be used to infer direction towards/away from the legislation/policy objective (direction of change) of ecosystem state. In this case, a state classification (i.e. 'pass' or 'fail') cannot be given, only that for the direction of change in the state.	Trends in nutrient concentrations which are known to impact phytoplankton biomass (e.g. the EEA indicator nutrient concentrations, EEA, 2013c)	This information has low confidence associated with the direction of change in ecosystem state.

Step 3.2 Synthesise the ecosystem state and trend information from the different pieces of EU (and other) legislation and policy used to assess the metric(s)

Step 1	**Identify the critical ecosystem components for service supply capacity**
Step 2	**Establish the relationship between the critical ecosystem component(s) and the service class or type, and identify metric(s) describing this relationship**
Step 3	**Assess the current state and direction of change in the state of the critical ecosystem component(s) and other parts of the ecosystem where relevant**
3.1	Identify EU (and other) legislation and policy generating ecosystem state and trend information to assess the metric(s) of the critical ecosystem component(s) and other parts of the ecosystem, where relevant, identified in Step 2
3.2	Synthesise the ecosystem state and trend information from the different pieces of EU (and other) legislation and policy used to assess the metric(s)

Once the marine ecosystem state and state trend information available to assess the metrics from all sources has been identified, it needs to be made comparable across these sources. This requires some synthesis of the reported information. A list of the best fitting information for the metrics representing the (ecosystem) state-service (generation) relationship, as identified in Step 2, i.e. metrics of the critical ecosystem component and other parts of the ecosystem where relevant, should be created and the information reported from the different sources aligned to this; where, in some cases, a proxy is used for the actual/direct metric (as in Table 5.14). For example, for the *Waste nutrient removal and storage* service, the best fitting metrics identified during Step 2.2 were the nutrient concentrations, phytoplankton biomass and a composite metric of (eutrophication) impact on the benthos (Table 5.15).

In some cases, the state information can be aggregated within a piece of legislation/policy (e.g. the WFD gives an overall classification of water body status which integrates all the collected information including phytoplankton (composition, abundance and biomass) and nutrient conditions) (see also other examples of aggregation in Table 5.15). Using this aggregated information for a specific state metric can only be done when it is known that the classification of each aggregated element within a classification is the same (which would be the case for the WFD, see 'First alternative' in Table 5.14). Ideally, disaggregated reported information would be available and would produce a better quality assessment (aggregated information represents a first alternative source of information (see Step 3.1)).

Table 5.15 Example: Synthesis of the information on the metrics needed to assess the ecosystem capacity to supply the *Waste nutrient removal and storage* service reported by each relevant piece of EU legislation and policy

Metric	MSFD[146]	WFD[147]	EEA Indicators
Nitrogen concentrations	The MSFD reports on the criterion 'nutrient levels', which includes an aggregation of indicators on nutrient concentrations and nutrient ratios in marine waters. For the purposes of this assessment approach, the *same* classification for the aggregated 'nutrient levels' criterion is applied to *both* of the indicators 'nitrogen concentration' and 'phosphorus concentration'.	The quality elements for the WFD classification of ecological status include phytoplankton (composition, abundance and biomass) and nutrient conditions for transitional and coastal waters. The WFD operates a 'one-out-all-out' aggregation rule; thus, the aggregated water body status classification (for ecological status) was applied for all the relevant indicators: phytoplankton biomass, and nitrogen and phosphorus concentrations, for the purposes of this assessment approach.	The EEA reports on winter oxidized nitrogen (NO_2+NO_3) concentrations (note this is mostly for transitional and coastal, rather than marine, waters)
Phosphorus concentrations			The EEA reports on winter orthophosphate concentrations (note this is mostly for transitional and coastal, rather than marine, waters)
Phytoplankton biomass (chlorophyll-a concentrations)	The MSFD 'direct effects of enrichment' criterion aggregates the indicators chlorophyll concentration, phytoplankton community composition (species shift in floristic composition) and water transparency in marine waters. For the purposes of this assessment approach, this aggregated classification for 'direct effects of enrichment' criterion is applied to the 'phytoplankton biomass' metric used here		The EEA reports on Chlorophyll-a concentrations (note this is mostly for transitional and coastal, rather than marine, waters)
Impacts on the Benthos	The MSFD 'indirect effects of enrichment' criterion aggregates the indicators 'abundance of perennial seaweeds and seagrasses' and levels of 'dissolved oxygen' in marine waters. For the purposes of this assessment approach, this classification for the aggregated 'indirect effects of enrichment' criterion is applied to the 'impacts benthos' metric used here.	-	-

Notes:

- The metrics have been identified in Step 2.2
- Taken from Table AIII.13 in Annex III

[146] Unlike the WFD, which follows a 'one all-out out' aggregation rule for the overall status of water bodies (see next column), the MSFD status aggregation rules do not allow to infer the status of individual indicators from the overall status of the different GES criteria (i.e. to 'disaggregate' from the overall criterion classification). However, other information available at the EU level was not suitable to assess the metrics in marine waters (see other columns in Table 5.15) and so this, inferring the status of an indicator from the status of the criterion, has been done here purely to illustrate the method.

[147] Here we used the whole waterbody aggregated assessment and followed the one-out-all-out rule to assign the status assessment to each indicator. We did not use the disaggregated national data for each indicator as not all the Member States had reported on them. However, normally, the most disaggregated information available should be used.

Step 3.3 Establish the quality classifications for the ecosystem state ('pass'/'fail') and trend ('increasing'/'decreasing'/'stable') information from each piece of EU (and other) legislation/policy used to assess each metric(s)

Step 1	**Identify the critical ecosystem components for service supply capacity**
Step 2	**Establish the relationship between the critical ecosystem component(s) and the service class or type, and identify metric(s) describing this relationship**
Step 3	**Assess the current state and direction of change in the state of the critical ecosystem component(s) and other parts of the ecosystem where relevant**
3.1	Identify EU (and other) legislation and policy generating ecosystem state and trend information to assess the metric(s) of the critical ecosystem component(s) and other parts of the ecosystem, where relevant, identified in Step 2
3.2	Synthesise the ecosystem state and trend information from the different pieces of EU (and other) legislation and policy used to assess the metric(s)
3.3	Establish the quality classifications for the ecosystem state ('pass'/'fail') and trend ('increasing'/'decreasing'/'stable') information from each piece of EU (and other) legislation/policy used to assess each metric(s)

In order to establish the quality classification for the state and direction of change in the state of the metrics using the information, e.g., assessment products, provided by the relevant EU (and other) legislation/policy and arrive at an assessment of the state and direction of change in the state of the critical ecosystem components, and other parts of the ecosystem where relevant, the information may be used directly or some manipulation will be required depending on how it is reported.

Example 1 Using the quality classifications of the information from relevant EU (and other) legislation/policy directly to assess the metric(s)

The IUCN Red List reports a classification status for the state (and trend in state) of each whale species (Table 5.16). This information can be used directly in the assessment method here by assigning the IUCN status categories into a 'pass' or 'fail' for the state of whale species (following Table 5.12), and to ascertain whether the direction of change in the state of the population is 'increasing' or 'decreasing'.

Table 5.16 Example of some IUCN reported status for cetacean species of the North East Atlantic identified as important for whale watching.

Species	Population status and trend	'Pass'/'Fail' policy objective and 'direction of change' in the state of population
Common Minke Whale *Balaenoptera acutorostrata*	Status: Least Concern Trend: Stable Reilly et al. (2008a)	Pass Stable
Sei whale *Balaenoptera borealis*	Status: Endangered Trend: Unknown Reilly et al. (2008b)	Fail Unknown
Fin whale *Balaenoptera physalus*	Status: Endangered Trend: Unknown but North Atlantic population may be increasing Reilly et al. (2013)	Fail Increasing

Notes:

- Population status and trends are global, except where indicated
- The information from the policy is then translated into whether it represents a 'pass' or 'fail' of the respective policy objectives following Table 5.12, and whether the direction of change of the ecosystem component's state is 'increasing' or 'decreasing'.
- Taken from Table AII.11 in Annex II.

Example 2 Manipulating the quality classifications of the information from the relevant EU (and other) legislation/policy to assess the metric(s): Taking 'the most frequent classification' from the information provided <u>*within*</u> *one piece of EU (and other) legislation/policy*

If one overall classification is not given for an indicator, or another type of assessment product, within one piece of EU (and other) legislation/policy instrument, as done in Example 1 above, some manipulation and interpretation of the different quality classifications provided for that indicator/product is required. For example, a certain proportion of what is reported, such as an area within a marine region, may be assigned to 'good', 'moderate', 'bad' or 'unknown' classifications, but this assessment approach requires arriving at one overall classification of 'pass' or 'fail' for the state of the metric (of the, e.g., the critical ecosystem components) per legislation/policy. In determining the overall outcome, in each case (for each individual piece of legislation/policy), the most frequent quality classification should be established and taken, where feasible.

'The most frequent classification' may be determined by weighting the classifications according to area (i.e. largest proportion of area determines the overall classification). For example, here (Table 5.17) we want to generate an overall classification for the status of the MSFD criterion (i.e. a metric or indicator <u>within</u> a piece of legislation/policy) on 'Direct effects of enrichment'. We take the most frequent classification and, in this case, this is based on percentage of the area covered by each classification. For the Baltic Sea the most frequent classification is 'Not Good' and for the other seas it is 'insufficient information'. A 'Not Good' classification is a failure to meet policy objectives, thus we classify this as 'fail'. If two classifications are equally assigned, we take the most conservative classification (e.g., 35 % of the area is assigned 'Good' and 35 % assigned 'Not Good, we take a precautionary approach as we take the overall classification as 'Not Good').

In this assessment approach, 'insufficient information' is used where no classification can be given. For example, the MSFD can report 'Good' ('pass' – meeting policy objectives) and 'Not good' ('fail' – not meeting policy objectives) classifications but also 'Other', 'Unknown' and 'Not reported/not assessed'. None of the latter three categories can be classed as 'pass' or 'fail' in this assessment approach and, thus, are combined under one heading 'Insufficient information'. The same applies for 'unknown' or 'unreported' categories in other law/policy reporting.

- When the most frequent classification is **greater than 50 %** 'Insufficient information' for a given metric/indicator within the relevant legislation/policy instruments, the overall classification for the region is given as 'Insufficient information'.

The above means that 49 % of a region may have 'unknown' or 'unreported' quality but the region can still be classified based upon the remaining area. The 'insufficient information' parts of a region are assumed to have the same quality as the rest of the region. This (49 %) is a large proportion of a region, which may be unrepresented by the overall classification; however, this spilt (50-50) is necessary to move forward with the assessment due to the often large areas of regions that are included in the 'insufficient information' category.

A similar approach can be used by weighting the classifications according to the number of monitoring stations involved in developing the indicator/assessment product (i.e. largest proportion of monitoring stations linked to a particular classification determines the overall classification).

Table 5.17 Status of assessment areas reported at the EU level for MSFD Criterion 5.2 on 'Direct Effects of Enrichment' with the greatest proportion (i.e. 'the most frequent classification') highlighted in yellow for each marine region

Region	Percentage area of each region assigned to each quality classification (%)			Overall Outcome
	Good	Not Good	Insufficient Information	
Baltic Sea	0.0	52.3	47.7	Fail
Black Sea	0.0	0.0	100	Insufficient information
Mediterranean Sea	34.6	0.0	65.4	Insufficient information
NE Atlantic Ocean	13.1	3.0	83.8	Insufficient information
EU overview	19.0	5.9	75.1	

Notes:

- 'Insufficient information' includes 'Other', 'Unknown' and 'Not reported/assessed'
- Taken from Table AIII.19 in Annex II
- Original information from ETC/ICM (2014b)

Example 3 Manipulating the quality classifications of the information from the relevant EU (and other) legislation/policy to assess the metric(s): Aggregating the quality classifications of the information provided <u>within</u> one piece of EU (and other) legislation/policy

There may be several 'degrees' of quality classification within a piece of legislation/policy, e.g. in the OSPAR eutrophication status assessment, which is divided into 'many problems', 'some problems' and 'no problems'. In cases such as this, the overall area which has 'passed' or 'failed' meeting the respective policy objective can be derived in order to arrive at the most frequent quality classification. For example, the different OSPAR regions showed various degrees of impact due to eutrophication (Table 5.18). If these categories of impact are divided into 'pass' or 'fail' following the approach in Table 5.12, the total area which has passed or failed can be determined (Table 5.19), with the result in this case being a 'pass' as this is the most frequent classification.

Table 5.18 Reported status of eutrophication in each of the OSPAR regions (OSPAR 2010)

Region		Eutrophication status (by 2010)	Change in status	Marine surface area (km²)	% Region
I	**Arctic Waters**	No problems	No trend	5,491,483.54	41
II	**Greater North Sea**	Many Problems	No trend (*)	766,884.8	6
III	**Celtic seas**	Some problems	No trend (*)	366,358.21	3
IV	**Bay of Biscay and Iberian Coast**	Some problems	No trend (*)	533,432.69	4
V	**Wider Atlantic**	No problems	No trend	6,316,602.85	47
	TOTAL			13,474,762	

Notes:

- (*) 2001–2006 compared to 1990–2000
- Taken from Table AIII.36 in Annex III

Table 5.19 Total proportion of OSPAR areas passing (i.e. having 'no problems', green) or failing policy objectives ('many' and 'some problems', red) (OSPAR, 2010)

Eutrophication status (by 2010)	Change in status	% Region
No problems	No trend	88
Many Problems	No trend	6
Some problems	No trend	7
Total Pass		**88**
Total Fail		**13**

Notes: Taken from Table AIII.38 in Annex III

Example 4 Using information on trends in marine ecosystem pressure or impact from relevant EU (and other) legislation/policy to determine the 'direction of change' in the state of the metrics

In simple, one-to-one (ecosystem) state-service (generation) relationships, the set of properties used to determine the state of the ecosystem may be only metrics reflecting purely the state of the critical ecosystem component (e.g. abundance of the populations of certain whale species). However, in some cases, the metrics being assessed can directly relate to a pressure or an impact (e.g. nutrient concentrations and levels of dissolved oxygen, the latter included in the assessment of eutrophication impacts on benthos) are also used in characterising the ecosystem state and changes in state, which is all that is described at this point in the assessment.

In this assessment method, the information on trends in marine ecosystem state (used to assess the 'direction of change' in the state of the metrics) is almost always[148] presented in relation to their interpretation for the quality of the state of the ecosystem (and hence in their direction 'towards' or 'away' from achieving legislation/policy objectives). Therefore, in the tables used to show the assessment (e.g. see sub-step 3.4), an upwards arrow for the 'direction of change' means an improvement in ecosystem state (quality improving), and a downwards arrow for the 'direction of change' means a 'decrease' (reduction) in ecosystem state (quality deteriorating). However, the direction of the 'direction of change' arrows can be

[148] Exceptions include the use of Table 5.11, see Step 2.2

counter-intuitive where the metrics being assessed directly relate to a pressure or an impact. For example, if the legislation/policy reports a trend in an indicator/assessment product that could be used to assess the 'nutrient concentrations' metric, where the nutrient concentrations are 'increasing', this trend should be interpreted in relation to what it means for the ecosystem state (or policy objectives) in the assessment of this metric here. Thus, 'increasing' nutrient concentrations represent a 'decrease' in ecosystem state, i.e. a reduction or deterioration of its quality ('away' from legislation/policy objectives) and this is therefore, represented by a 'decreasing' (downward) arrow (↓). This follows the MSFD model, where trends for the descriptors/criteria on 'good environmental status' are trends in status, i.e. whether a marine region is moving away from (decreasing trend, i.e. deteriorating) or towards (increasing trend, i.e. improving) achieving 'good' status, and do not represent the actual trend in the indicators underpinning the criterion in question (see ETC/ICM, 2014a, 2014b).

Step 3.2 (above) and Step 3.3 require a number of decisions to be made about the information to use, hence an assessment of confidence is required, taking into account different factors that may affect the outcome of the service supply capacity assessment. See Annex V for more detail in the confidence assessment linked to these steps, including guidelines to assign the confidence in the different information sources used in the assessment.

Step 3.4 Aggregate the quality classifications for the ecosystem state and trend information across all pieces of EU (and other) legislation and policy used to assess each metric(s), and determine the overall current state and direction of change in the state of the critical ecosystem component(s) and other parts of the ecosystem where relevant

Step 1	**Identify the critical ecosystem components for service supply capacity**
Step 2	**Establish the relationship between the critical ecosystem component(s) and the service class or type, and identify metric(s) describing this relationship**
Step 3	**Assess the current state and direction of change in the state of the critical ecosystem component(s) and other parts of the ecosystem where relevant**
3.1	Identify EU (and other) legislation and policy generating ecosystem state and trend information to assess the metric(s) of the critical ecosystem component(s) and other parts of the ecosystem, where relevant, identified in Step 2
3.2	Synthesise the ecosystem state and trend information from the different pieces of EU (and other) legislation and policy used to assess the metric(s)
3.3	Establish the quality classifications for the ecosystem state ('pass'/'fail') and trend ('increasing'/'decreasing'/'stable') information from each piece of EU (and other) legislation/policy used to assess each metric(s)
3.4	Aggregate the quality classifications for the ecosystem state and trend information across all pieces of EU (and other) legislation and policy used to assess each metric(s), and determine the overall current state and direction of change in the state of the critical ecosystem component(s) and other parts of the ecosystem where relevant

In Step 3.1, once the information reported under one piece of EU environmental legislation and other EU (and other) legislation and policy is deemed useful to assess a given metric (characterising the (ecosystem) state – service (generation) relationship, such as the critical ecosystem components), it can be included in the assessment and is considered to be of equal importance to information from other pieces of EU and other legislation/policy; that is to say: the information from different sources is not weighted or prioritised amongst them. In this step, we aggregate all of the information from different sources to come out with one overall assessment for each metric relevant for consideration of the (ecosystem) state – service (generation) relationship. In some cases, depending on what has been deemed appropriate, this may result in several sources of information being used, such as from several EU environmental directives, and these directives may cover different temporal and spatial scales. This is justified in the first instance by only having chosen *relevant* policy information initially in Step 3.1 (i.e. that all information taken forward was deemed useful). The aggregation of information (i.e. all status quality classifications that could be used to assess a metric) across pieces of legislation/policy is justified because the directives may cover different parts of the sea (spatially) and different aspects of ecological integrity (condition). Thus, they can be considered as complementary and can be used together in an assessment of service supply capacity (see introduction to Step 3 and criteria for selection under Step 3.1).

Where information from different pieces of legislation/policy based information is used, it is important to establish whether they are indeed complementary[149]. In addition to the points made above on differences in spatial scope or coverage of different aspects of state/condition, this may also be the case if the same data was used to arrive at the quality classifications, but then this was assessed against different objectives for status, potentially leading to different outcomes.

The different classifications provided by different pieces of legislation/policy are aggregated through this sub-step here to ascertain what would be the overall state, and direction of change in the state, of the (metric(s) used to assess the) relevant critical ecosystem component(s) (and other attributes of marine systems where relevant) and, thus, be able to derive (the state of and direction of change in) the ecosystem capacity for service supply. This is following the above-mentioned assumption that different pieces of legislation/policy are complementary and together cover all relevant spatial areas and aspects of ecological integrity. The aggregation of assessment results **across** different pieces of legislation/policy is done following either of two approaches, 'majority' or 'conservative', as described in the sub-sections below. See Table 5.20 for an example of the overall assessment outcomes resulting from the former aggregation approach.

The 'majority' approach for the aggregation of assessment results ***across*** *different pieces of EU (and other) legislation/policy*

Where there is variation in the classifications, the '**majority'** approach implies taking the majority classification (i.e. where most pieces of legislation/policy agree on the same classification) leading to one status classification of the 'state' of a given metric and a 'trend in the state' (direction of change) of a given metric characterising the (ecosystem) state – service (generation) relationship, such as the critical ecosystem component(s).

[149] Experience from undertaking the test case assessments (Annexes II–IV) showed, however, that it is not always obvious how complementary the different information sources used are. This was particularly complicated to establish for the test case on *Waste nutrient storage and removal* (further discussion is found on this below). When it is clear the one piece of EU policy has used the same data and targets for arriving at the relevant assessment product as another, the resulting classification is counted only once. This means that there should not be 'double-counting' of assessments in cases where there is some overlap between them. For example, assessment products from two pieces of EU policy that partially overlap, IUCN and ACCOBAMS, have been used for the assessment of whale species in the Mediterranean Sea because the latter provides specific, additional information to the former for some species, and this information should not be lost. Nevertheless, it has not always been possible to verify and account for the possible overlap between, or even full duplication of, EU-level assessment products. For this reason, a lower confidence in the assessment would be given in case of a possible overlap compared to when the overlap has been identified and can be managed.

As said, each assessment outcome for the state and trend in state (direction of change) metrics used to assess the critical ecosystem component(s), and other attributes of marine systems where relevant, characterising the ecosystem state – service generation relationship from each piece of legislation/policy is first given separately. The outcomes are presented as 'failing' to achieve the respective, overall policy objectives or 'achieving' policy objectives (with a direction of change 'towards' or 'away' from the policy objective[150], where known) as shown in the tables below. An overall classification for each metric is then given in the final column of each table.

The classifications are coded as in the following legend (see Table 5.20):

	Metric not directly assessed under this legislation/policy
	Fail to meet policy objectives
	Achieve policy objectives
	Unable to assess (insufficient information)
↑	Direction towards achieving policy objectives
↓	Direction away from achieving policy objectives
↔	No change in direction
No arrow	Unable to assess (insufficient information)

*<u>Applying the 'majority' approach for the aggregation of assessment results **across** different pieces of EU (and other) legislation/policy</u>*:

- Where there is variation in the classifications, but a majority in favour of one, take the **most common**

Example (1)

Metric	Legislation/ policy 1	Legislation/ policy 2	Legislation/ policy 3	**Overall Outcome**
Metric 1	↓	↓	↑	↓
Metric 2	↑	↑	↔	↑

In the example above, Metric 1 shows a 'pass' classification for two out three legislation/policy information sources, giving an overall 'pass' classification for state. For the direction of change in state, two out of the three arrows show a 'decrease', thus the overall direction is 'decreasing' (i.e. moving away from the legislation/policy objective).

Metric 2 shows a 'fail' classification for two out three legislation/policy information sources, giving an overall 'fail' classification for state. For the direction of change in state, two out of the three arrows show an 'increase', thus the overall direction is 'increasing' (i.e. moving towards the legislation/policy objective).

[150] As per Example 4 under sub-step 3.3, note that the direction of the arrows representing the 'direction of change' (in state) in relevant tables can be counter-intuitive where the metrics being assessed are metrics that directly relate to a pressure (e.g. nutrient concentrations) or an impact. If the legislation/policy reports a trend in an indicator/assessment product that could be used to assess, e.g., the 'nutrient concentrations' metric, where the nutrient concentrations are 'increasing', this trend should be interpreted in relation to what this means for the ecosystem state (or policy objectives) in the assessment of this metric here. Therefore, an 'increasing' trend in nutrient concentrations represents a 'decrease' in ecosystem state, i.e. a reduction or deterioration of its quality ('away' from legislation/policy objectives) and this is, therefore, represented by a 'decreasing' (downward) arrow (↓). This follows the MSFD model, where trends for the descriptors/criteria on 'good environmental status' are trends in status, and do not represent the actual trend in the indicators underpinning the criterion in question (see ETC/ICM, 2014).

- Where there is ‘insufficient information’

  In some cases, no classification may have been concluded from some of the sources of information used due to individual pieces of legislation/policy not providing enough information to do so. For example, in the earlier case of aggregating **within** one law/policy, if there was greater than 50 % of the region not classified, the overall classification of ‘insufficient information’ would be carried forward (see Step 3.3 Example 2).

  In contrast, in this overall assessment **across** the different pieces of legislation/policy used as information sources there is an exception to the general rule of taking the majority classification. This part of the assessment takes the majority outcome *from those legislation/policy information sources where a (status) classification has been arrived at for the assessment of the relevant metric*, discarding those information sources where the outcome was ‘insufficient information’. The value of using information from several sources is the additional information that each contributes; therefore, it is considered better to use classified information where available. In the extreme case of a single assessment product, then that value is taken to be that for the overall assessment. This recognises that the assessment product, even if it is the only one available, has resulted from a classification process as required by the relevant legislation/policy and is therefore robust.

Example (2)

Metric	Legislation/ policy 1	Legislation/ policy 2	Legislation/ policy 3	**Overall Outcome**
Metric 1			↑	↑
Metric 2	↑			↑

In the example above, for metric 1, the majority state classification would be ‘insufficient information’; however, one source gives a status classification (‘pass’, ‘increasing’). Therefore, this classification is taken forward as the overall outcome.

For metric 2, the majority state classification would be a ‘pass’. For the direction of change in state, the majority would be ‘insufficient information’; however, one source gives a status classification (‘increasing’). Therefore, this status classification is taken forward as the overall outcome for the change in state and the majority state classification (‘pass’) is also taken forward.

- If 50-50 ‘pass’/’fail’ or ‘increasing’/’decreasing’: take the least precautionary classification (i.e. the best outcome for the ecosystem as the other method, ‘conservative’, demonstrates the precautionary approach, i.e. the worst outcome, see Box 1 below)

Example (3)

Metric	Legislation/ policy 1	Legislation/ policy 2	Legislation/ policy 3	Legislation/ policy 4	**Overall Outcome**
Metric 1	↓	↓	↑	↑	↑
Metric 2	↑	↑	↔	↔	↑

In the example above, metric 1 shows two pieces of legislation/policy with a ‘pass’ classification and two with a ‘fail’, and two of these are ‘decreasing’ while the other two are ‘increasing’. The overall outcomes is given as a ‘pass’ state (as this is the least conservative and 50 % of classifications agree on this), and ‘increasing’ (as this is the least conservative and 50 % of classifications agree on this).

For metric 2, 50 % of the classifications show a 'pass' and 50 % show a 'fail'; therefore 'pass' is taken as the overall classification as this is the least conservative outcomes. The direction of change is given as 'increasing', as an increasing change is considered the least conservative out of that and 'stable'.

*<u>The 'conservative' approach for the aggregation of assessment results **across** different pieces of EU (and other) legislation/policy</u>*

Alternatively, a 'conservative' aggregation approach has also been developed. This is because there are currently no status or numerical objectives for a specific state of marine ecosystem services in EU policy, and it is unknown at what point potential future service objectives can be met using the existing EU (and other) legislation/policy information on ecosystem state as done here. Meaning that potential future numerical objectives for the state of marine ecosystem services across the EU may be more or less precautionary in relation to the current objectives for marine ecosystem state. To account for a precautionary approach potentially being taken in future assessments, an additional approach is also presented here which takes the most **conservative** assessment of a metric across the legislation/policy classifications used in its assessment (i.e. a precautionary approach). This assumes that the legislation/policy with the most conservative classification has the highest objectives for the ecosystem state (see Box 5.1). This is in contrast to the majority approach where, in the case of disagreement between the legislation/policy classifications used to assess a metric, the worst classification (most pessimistic) would be ignored if it is not in the majority.

Box 5.1 Applying the 'conservative' approach for the aggregation of assessment results across different pieces of EU (and other) legislation/policy

- Always take the **most conservative** classification i.e. where conservative means the worst potential state of the ecosystem or worst potential change of state of the ecosystem, even if most classifications are a 'pass'/'increasing' trend and only one shows a 'fail' (i.e. a pre-cautionary approach).

Example (1a)

Metric	Law/policy 1	Law/policy 2	Law/policy 3	**Overall Outcome**
Metric 1	↓	↓	↑	↓
Metric 2	↑	↑	↔	↔

In the example above, Metric 1 shows a 'pass' classification for two out three law/policy information sources, but a 'fail' classification for one. Taking the most conservative outcome gives an overall 'fail' classification for state. For the direction of change in state, two out of the three arrows show a decrease and this also the most conservative assessment; thus, the overall direction is 'decreasing' (i.e. moving away from the policy objective).

Metric 2 shows a 'fail' classification for two out three information sources, giving an overall 'fail' classification for state. For the direction of change in state, two out of the three arrows show an 'increase', and one shows 'stable'. The overall direction is 'stable' (i.e. not moving towards or away from the policy objective) because a 'stable' trend is considered more conservative than an 'increasing' trend.

- If there are some known and some 'insufficient information' classifications: The value of using data/information from several sources is the additional information that they contribute. Therefore, it is considered better to use classified information where given, even if other laws/policies have had 'insufficient information' to classify a metric.

Example (2a)

Metric	Law/policy 1	Law/policy 2	Law/policy 3	Law/policy 4	**Overall Outcome**
Metric 1			↑	↑	↑
Metric 2	↑		↔		↔

In the example above, Metric 1 shows one ‘pass’ classification, one ‘fail’ and two ‘insufficient information’ classifications. Taking the most conservative, classified outcome gives an overall ‘fail’ classification for state. For the direction of change in state, two show an increase and two show ‘insufficient information’. Thus, the overall direction is ‘increasing’ (i.e. moving towards the policy objective).

Metric 2 shows a ‘fail’ classification for one, ‘pass’ for one and ‘insufficient information’ for two of the law/policy information sources, giving an overall ‘fail’ classification for state. For the direction of change in state, one shows an ‘increase’ and one shows ‘stable’, while two show ‘insufficient information’. Thus, the overall direction is ‘stable’ (as, of the two classified directions of change, ‘stable’ is the most conservative).

The confidence in this part of the assessment is measured as the level of agreement between different sources of assessment information. It accounts for whether different legislation/policy assessments appear to use different data sources, or if reporting of different policies/laws appears to all be based on the same data sources (where this is known or can be assumed). This assumes that there is an equal degree of confidence associated with all the assessments carried out under all the different pieces of legislation/policy. However, when only one legislation/policy classification appears to be used, the actual confidence in that assessment is taken into account. See Annex V for more detail in the confidence assessment linked to this step.

Table 5.20 Example: Overall assessment outcomes (following the 'majority' aggregation approach) for the metrics of the critical ecosystem component and physico-chemical attributes of the marine ecosystem used to assess the current capacity of the Baltic Sea ecosystem to supply the service *Waste nutrient removal and storage*, including confidence in the assessment

Legend

	Metric not directly assessed under this legislation/policy
	Fail to meet policy objectives
	Achieve policy objectives
	Unable to assess (insufficient information)
↑	Direction towards achieving policy objectives
↓	Direction away from achieving policy objectives
↔	No change in direction
No arrow	Unable to assess (insufficient information)

	EU and Other Law and Policy				Majority Assessment		
	EU level			Regional Level			
Metric	Marine Strategy Framework Directive	Water Framework Directive	EEA Indicators	HELCOM	Overall assessment	Confidence: State	Confidence: Direction
Nitrogen concentration	↑		↔		↑	Moderate	Low
Phosphorus concentration	↑		↔		↑	Moderate	Low
Phytoplankton biomass (Chlorophyll-a)	↓		↔		↔	Moderate	Low
Oxygen						Moderate	
Benthos							

Notes:

- Data/information from:
  - MSFD: Assessments from 2012–2013 (ETC/ICM, 2014a, 2014b), where an arrow pointing up in the cells for nutrient concentrations does not represent the actual trend (i.e. 'increasing') in the indicators underpinning the relevant MSFD GES Descriptor 5 criterion, but an 'increase' in ecosystem state, i.e. an improvement of its quality and so moving towards achieving policy objectives, and vice versa (see full explanation in Example 4 under sub-step 3.3).
  - WFD : Reporting from 2010–2012 (accessed 2014)
  - EEA: Trends 1985–2010 (indicators accessed 2014)
  - HELCOM: Average data from 2007–2011 (from HELCOM, 2014)
- Taken from Table AIII.42 in Annex III

Step 4 Assess the current state of and direction of change in the capacity of the ecosystem to supply the service class or type

Step 1	**Identify the critical ecosystem components for service supply capacity**
Step 2	**Establish the relationship between the critical ecosystem component(s) and the service class or type, and identify metric(s) describing this relationship**
Step 3	**Assess the current state and direction of change in the state of the critical ecosystem component(s) and other parts of the ecosystem where relevant**
Step 4	**Assess the current state of and direction of change in the capacity of the ecosystem to supply the service class or type**

This step takes the outcomes of the assessment of the metrics relating to the current state of the critical ecosystem component(s), and of other attributes of the marine system where relevant, and its direction of change from Step 3 and uses these, along with knowledge of the (ecosystem) state-service (generation) relationship established in Step 2, to determine the current capacity of the ecosystem to supply a service and the direction of change in this capacity.

If the current state of the (metric(s) of a) component (and of other ecosystem attributes where relevant) is failing to achieve the respective, overall policy objectives of the EU (and other) legislation/policy that has informed the state assessment, we assume that the component is in a 'bad' state; and if it is achieving policy objectives, it is in a 'good' state. This is the classification we take forward for this step as, in this approach, we *assume* that the state of the ecosystem component(s) (and of other ecosystem attributes where relevant) translates to an indication of the capacity of the ecosystem to supply a service. The *actual* state of and direction of change in the state of the ecosystem capacity for service supply depends on the type of relationship between the service and the state of the critical ecosystem component(s), including aspects (ecosystem processes and functions) of the capacity of the component(s) to supply the service. This relationship, which has already been worked out as part of Step 2, varies widely depending on the service being assessed and is illustrated for two possible examples below. Expert judgement is required in the interpretation of how the current state and direction of change in the state of the metrics relating to the ecosystem component(s) (and to other ecosystem attributes where relevant) representing this relationship relate to the ecosystem capacity to supply a service, and such judgment is accounted for in the confidence assessment (see Annex V).

Example 1 Where the (ecosystem) state-service (generation) relationship is expected to be ***simple*** *(Step 2), such as for the Recreation and leisure from whale watching service:*

Good state of (the relevant) whale populations corresponds to a good capacity of the ecosystem to supply the *Recreation and leisure from whale watching service*, and an increase in (the state of the relevant) whale populations leads to an increase in this capacity (through increased potential for seeing and enjoying whales while whale watching) (see Annex II)

The simple (ecosystem) state-service (generation) relationship above implies that:

- An overall state assessment of the metric(s) selected to assess the critical ecosystem component(s) concluding the achievement of legislation/policy objectives (i.e. fulfilling a 'good' status), represents a 'good' current state of the component(s). This is then assumed to mean a 'good' current (state of the) capacity of the ecosystem to supply the service. An overall state assessment of the metric(s) selected to assess the critical ecosystem component(s) concluding the failure to achieve legislation/policy objectives (i.e. not fulfilling a 'good' status), represents a 'bad' current state of the component(s). This then is assumed to mean a 'bad' current (state of the) capacity of the ecosystem to supply the service.

- An overall direction of change in the state (trend in the status) of the metric(s) selected to assess the critical ecosystem components towards, or away, from achieving legislation/policy objectives (i.e. fulfilling a ‘good’ status), represents a ‘increasing’, or ‘decreasing’, current state of the component. This is then assumed to mean that the (state of the) current capacity of the ecosystem to supply the service is ‘improving’ (when increasing), or ‘deteriorating’ (when getting worse, decreasing), i.e. reflects the direction of change in the current capacity of the ecosystem to supply the service.

Following with the above example, the service supply capacity assessment is concluded as follows:

- The status of whale species populations, which includes their size and abundance, is reported per individual species in the relevant legislation/policy (see Table 5.13). It was established in Step 2 of this assessment method that all the whale species considered (i.e. those relevant for whale watching in EU marine regions) would be given an equal weighting. Therefore, if most species achieved a ‘pass’ (i.e. fulfilling a ‘good’ status), this would indicate ‘good’ current capacity for the supply of the service; and if most species showed an ‘increase’ state trend in their populations, this would indicate that the current capacity for the supply of the service is ‘increasing’, regardless of which species are responsible for most of the classifications[151].
- In order to determine the final outcomes for the assessment of the ecosystem capacity to supply the *Recreation and leisure from whale watching* service, where the metric is the population size and abundance for individual species (relevant for whale watching in EU marine regions), we take ‘the most frequent classification’ for the state and direction of change in the state of the metric across species (based on the percentage of species). However, when there is **more than 50 %** ‘insufficient information’, the overall classification is given as ‘Insufficient information’.
- For example, in the North East Atlantic (NEA), the state of 56 % of relevant whale species were classified as a ‘pass’ and, thus, the most frequent classification is a ‘pass’ for the current state of whale populations (Table 5.21). However, 78 % of species were found to have ‘insufficient information’ (status unknown) when assessing the direction of change in their state (although of those with classifications, 22 % were found to be ‘increasing’).

[151] If not all species had been considered equal, or in other cases where several critical ecosystem components may be have been included in the assessment, the overall outcome here may be determined by weighting the frequency of classifications according to the relative contribution to service supply capacity on those species, or ecosystem components; thus assigning more importance to the classification of those species/components that contribute more. See also Section 7.

Table 5.21 Example: Summary of the assessment results and confidence classifications for the metrics relating to the current state and direction of change in the state of the critical ecosystem components relevant to assess the North East Atlantic Ocean's ecosystem capacity to supply the *Recreation and leisure from whale watching* service

Assessment	Metric	Classification (and input information)	% whale species assigned	Confidence (No. of whale species)		
				High	Moderate	Low
State	Population size and abundance of relevant whale species populations	Good (State)	56	4	0	8
		Bad (State)	17	0	0	4
		Unknown (State)	28			
Direction of change	Population size and abundance of relevant whale species populations	Increasing (Trend)	22	0	0	4
		Stable (Trend)	0			
		Decreasing (Trend)	0			
		Unknown (Trend)	78			

Notes:

- Assessment outcomes determined using the 'majority' aggregation approach
- Taken from Table AII.19 in Annex II – see information sources there

Thus, the overall assessment of the capacity of the NEA ecosystem to supply the *Recreation and leisure from whale watching service* (following the 'majority' aggregation approach) was a 'good' state, i.e. a 'good' current capacity for the supply of the service; while the trend (direction of change) in this capacity cannot be assessed (Table 5.22).

Table 5.22 Example: Summary of the current (state of the) capacity and the direction of change in the capacity of the North East Atlantic Ocean's ecosystem to supply the *Recreation and leisure from whale watching* service

Ecosystem service	Critical ecosystem component(s)	Current capacity for service supply	Confidence in the assessment
Recreation and leisure from whale watching	Whale species relevant for whale watching	(Unable to assess direction of change)	Step / Confidence: Step 1: low (red) Step 2: high (green) Step 3: low (red) Step 4: moderate (yellow)

Notes:

- Assessment outcomes determined using the 'majority' aggregation approach
- The colour in the cells refers to the current state of service supply capacity (green='good', pink='bad', no colour='unable to assess').
- The bracketed words in the cells refer to the direction of change in the current state of service supply capacity ('improving', 'deteriorating' or 'stable').
- Confidence is shown for each step of the assessment, where red = low, yellow = moderate, and green = high confidence. The full confidence assessment is described in Annexes II and V.
- Taken from Table AII.23 in Annex II – see information sources there

*Example 2 Where the (ecosystem) state-service (generation) relationship is **complex**, such as for the Waste nutrient removal and storage service, different outcomes for the assessment of the ecosystem capacity to supply a service are possible, and these will have been identified during Step 2*:

Available potential for phytoplankton to sequester nutrients and no impact on the benthos from eutrophication corresponds to a good capacity of the ecosystem to supply the *Nutrient waste removal and storage* service. Limited potential for phytoplankton to sequester nutrients and impact on the benthos from eutrophication corresponds to a bad capacity of the ecosystem to supply the service. The direction of change in this capacity depends on the trends in the state of phytoplankton concentrations, nutrient concentrations and impacts on the benthos, which are the metrics selected to characterise the (ecosystem) state-service (generation) relationship and assess the ecosystem capacity to supply the service (see Annex III).

There were multiple potential outcomes for the assessment of the ecosystem capacity to supply the service depending on the state and state trends of the three metric types (i.e. phytoplankton concentrations, nutrient concentrations and impacts on the benthos). The (classifications for the) state of each of these metrics needed to be considered together (see Table AIII.5 in Annex III) and the same with the trend in their state (see Table 5.11 above Table 5.24 below for a specific example for the Baltic Sea) to arrive at a conclusion on the state of and direction of change in the current capacity of the ecosystem to supply the service, respectively (Table 5.23 and Table 5.25). Doing this required expert judgement to interpret the meaning of the metrics' state and state trends towards service supply capacity as follows:

- The state of the impacts on the benthos in the Baltic Sea was found to be 'bad' (along with the state of the nutrients and phytoplankton concentrations); thus, the ecosystem capacity for service supply was found to be 'bad' because there were eutrophic effects on the wider ecosystem (Table 5.23 and Table 5.25).
- The concentrations of nutrients in the Baltic Sea were found to be 'decreasing', and phytoplankton concentrations were found to be 'stable', but there was 'insufficient information' to assess the trend of impacts on the benthos (Table 5.23). The overall direction of change in the ecosystem capacity to supply the service could not be assessed because there could be different potential outcomes depending on what the (unknown) impact on the benthos was (Table 5.24).

Table 5.23 Example: Summary of the assessment results for the current (state of the) capacity and direction of change in the capacity of the Baltic Sea ecosystem to supply the *Waste nutrient removal and storage* service

Assessment	Metric	Classification (and input information)	Current capacity for service supply
State	Nutrient (Nitrogen and Phosphorus) concentrations	Bad (State)	Bad State, Unable to assess direction of change
	Phytoplankton biomass	Bad (State)	
	Impact on Benthos	Bad (State)	
Direction of change	Nutrient (Nitrogen and Phosphorus) concentrations	Decreasing (Trend)[152]	
	Phytoplankton biomass	Stable (Trend)[153]	
	Impact on Benthos	Insufficient information (Trend)	

Notes:

- Assessment outcomes determined using the 'majority' aggregation approach
- The current state of and direction of change in service supply capacity are based on the metrics relating to the state of phytoplankton, nutrients and benthos in the Baltic Sea assessed in Step 3 and the state- service relationship described in Step 2 (and in Table 5.24 below)
- Taken from Table AIII.46 in Annex III – see information sources there

The actual trend in the state of the metrics assessed is needed in order to follow the (ecosystem) state-service (generation) relationship and determine the direction of change in the ecosystem capacity to supply the service when a suite of metrics is used, and this trend is what is used in relevant tables (i.e. Tables 5.11 and 5.24). To note, therefore, that this is different from representing the state trends in terms of the direction of change of the metrics 'towards' or 'away' from achieving policy objectives for ecosystem state/quality, i.e. as trends in status, as done in Step 3 (which, as noted there, could have been counter intuitive when the metrics of state are directly related to a pressure or an impact). Table 5.23 shows, e.g., that nutrient concentrations are actually 'decreasing', and this is from knowing that nutrient concentrations showed an 'increasing' trend towards the MSFD 'good environmental status' in Step 3 (Table 5.20).

[152] The 'majority' aggregation approach, as applied in Table 5.20, reflects the result from the 2012 MSFD reporting, which found an improvement in ecosystem state in terms of nutrient concentrations (i.e. nutrient concentrations were 'decreasing'), but this conclusion was only reached by a relatively small margin. If the 'conservative' aggregation approach was used instead, the result would be a 'stable' trend (see Annex III).

[153] The 'majority' aggregation approach, as applied in Table 5.20, reflects the result from the EEA indicator, which reported phytoplankton concentrations were 'stable'. If the 'conservative aggregation' approach was used instead, the result would be a 'decreasing' trend (see Annex III).

Table 5.24 A few scenarios for the change in the direction of the ecosystem capacity to supply the *Waste nutrient removal and storage* service based on the (ecosystem) state-service (generation) relationship, including 'stable' trends for the metrics used

A	Increasing	Decreasing	Stable	Service Capacity
Phytoplankton concentration				**Unable to assess change in direction**
Nutrient concentration				
Impact on benthos				
B	Increasing	Decreasing	Stable	Service Capacity
Phytoplankton concentration				**Deteriorating**
Nutrient concentration				
Impact on benthos				
C	Increasing	Decreasing	Stable	Service Capacity
Phytoplankton concentration				**Improving**
Nutrient concentration				
Impact on benthos				
D	Increasing	Decreasing	Stable	Service Capacity
Phytoplankton concentration				**Stable or Improving**
Nutrient concentration				
Impact on benthos				

Notes:

- The actual trend, rather than the direction of change, in the state of the metrics is needed to fuel this table, and this is estimated using the relevant (ecosystem) state trend information directly (see also Table 5.11)
- Scenario A shows the results from this assessment in the Baltic Sea (see above) where the 'impacts on benthos' were 'unknown' (see Table 5.23). Scenarios B, C and D show the different potential outcomes for such a change in direction based on different scenarios for this 'unknown' metric.

Table 5.25 Example: Summary of the current (state of the) capacity and the direction of change in the capacity of the Baltic Sea ecosystem to supply the *Waste nutrient removal and storage* service

Ecosystem Service	Critical ecosystem component(s)	Current capacity for service supply	Confidence in the assessment
Waste nutrient removal and storage	Phytoplankton in all pelagic habitats	(Unable to assess direction of change)	Step / Confidence Step 1 Step 2 Step 3 Step 4

Notes:

- Assessment outcomes determined using the 'majority' aggregation approach
- The colour in the cells refers to the current state of service supply capacity (green = 'good', pink = 'bad', no colour = 'unable to assess').
- The bracketed words in the cells refer to the direction of change in the current state of service supply capacity ('improving', 'deteriorating' or 'stable')
- Confidence is shown for each step of the assessment where red = low, yellow = moderate, and green = high confidence. The full confidence assessment is described in Annexes III and V
- Taken from Table AIII.49.b in Annex III – see information sources there

Step 5 Assess the future state and direction of change in the state of the critical ecosystem component(s), and other parts of the ecosystem where relevant, and use that to determine the future state of and direction of change in the capacity of the ecosystem to supply the service class or type

Step 1	**Identify the critical ecosystem components for service supply capacity**
Step 2	**Establish the relationship between the critical ecosystem component(s) and the service class or type, and identify metric(s) describing this relationship**
Step 3	**Assess the current state and direction of change in the state of the critical ecosystem component(s) and other parts of the ecosystem where relevant**
Step 4	**Assess the current state of and direction of change in the capacity of the ecosystem to supply the service class or type**
Step 5	**Assess the future state and direction of change in the state of the critical ecosystem component(s), and other parts of the ecosystem where relevant, and use that to determine the future state of and direction of change in the capacity of the ecosystem to supply the service class or type**

The current state of and direction of change in the capacity of marine ecosystems to supply services can give us insight into the situation we are in presently and where we could be moving towards[154]. However, to fully consider whether this capacity can be sustained in view of the pressures/impacts on the marine ecosystem and the direct exploitation of marine ecosystem services (i.e., whether marine ecosystem capital is maintained because marine (and other) natural capital is used sustainably, see Section 1), we also need to consider the longer-term outlook. There are many predictions about how the marine environment is changing and how anthropogenic climate change is affecting and will affect marine ecosystems in the future. These types of forecasts should be useful for application in the MECSA method and allow an assessment of the future marine ecosystem capacity for service supply and its direction of change.

A change in the current state of the ecosystem may change its capacity to supply services in the future. Existing outlooks on future ecosystem state could be used to forecast its potential future capacity for service supply. If these outlooks are not available, information on current ecosystem state, together with current state trends, and on future trends in ecosystem state, or on current and future trends in critical pressures on service supply capacity, can be identified and used – together with knowledge of the (ecosystem) state-service (generation) relationship (Step 2) – to forecast the future capacity of the ecosystem to supply a service (see Figures 5.2 and 5.7).

Thus, when considering only the future trend in the state of the metrics (based on information on future trends in ecosystem state) and knowing the current state of and direction of change in service supply capacity from Steps 1–4 above, this alternative approach allows the potential future direction of change in this capacity to be established, i.e. whether service supply capacity will be 'improving', 'deteriorating' or 'stable' in the future, and – at times- also the future state of this capacity following the scenarios in Table 5.26. The potential future direction of change in service supply capacity can be based on existing outlooks for the future trend in ecosystem state directly (which need to be used as such to run Table 5.26 instead of being turned into the 'direction of change' of ecosystem state as per other steps). In the absence of such outlooks, the future trend in ecosystem state (and, thus, the future direction of change in service supply capacity) can be inferred from current or forecasted trends in critical pressures on service supply capacity, which would be those pressures on the critical ecosystem

[154] Note that here we consider that current (and future) state of the ecosystem is not a static state but is changing over a time period based on the direction of change in its current state, and depending on the magnitude of the change, could change to a different current state classification within the time period still considered current. We, thus, consider a transitional period between current state and future state, where the (observed) trend in current state still applies before the future (forecasted) trend does.

component(s). If a current or forecasted trend in a critical pressure(s) is used as a proxy for the future trend in ecosystem state, it is assumed that the pressure-state relationship is understood, i.e. that it is known that change in a given pressure will affect the state of an ecosystem component, causing it to 'increase' or 'decrease' in status. If the current trend in a critical pressure is used, it is also assumed that the pressure will continue in the same direction in the future.

Unless an outlook on the future state of (the metrics of) the critical ecosystem component(s), and other parts of the ecosystem where relevant, is available (for direct use), such as from the Habitats Directive, the future state of service supply capacity can only be forecasted in specific scenarios (indirectly) when having to follow the alternative method above (see Table 5.26). For example, if the current state of service supply capacity is 'good' and 'stable', and the future direction of change in this capacity is 'increasing', the future state must be' good' (see Table 5.26 for example scenarios). However, if the current state of service supply capacity is 'good' and 'stable', and the future direction of change in this capacity is 'decreasing', we do not know how much the current state will decrease in the future and whether this would cause a change in its quality, and, thus, cannot forecast the future state. Additional information to that used already in the assessment, e.g. contextual information from thematic assessments carried out by the relevant regional sea convention, and expert judgment could help determine whether such threshold has been overcome in the specific case of scenarios where the future direction of change in (current) service supply capacity is 'stable'. However, this depends on the information available.

Depending on the information available, Step 5 may be a relatively straightforward assessment based on existing outlooks for the future state and state trends of the ecosystem, which are then used to assess the metric(s) identified in Steps 2 following a similar process to steps 3 and 4. However, Step 5 can also involve a number of sub-steps requiring the identification of the critical pressures on the critical ecosystem component(s), current or future trends in these pressures and, finally, a prediction of how all this may affect the ecosystem capacity to supply services in the future (see Table 5.27).

There are three alternative methods to assess potential future changes in marine ecosystem capacity for service supply:

A. In the absence of outlooks on future ecosystem state, base future changes in service supply capacity[155] on the future trend in the state of the metric(s) identified in Step 2 and assess that using outlooks on future trends in ecosystem state.
B. In the absence of outlooks on future trends in ecosystem state and if critical pressure(s) on the critical ecosystem component(s) are known, when basing future changes in service supply capacity[156] on the future trend in the state of the metric(s) identified in Step 2, assess that using future trend(s) in the critical pressure(s). In this alternative, future trend(s) in critical pressure(s) (which are outlooks on future trend(s) or current trend(s) which are assumed to continue into the future) are used as a proxy for the future trend in ecosystem state.
C. In the absence of outlooks on future trends in ecosystem state and if critical pressure(s) on the critical ecosystem component(s) are not known, identify these and, when basing future changes in service supply capacity[157] on the future trend in the state of the metric(s) identified in Step 2, assess that using future trend(s) in the critical pressure(s). In this alternative, future trend(s) in critical pressure(s) (which are outlooks on future trend(s) or current trend(s) which are assumed to continue into the future) are, again, used as a proxy for the future trend in ecosystem state, but as these critical pressure(s) trend(s) have not already been identified, this identification must be undertaken first.

[155] This refers to the future direction of change in the capacity and, if possible, the future state of the capacity of the ecosystem to supply the service
[156] This refers to the future direction of change in the capacity and, if possible, the future state of the capacity of the ecosystem to supply the service
[157] This refers to the future direction of change in the capacity and, if possible, the future state of the capacity of the ecosystem to supply the service

Table 5.26 Potential outcomes for the future state of marine ecosystem capacity for service supply when the current state of and the direction of change in this capacity are known and the future trend in the state of the (metrics of the) critical ecosystem component(s), and other parts of the ecosystem where relevant, which determines the future direction change in service supply capacity, is also known

Legend:

	Unable to assess		Bad State		Good State

Scenario	State of and direction change in service supply capacity	Future trend in state of metric	Future direction of change in service supply capacity	Future state of service supply capacity		Scenario	State of and direction change in service supply capacity	Future trend in state of metric	Future direction of change in service supply capacity	Future state of service supply capacity
A	Deteriorating	Stable	Stable			J	Deteriorating	Stable	Stable	
B	Deteriorating	Increasing	Improving			K	Deteriorating	Increasing	Improving	
C	Deteriorating	Decreasing	Deteriorating			L	Deteriorating	Decreasing	Deteriorating	
D	Stable	Stable	Stable			M	Stable	Stable	Stable	
E	Stable	Increasing	Improving			N	Stable	Increasing	Improving	
F	Stable	Decreasing	Deteriorating			O	Stable	Decreasing	Deteriorating	
G	Improving	Stable	Stable			P	Increasing	Stable	Stable	
H	Improving	Increasing	Improving			Q	Increasing	Increasing	Improving	
I	Improving	Decreasing	Deteriorating			R	Increasing	Decreasing	Deteriorating	

Notes: The actual future trend in the state of the metric (or metrics) identified in Step 2 is used to determine the future direction of change in service supply capacity according to the understanding of the (ecosystem) state service (generation) relationship (this example shows a simple relationship; in the case of a complex relationship involving several metrics, using Table 5.11 in Step 4 would have already provided the classification to use in the 'future direction of change in service supply capacity' column). The (classifications for) current (state of) service supply capacity and the direction of change in this capacity are used together with the (classification for the) future direction of change in service supply capacity to determine the (classification for the) future state of service supply capacity. In many cases, the future state of service supply capacity cannot be assessed, as it is not known by how much the state of the metric(s) will change with future state trends.

Table 5.27. Method options and sub-steps involved in assessing the future changes[158] in marine ecosystem capacity for service supply

Step 5	Assess the future state and direction of change in the state of the critical ecosystem component(s), and other parts of the ecosystem where relevant, and use that to determine the future state of and direction of change in the capacity of the ecosystem to supply the service class or type
5.A	In the absence of outlooks on future ecosystem state, base future changes in service supply capacity on the future trend in the state of the metric(s) identified in Step 2 and assess that using outlooks on future trends in ecosystem state.
5.B	In the absence of outlooks on future trends in ecosystem state and if critical pressure(s) on the critical ecosystem component(s) are known, when basing future changes in service supply capacity on the future trend in the state of the metric(s) identified in Step 2, assess that using future trend(s) in the critical pressure(s).
5.C	In the absence of outlooks on future trends in ecosystem state and if critical pressure(s) on the critical ecosystem component(s) are not known, identify these and, when basing future changes in service supply capacity on the future trend in the state of the metric(s) identified in Step 2, assess that using future trend(s) in the critical pressure(s).
5.C.1	Identify the critical pressure(s) on the critical ecosystem component(s)
5.C.2	Identify EU (and other) legislation/policy generating information on trends in critical pressures on the critical ecosystem component(s)
5.C.3	Synthesise the information on the critical pressure(s) on the critical ecosystem component(s) from different pieces of EU (and other) legislation/policy
5.C.4	Report the trend (future or current assumed to continue in the future) for each critical pressure from each piece of EU (and other) legislation/policy
5.C.5	Carry out an overall assessment of the future trend in the critical pressure(s) and determine the outlook (future trend in the state) for the critical ecosystem component(s)
5.C.6	Determine the future direction of change in the capacity of the ecosystem to supply the service class or type and, if possible, the future state of this capacity

The future state of the capacity of the ecosystem to supply a service could be assessed if the future state of the metrics of the critical ecosystem component(s) (and other parts of the ecosystem where relevant) is known in the same way as when current state was known (Step 4). We cannot include an illustration of this situation here because relevant information was not available at the EU-level when the MECSA method was developed. However, the Habitats Directive is an example of an EU policy information source that should provide outlooks forecasting the future state of certain marine species[159] and habitats.

[158] This refers to the future direction of change in the capacity and, if possible, the future state of the capacity of the ecosystem to supply the service

[159] Our test case assessment on the ecosystem capacity to supply the *Recreation and leisure from whale watching* service did not include an example of the assessment of the future state of (relevant) whale populations using information from the Habitats Directive due to the number of 'unknown' classifications provided for the relevant species. Thus, we showed alternative approaches to assess future state, including using aggregated MSFD information on the 'marine mammals' group. However, the Habitats Directive could be a potential source of relevant information for other services in this part of the assessment, or for this service where the future state of relevant species has been classified.

Step 5.A In the absence of outlook information on future ecosystem state, base future changes in service supply capacity[160] on the future trend in the state of the metric(s) identified in Step 2 and assess that using future state trend outlook information.

Step 5	Assess the future state and direction of change in the state of the critical ecosystem component(s), and other parts of the ecosystem where relevant, and use that to determine the future state of and direction of change in the capacity of the ecosystem to supply the service class or type
5.A	In the absence of outlooks on future ecosystem state, base future changes in service supply capacity on the future trend in the state of the metric(s) identified in Step 2 and assess that using outlooks on future trends in ecosystem state.

In some cases, the EU-level reporting linked to the implementation of EU environmental legislation (e.g. the MSFD), or other EU legislation and policy, will provide outlooks on future trends in the state of the critical component(s) for the ecosystem capacity for the supply the service being assessed. These outlooks can be used to assess future changes to service supply capacity. For example, in the case of the *Recreation and leisure from whale watching* service, the reporting on marine mammals under the MSFD 'Biodiversity' descriptor (no. 1) includes the future trend in the state of marine mammal populations in the Mediterranean Sea (Table 5.28). As with assessing the current state of the critical ecosystem component(s), the most direct information to assess the metrics should be used where available (see Table 5.14). However, the use of such MSFD marine mammal information in the assessment of the *Recreation and leisure from whale watching* service would represent a 'second alternative' source of information, since this marine mammal information includes seals (as well as whale and dolphin species), which are not relevant for whale watching.

'The most frequent classification' is taken as the overall classification for the future trend in the marine mammal populations of the Mediterranean Sea, with an 'insufficient information' given if more than 50 % of the trends are 'unknown' (e.g. for marine mammal distribution, population size and population condition in Table 5.28). If two classifications are equally assigned, we take the most conservative classification (e.g., 35 % of the area is assigned 'Good' and 35 % assigned 'Not Good, we take a precautionary approach as take the overall classification as 'Not Good').

Table 5.28 Marine mammals: Tabular summary of the future trends in the state of Marine mammal populations in the Mediterranean Sea from the reporting on MSFD Descriptor 1 (from ETC/ICM, 2014a), with 'the most frequent classification' highlighted in yellow

Regional Sea	Marine Mammal Population Criterion	Percentage of marine mammal population criteria assigned to each trend classification (%)				
		Increasing	Stable	Decreasing	Unknown	Number of reported features
Mediterranean Sea	Distribution	0	24	0	76	41
	Population Size	0	22	0	78	41
	Population Condition	0	24	0	76	41
	Species Composition	0	50	0	50	12
	Abundance / Biomass	0	50	0	50	12

Notes: Taken from Table AII.27 in Annex II

[160] This refers to the future direction of change in the capacity and, if possible, the future state of the capacity of the ecosystem to supply the service

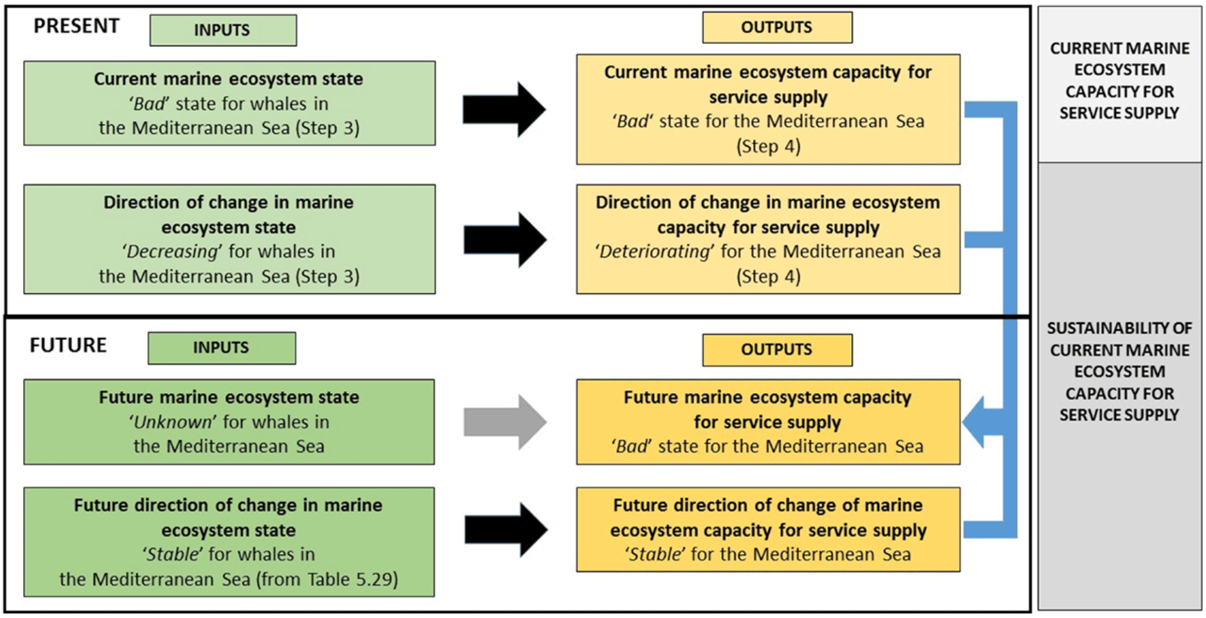
As with assessing the current capacity for service supply (Step 4), the assessment of the future trend in the state of the metrics of the critical ecosystem component(s), and other parts of the ecosystem where relevant, is used together with understanding of the (ecosystem) state-service (generation) relationship (Table 5.26) to interpret what this future state trend means for the future capacity of the ecosystem to supply a service. In the case of the *Recreation and leisure from whale watching* service, the (ecosystem) state-service (generation) relationship is expected to be simple as identified in Step 2:

an increase in (the state of the relevant) whale populations leading to an increase in the potential for seeing and enjoying whales while whale watching, i.e. in service supply capacity

In the example of the Mediterranean Sea above, two of the indicators ('Species composition' and 'Abundance/biomass') both show a *future* 'stable' state trend. This is, thus, taken to indicate that the *future* trend in the (state of the) capacity of the Mediterranean Sea ecosystem to supply the *Recreation and leisure from whale watching* service is 'stable' (see also Table 5.26).

Then even where an outlook for the future state of the critical ecosystem component(s) is not available, in some cases, but not all, a forecast of the *future* (state of the) ecosystem capacity for service supply can also be made using the other input information outlined in Figure 5.2 (while normally the future marine ecosystem state would be used to infer the future (state of) marine ecosystem capacity for service supply, if this is not available, a different approach can be used). This is the current (state of) service supply capacity and its direction of change, together with the future direction of change in service supply capacity, which is based on the future trend in the state of (the metrics of) the critical ecosystem component(s) and other parts of the ecosystem where relevant (see blue arrow in Figure 5.7). For example, the current (state of the) capacity of the Mediterranean Sea to supply the *Recreation and leisure from whale watching* service was found to be 'bad', and the direction of change in that capacity was 'deteriorating' (Table 5.29 and Figure 5.7). This means that the current (state of the) capacity is getting worse, so it cannot improve from 'bad'. Then, since the *future* trend in the state of the whales relevant for whale watching and, thus, the future direction of change in service supply capacity is 'stable', as per the assessment above (Table 5.28), this would indicate that the future (state of) service supply capacity cannot be 'good'. Thus, the future state of the capacity of the Mediterranean Sea ecosystem to deliver the *Recreation and leisure from whale watching* service is a 'bad' and its direction of change is 'stable' (see scenario A in Table 5.26 and also Table 5.29).

Figure 5.7: Adaptation of Figure 5.2 illustrating how to assess the future state of the Mediterranean Sea ecosystem capacity to supply the *Recreation and leisure from whale watching* service in the absence of outlooks on the future state of the whales that are relevant for whale watching there



Notes: The figure, based on Figure 5.2, shows how the assessment of the Mediterranean Sea ecosystem current capacity to supply the *Recreation and leisure from whale watching* service and its direction of change as well as the future trend in the state of the whales that are relevant for whale watching there, leading to determining the future direction of change in the ecosystem capacity to supply this service, have been used to assess the future state of this capacity. In this case, the future marine ecosystem state is 'unknown', thus the black arrow has been greyed out, and the approach taken here follows the blue arrow. These three outputs – the current state of service supply capacity ('bad'), the direction of change in current service supply capacity ('deteriorating') and the future direction of change in service supply capacity (based on the relevant whale's future state trend = 'stable') – are then run through the scenarios based on the (ecosystem) state-service (generation) relationship in Table 5.26 to infer the likely future (state of) marine ecosystem capacity for service supply ('bad') (Table 5.29).

Confidence in the assessment should consider the information sources used and the interpretation of the outlook future state of the critical ecosystem components into what this means for the service supply capacity. See Annex V for full details on the confidence assessment.

Table 5.29 Example: Summary of the current and future (state of the) capacity as well as the direction of change in the capacity of the Mediterranean Sea ecosystem to supply the Recreation and leisure from whale watching service

Ecosystem Service	Critical ecosystem component(s)	Current capacity for service supply	Future capacity for service supply	Confidence in the assessment
Recreation and leisure from whale watching	Whales relevant for whale Watching	(Deteriorating)	(Stable)	Step / Confidence: Step 5.A (i) – red; Step 5.A (ii) – red

Notes:

- Assessment outcomes determined using the 'majority' aggregation approach
- The future capacity for service supply is based on aggregated outlook future trends in the state of marine mammal population reported for the MSFD in 2012 and not on specific whale species. The assessment was also carried out using future pressure trends as a proxy to assess future trends in the state of the specific whale species (see Step 5.C).
- The colour in the cells refers to the current and future state of service supply capacity (green = 'good', pink = 'bad', no colour = 'unable to assess').
- The bracketed words in the cells refer to the current and future direction of change in the state of service supply capacity ('improving', 'deteriorating' or 'stable')
- Confidence is shown for each step of the future assessment, where red = low, yellow = moderate, and green = high confidence. The full confidence assessment is described in Annexes II and V
- Taken from Table AII.27bis in Annex II – see information sources there

Step 5.B In the absence of outlook information on future trends in ecosystem state and if critical pressure(s) on the critical ecosystem component(s) are known, when basing future changes in service supply capacity[161] on the future trend in the state of the metric(s) identified in Step 2, assess that using information on future trend(s) in critical pressure(s)

Step 5	**Assess the future state and direction of change in the state of the critical ecosystem component(s), and other parts of the ecosystem where relevant, and use that to determine the future state of and direction of change in the capacity of the ecosystem to supply the service class or type**
5.B	In the absence outlooks on future trends in ecosystem state and if critical pressure(s) on the critical ecosystem component(s) are known, when basing future changes in service supply capacity on the future trend in the state of the metric(s) identified in Step 2, assess that using future trend(s) in the critical pressure(s).

If no outlook for the future trends in the state of the metrics of the critical ecosystem component(s), and other parts of the ecosystems where relevant, is available, pressure trend information can be used as a proxy to infer such a change. For some services, the critical pressure(s) on service supply capacity, which would be those on the critical ecosystem component(s), would have already been identified as part of the assessment of the current (state of) service supply capacity (steps 1–4). For example, for the *Waste nutrient removal and storage* service, nutrient concentrations can be taken as a critical pressure on the service, because they are a critical pressure on phytoplankton, i.e. the critical ecosystem component for its supply, and are already one of the metrics used to carry out that assessment, which follows a complex (ecosystem) sate-service (generation) relationship.

[161] This refers to the future direction of change in the capacity and, if possible, the future state of the capacity of the ecosystem to supply the service

Examples of this way of assessing future changes in service supply capacity based on the likely future change in the state of the critical ecosystem component(s), and other ecosystem attributes, are provided below. The best available information for this assessment are outlooks on future trend(s) in the critical pressure(s). An alternative, if that is not available, is to use current (or recent) trend(s) in the critical pressure(s) and assume that these will continue in the future. There is a greater level of confidence associated with using existing outlooks on future pressure trend(s) than making a forecast based on current (or recent) pressure trend(s).

Confidence in the assessment should consider the information sources used and the interpretation of the predicted future change in state of the critical ecosystem component(s), and other parts pf the ecosystem where relevant, into what this means for the service supply capacity. See Annex V for full details on the confidence assessment.

Example 1: Using outlooks on future trend(s) in critical pressure(s)

OSPAR develops outlooks for the future trends of pressures related to eutrophication, which can be used to forecast the future change in the state of phytoplankton, which is the critical ecosystem component for the supply of the *Waste nutrient removal and storage* service (Table 5.30).

Table 5.30 Outlook for pressures contributing to eutrophication from OSPAR

Outlook for pressure	% Region
Increasing	88
No trend	13

Notes: Based on OSPAR (2010) and taken from Table AIII.58 in Annex III

The pressures are expected to increase in 88 % of the OSPAR/North East Atlantic (NEA) region. Based on this future trend, the future trend in the state of the ecosystem component/phytoplankton, and hence the direction of change in the capacity of the NEA ecosystem to supply this service in the future can be predicted (following the assumption that trends in the state of the critical ecosystem component(s) reflect trends in the capacity of the ecosystem to supply services and considering (ecosystem) state-service (generation) relationship).

Thus, following the (ecosystem) state-service (generation) relationship (Step 2, Tables 5.11 and 5.26), the future direction of change in service supply capacity is expected to be 'decreasing' (since the pressure across the system is increasing) (Table 5.30). While this relationship is complex, the increasing nutrient concentrations are expected to, eventually, lead to a deterioration in the ecosystem capacity to supply the service due to eutrophication and the associated impacts on both the phytoplankton and benthos, even if there could be an improvement temporarily. Here we take a more precautionary and long-term outlook and give the final classification for the future direction of change in service supply capacity as 'deteriorating'.

The assessment of (the state of) the current capacity of the NEA ecosystem to supply the service (Annex III) found it was 'good' and that its direction of change was 'stable' (Table 5.31). Based on the above-mentioned assessment, the future capacity to supply the *Waste nutrient removal and storage* service is expected to 'decrease', i.e. deteriorate, but it is not known by how much. Therefore, the actual future (state of the) service supply capacity cannot be forecasted (see scenario O in Table 5.26) because whether the forecasted decrease in this capacity will reach a point from which it would move from the current 'good' to a 'bad' state is not known (Table 5.31).

Table 5.31 Example: Summary of the current and future (state of the) capacity as well as the current and future direction of change in the capacity of the NEA ecosystem to supply the *Waste nutrient removal and storage* service

<table>
<tr><th>Ecosystem Service</th><th>Critical eco-system com-ponent(s)</th><th>Current capac-ity for service supply</th><th>Future capacity for service supply</th><th>Confidence in the assessment</th></tr>
<tr><td>Waste nutrient removal and stor-age</td><td>Phytoplank-ton in all pe-lagic habitats</td><td>(Stable)</td><td>(Deteriorating)</td><td><table><tr><th>Step</th><th>Confidence</th></tr><tr><td>Step 1</td><td></td></tr><tr><td>Step 2</td><td></td></tr><tr><td>Step 3</td><td></td></tr><tr><td>Step 4</td><td></td></tr><tr><td>Step 5.B(i)</td><td></td></tr><tr><td>Step 5.b (ii)</td><td></td></tr></table></td></tr>
</table>

Notes:

- Assessment outcomes determined using the ‘majority’ aggregation approach
- The colour in the cells refers to the current and future state of service supply capacity (green = ’good’, pink = ’bad’, no colour = ’unable to assess’).
- The bracketed words in the cells refer to the current and future direction of change in the state of service supply capacity (‘improving’, ‘deteriorating’ or ‘stable’)
- Confidence is shown for each step of the assessment where red = low, yellow = moderate, and green = high confidence. The full confidence assessment is described in Annexes III and V.
- Taken from Table AIII.59 in Annex III – see information sources there

Example 2: Using current trend(s) in critical pressure(s) and assuming they will continue in the future

To forecast the potential change in the supply of the *Waste nutrient removal and storage* service in the future, where no outlooks for the future trend(s) in (critical) pressure(s) are available, the current trend(s) in the critical pressure(s) is assumed to continue in the future.

For example, for the Baltic Sea, no outlook future trend(s) in (critical) pressure(s) were available and the current trend in the critical pressure(s), i.e. nutrient concentrations, was assumed to continue. The outcome of the assessment of the current state trend of the metrics involved in assessing the current capacity of the Baltic Sea to supply the service (Annex III) indicated that nutrient concentrations were ‘decreasing’ (following the ‘majority’ aggregation approach, see Tables 5.20 and 5.23, and which would be ‘stable’ following the ‘conservative’ aggregation approach[162], see Annex III). This result was based largely on the 2012 MSFD reporting, which found a reduction in nutrient concentrations and so an improvement of ecosystem state in relation to nutrients (see Table 5.20), but only by a relatively small margin. This could imply that there was some potential for improvement of the ecosystem capacity to supply this service in the future in at least part of the region, while other parts of the region were not improving. Given, as explained, that nutrient concentrations are a type of pressure on the service and were decreasing, it was assumed that, in the future, the ecosystem would begin to recover from the impacts of this pressure, i.e. that the impact on the benthos and on the concentration of phytoplankton would decrease, and so that service supply capacity would ‘improve’[163] (following the (ecosystem) state-service (generation) relationship, Step 2, see Tables 5.11, 5.24 and 5.26).

[162] Reporting on the state of eutrophication in the Baltic Sea in 2014 suggested that the ‘conservative’ approach outcome may be the most appropriate assessment for the region at that time.
[163] Reporting on the state of eutrophication in the Baltic Sea in 2018 suggests this assumption was correct.

The overall current and future capacity of the Baltic Sea ecosystem to supply the service *Waste nutrient removal and storage* service is presented below (Table 5.32). The current state of this capacity was found to be 'bad' and its direction of change could not be assessed (see Step 4 and Table 5.24). This meant that, even if the future direction of change in service supply capacity might be 'improving', its future state could not be assessed because we do not know by how much, and if, this direction would change the current state from 'bad' to 'good', or not.

Table 5.32 Example: Summary of the current and future (state of the) capacity as well as the current and future direction of change in the capacity of the Baltic Sea ecosystem to supply the Waste nutrient removal and storage service

<table>
<tr><th>Ecosystem Service</th><th>Critical ecosystem component(s)</th><th>Current capacity for service supply</th><th>Future capacity for service supply</th><th>Confidence in the assessment</th></tr>
<tr><td>Waste nutrient removal and storage</td><td>Phytoplankton in all pelagic habitats</td><td>(Unable to assess)</td><td>(Improving)</td><td><table><tr><th>Step</th><th>Confidence</th></tr><tr><td>Step 1</td><td></td></tr><tr><td>Step 2</td><td></td></tr><tr><td>Step 3</td><td></td></tr><tr><td>Step 4</td><td></td></tr><tr><td>Step 5.B (i)</td><td></td></tr><tr><td>Step 5.B (ii)</td><td></td></tr></table></td></tr>
</table>

Notes:

- Assessment outcomes determined using the 'majority' aggregation approach
- The colour in the cells refers to the current and future state of service supply capacity (green = 'good', pink = 'bad', no colour = 'unable to assess').
- The bracketed words in the cells refer to the current and future direction of change in the state of service supply capacity ('improving', 'deteriorating' or 'stable')
- Confidence is shown for each step of the assessment where red = low, yellow = moderate, and green = high confidence. The full confidence assessment is described in Annexes III and V.
- Taken from Table AIII.60.a in Annex III – see information sources there

Step 5.C In the absence of outlook information on future trends in ecosystem state and if critical pressure(s) on the critical ecosystem component(s) are not known, identify these and, when basing future changes in service supply capacity[164] on the future trend in the state of the metric(s) identified in Step 2, assess that using information on future trend(s) in the critical pressure(s).

Step 5	Assess the future state and direction of change in the state of the critical ecosystem component(s), and other parts of the ecosystem where relevant, and use that to determine the future state of and direction of change in the capacity of the ecosystem to supply the service class or type
5.C	In the absence of outlooks on future trends in ecosystem state and if critical pressure(s) on the critical ecosystem component(s) are not known, identify these and, when basing future changes in service supply capacity on the future trend in the state of the metric(s) identified in Step 2, assess that using future trend(s) in the critical pressures.
5.C.1	Identify the critical pressure(s) on the critical ecosystem component(s)
5.C.2	Identify EU (and other) legislation/policy generating information on trends in critical pressures on the critical ecosystem component(s)
5.C.3	Synthesise the information on the critical pressure(s) on the critical ecosystem component(s) from different pieces of EU (and other) legislation/policy
5.C.4	Report the trend (future or current assumed to continue in the future) for each critical pressure from each piece of EU (and other) legislation/policy
5.C.5	Carry out an overall assessment of the future trend in the critical pressure(s) and determine the outlook (future trend in the state) for the critical ecosystem component(s)
5.C.6	Determine the future direction of change in the capacity of the ecosystem to supply the service class or type and, if possible, the future state of this capacity

If no outlook for the future trends in the state of the critical ecosystem component(s) is available, pressure trend information can be used as a proxy to infer such a change. For some services, the critical pressures on service supply capacity, which would be those on the critical ecosystem component(s), would not have been already identified as part of the assessment of the current (state of) service supply capacity (steps 1–4). For example, for the *Recreation and leisure from whale watching* service, only the current state of the population of those whale species susceptible of being spotted needed to be known to assess current service supply capacity. Therefore, in order to predict what may happen with this capacity in the future, a forecast of the future change in the state of those whale populations is required. The main threats and pressures affecting whales, and whether these are increasing or decreasing, can be used as a proxy in order to identify potential future changes in the relevant whale species' populations.

[164] This refers to the future direction of change in the capacity and, if possible, the future state of the capacity of the ecosystem to supply the service

Step 5.C.1 Identify the critical pressure(s) on the critical ecosystem component(s)

Step 5	**Assess the future state and direction of change in the state of the critical ecosystem component(s), and other parts of the ecosystem where relevant, and use that to determine the future state of and direction of change in the capacity of the ecosystem to supply the service class or type**
5.C	In the absence of outlooks on future trends in ecosystem state and if critical pressure(s) on the critical ecosystem component(s) are not known, identify these and, when basing future changes in service supply capacity on the future trend in the state of the metric(s) identified in Step 2, assess that using future trend(s) in the critical pressure(s).
5.C.1	Identify the critical pressure(s) on the critical ecosystem component(s)

The first step in this MECSA method option (Step 5.C) is identifying the critical pressure(s) on the critical ecosystem component(s). Different types of information may be available in order to do this, such as the literature and reporting on relevant EU (and other) legislation/policy (Table 5.33). The best information to use is that which is most specific to the critical ecosystem components contributing to the supply of the service being assessed. More specific information will lead to greater confidence in the assessment outcome.

Confidence in this step takes into account the sources of information used and how specific the information is to the critical ecosystem components (as described in Table 5.33). See Annex V for full details on the confidence assessment.

Table 5.33 Types of information that can be used to identify the critical pressures affecting the critical ecosystem component(s) for service supply capacity

Best available (greater confidence)	Identify the greatest threat for the specific critical ecosystem component, e.g. if the critical components are individual species, the threats identified should be species specific.
Alternative (lower confidence)	Identify the greatest threat for a proxy of the specific critical ecosystem component, e.g. threats to whales as opposed to the threats for individual whale species, or the threats to marine mammals as opposed to the threats for whales.

Example 1 Identify the greatest threat for the specific critical ecosystem component

For the example of *Recreation and leisure from whale watching* service, the particular whale (and dolphin) species which are reported as being spotted on whale watching trips were identified as being the critical components for the ecosystem capacity to supply this service (Step 1). Different species of whales (and dolphins) have different critical pressures upon them, therefore the critical pressure(s) for each individual species was identified -in this case from the regional reporting of a global organisation (Table 5.34).

Table 5.34 IUCN[165] reporting on the most important threats to whale (and dolphin) species in the North East Atlantic Ocean (NEA) and Mediterranean Sea

Species	Main threats	
	Region	
	NEA	MED
Minke Whales *Balaenoptera acutorostrata*	Whaling (outside of EU region)	
Atlantic white-sided dolphin *Lagenorhynchus acutus*	Incidental catches/bycatch	
Common bottlenose dolphin *Tursiops truncates*	Hunting, Incidental catches/ bycatch, and habitat degradation	Incidental catches/bycatch and the reduced availability of key prey
Cuvier's Beaked Whale *Ziphius cavirostris*	Loss of prey species	Underwater noise
Harbour porpoise *Phocoena*	Incidental catches/bycatch	
Long-finned pilot whale *Globicephala melas*	Incidental catches/bycatch	Pathogens/parasites
Northern bottlenose *Hyperoodon ampullatus*	Underwater noise	
Risso’s dolphin *Grampus griseus*	Incidental catches/bycatch	Incidental catches/bycatch
Sei whale *Balaenoptera borealis*	Whaling (outside of EU region), trend unknown (IUCN)	
Short-beaked common dolphin *Delphinus delphis*	Incidental catches/bycatch	Climate change and combined human impacts (Loss of prey species and habitat degradation)
Sowerby's beaked whale *Mesoplodon bidens*	Unknown – Incidental catches/ bycatch/underwater noise	
Striped dolphin *Stenella coeruleoalba*	Incidental catches/bycatch	Pathogens/parasites
The Fin whale *Balaenoptera physalus*	Ship strikes	Ship strikes and underwater noise
The humpback whale *Megaptera novaeangliae*	Incidental catches/bycatch and ship strikes	
The killer whale *Orcinus orca*	Persecution and hazardous substances	Persecution and hazardous substances
The sperm whale *Physeter catodon*	Incidental catches/bycatch	Incidental catches/bycatch
True's beaked whale *Mesoplodon mirus*	Incidental catches/bycatch	
White-beaked dolphin *Lagenorhynchus albirostris*	Incidental catches/bycatch	

Notes: Taken from Table AII.28 in Annex II – see more on the IUCN assessment/information sources there

[165] The Habitats Directive also provides a list of threats per cetacean species. However, it is based on Member State inputs, rather than considering the regional populations per species as a whole, and so obtaining an overview for each EU marine region is not straightforward. In contrast, the IUCN information applies regionally and this is why it was used here instead.

Example 2 Identify the greatest threat for a proxy of the specific critical ecosystem component

In some cases, the main pressures affecting a critical component will be identified for a marine region as part of the reporting on relevant EU (and other) legislation/policy reporting. For example, continuing with the example of the *Recreation and leisure from whale watching* service, for marine mammals the MSFD ranks the greatest pressures upon them per marine region (Table 5.35). This reporting could then be used to identify the critical pressure(s) for the critical ecosystem component(s).

For the example of *Recreation and leisure from whale watching* service, the best information to identify critical pressures on the critical ecosystem components, i.e. the populations of whale (and dolphin) species relevant for whale watching, was that shown in Example 1 above, where the specific threat(s) for each relevant whale (and dolphin) species was identified. As the marine mammal information from the MSFD also includes seals and is not specific to individual whale (and dolphin) species, this is not the best source of information to use (Table 5.33). However, if whale (and dolphin) species-specific pressure information is unavailable, this aggregated marine mammal-pressure information could be used as a proxy.

Table 5.35 Marine mammals: Tabular summary of constituent MSFD pressures for the most important pressures themes adversely affecting reported criteria related to marine mammal populations in the North East Atlantic Ocean by total count and summed weighted rank

Pressure theme	Pressure	Total count	Rank not reported	Rank				Summed weighted rank
				0	1	2	3	
C – Other physical disturbance	Marine litter	2	-	-	1	1	-	5
	Underwater noise	21	-	9	2	9	1	25
	Physical disturbance (other)	1	-	-	-	-	1	1
E – Contamination by hazardous substances	Contamination by hazardous substances (all)	20	-	8	2	10	-	26
H – Biological disturbance	Biological disturbance (all)	3	-	3	-	-	-	0
	Selective extraction of species, including non-target catches (all)	20	-	13	5	1	1	18
	Extraction of species: fish & shellfish	9	-	-	9	-	-	27

Notes: From ETC/ICM (2014a)

5.C.2 Identify EU (and other) legislation/policy generating information on trends in pressures on the critical ecosystem component(s)

Step 5	**Assess the future state and direction of change in the state of the critical ecosystem component(s), and other parts of the ecosystem where relevant, and use that to determine the future state of and direction of change in the capacity of the ecosystem to supply the service class or type**
5.C	In the absence of outlooks on future trends in ecosystem state and if critical pressure(s) on the critical ecosystem component(s) are not known, identify these and, when basing future changes in service supply capacity on the future trend in the state of the metric(s) identified in Step 2, assess that using future trend(s) in the critical pressure(s).
5.C.1	Identify the critical pressure(s) on the critical ecosystem component(s)
5.C.2	Identify EU (and other) legislation/policy generating information on trends in critical pressures on the critical ecosystem component(s)

Once the relevant threats (pressures) on the critical ecosystem component(s) have been identified (Table 5.34), different pieces of EU (and other) legislation/policy reporting information on trends in these pressures, such as indicators or other assessment products, are identified/selected. For example, Table 5.36 shows the relevant legislation and policy collecting national information and reporting it at higher levels with regard to threats for whale (and dolphin) populations in the North East Atlantic Ocean and the Mediterranean Sea, which include the critical ecosystem components for the *Recreation and leisure from whale watching* service, as well as the pressure indicators, or other products, reported.

Table 5.36 Summary of pressure information relevant to whale (and dolphin) populations reported through relevant EU (and other) legislation/policy applicable to the North East Atlantic Ocean (NEA) and the Mediterranean Sea

Geographical relevance	Legislation/policy	Indicators, or other products, reported
EU level	MSFD	Pressures and impacts on 'Biodiversity' (Descriptor 1), including trends
	Common Fisheries Policy (CFP)	Marine mammal species caught as bycatch, including trends
Regional level	OSPAR Biological Diversity and Ecosystems Strategy (NEA)	4 threatened cetacean species monitored, pressures on cetaceans recorded, including trends
	ACCOBAMS (Mediterranean Sea)	Description of known information on cetacean species populations, trends and pressures

Notes:

- Pressure trends from ACCOBAMS are 'outlooks' for future pressure trends, while those from the MSFD are current and those from the CFP are past trends that are assumed to continue in the future. While the MSFD, in principle, reports future trends for pressures, in reality, future trends were not available for this period because very few Member States had reported them and there was no consistency at the EU level.
- Taken from Table AII.29 in Annex II – see more on the information sources there

5.C.3 Synthesise the information on the critical pressure(s) on the critical ecosystem component(s) from different pieces of EU (and other) legislation/policy

Step 5	**Assess the future state and direction of change in the state of the critical ecosystem component(s), and other parts of the ecosystem where relevant, and use that to determine the future state of and direction of change in the capacity of the ecosystem to supply the service class or type**
5.C	In the absence of outlooks on future trends in ecosystem state and if critical pressure(s) on the critical ecosystem component(s) are not known, identify these and, when basing future changes in service supply capacity on the future trend in the state of the metric(s) identified in Step 2, assess that using future trend(s) in the critical pressure(s).
5.C.1	Identify the critical pressure(s) on the critical ecosystem component(s)
5.C.2	Identify EU (and other) legislation/policy generating information on trends in critical pressures on the critical ecosystem component(s)
5.C.3	Synthesise the information on the critical pressure(s) on the critical ecosystem component(s) from different pieces of EU (and other) legislation/policy

Once the different pieces of EU (and other) legislation/policy generating pressure trend information(s) have been identified, this information needs to be made comparable across all of them in order to, eventually, arrive at an overall assessment of the future trend in the critical pressure(s) on the critical ecosystem component(s) for the ecosystem capacity to supply the service being assessed. This requires some synthesis of the reported pressures, which can be named differently depending on where they are reported in/from or aggregated as different groups of pressures. A list of the *most direct* pressures on the critical ecosystem component(s), which – in the example of the *Recreation and leisure from whale watching* service – are the populations of whale (and dolphin) species relevant for whale watching is created, and these are then taken as being the *critical* pressures on the components (e.g. Table 5.34 identifies the main pressures for whale species relevant for the *Recreation and leisure from whale watching* service).

The information from the different EU (and other) legislation/policy sources is then aligned to this critical pressure list, i.e. where the same pressure is reported in more than one piece of legislation/policy – even if they are called by different names. For example, a synthesis of pressures is presented here listing the pressures identified as being critical for the whale species that are relevant for whale watching and linking each of those pressures to what it is reported as under different pieces of EU (and other) legislation/policy (Table 5.37).

Table 5.37 Synthesis of the different pressures identified as being critical for the whale species that are relevant for whale watching and how they link to pressures reported from different pieces of EU and other legislation/policy

Critical pressure on whales relevant for whale watching	EU and other legislation/policy			
	MSFD	CFP	OSPAR	ACCOBAMS
Climate change	-	-	Climate change	
Underwater noise	Other physical disturbance, which includes underwater noise	-	Underwater noise	Noise pollution
Ship strikes	Other physical disturbance, which includes death or injury by ship strikes	-	Death or injury by ship strikes	
Hazardous substances	Contamination by hazardous substances	-	Hazardous substances	
Removal of target and non-target species	Biological disturbance, which includes selective extraction of species, including incidental non-target catches	Accidental bycatch of marine mammals	Removal of target and non-target species	Harvesting, accidental mortality, persecution
Loss of prey species	Biological disturbance, which includes extraction of species: fish & shellfish	-	Loss of prey species	Changes in native species dynamics: prey/food base
Habitat loss	Physical loss and Physical damage	-	Habitat Loss	Habitat loss/degradation
Pathogens/parasites	Biological disturbance, which includes introduction of microbial pathogens	-	-	Changes in native species dynamics: pathogens/parasites
Threats outside EU areas	-	-	-	-

Notes: Taken from Table AII.30 in Annex III -- see more on the information sources there

Step 5.C.4 Report the trend (future or current assumed to continue in the future) for each critical pressure from each piece of EU (and other) legislation/policy

Step 5	**Assess the future state and direction of change in the state of the critical ecosystem component(s), and other parts of the ecosystem where relevant, and use that to determine the future state of and direction of change in the capacity of the ecosystem to supply the service class or type**
5.C	In the absence of outlooks on future trends in ecosystem state and if critical pressure(s) on the critical ecosystem component(s) are not known, identify these and, when basing future changes in service supply capacity on the future trend in the state of the metric(s) identified in Step 2, assess that using future trend(s) in the critical pressure(s).
5.C.1	Identify the critical pressure(s) on the critical ecosystem component(s)
5.C.2	Identify EU (and other) legislation/policy generating information on trends in critical pressures on the critical ecosystem component(s)
5.C.3	Synthesise the information on the critical pressure(s) on the critical ecosystem component(s) from different pieces of EU (and other) legislation/policy
5.C.4	Report the trend (future or current assumed to continue in the future) for each critical pressure from each piece of EU (and other) legislation/policy

This step is about establishing the (future or current assumed to continue in the future) trends for each critical pressure from each different piece of relevant EU (and other) legislation/policy on the critical components for the ecosystem capacity to supply the service being assessed. This is needed to, eventually, arrive at an overall assessment of/outcome for the future trend in the critical pressure(s) affecting these components, which, in the example of the *Recreation and leisure from whale watching* service, are the populations of whale (and dolphin) species relevant for whale watching. In order to do so, the information may be used directly, or some further calculation/manipulation will be required depending on how it has been reported.

Example 1 Using the quality classifications of the pressure trend information from relevant EU (and other) legislation/policy directly

Threats affecting whale populations are identified by OSPAR (cf., e.g., OSPAR, 2010), including whether these will 'increase' or 'decrease' in the future (where known). Trends from OSPAR come from text descriptions of each pressure dealt with individually or from assessments of key issues in the relevant quality status report. These can be used directly, as they are reported, in the assessment approach here.

Example 2 Manipulating the quality classifications of the pressure trend information from the relevant EU (and other) legislation/policy: Taking 'the most frequent classification' from the information provided within one piece of EU (and other) legislation/policy

In some cases, e.g. the MSFD, pressures are not reported as an overall classification for the region, but as the proportions of different classifications according to how prevalent they are in the region. Where a range of classifications is reported through the legislation/policy (e.g. the MSFD), 'the most frequent classification' (as per Step 3.3) is taken as the overall classification by applying the following rules:

- 'The most frequent (most common) classification' (i.e. 'increasing', 'stable' or 'decreasing') is taken despite the % of 'unknown'/'insufficient information', except where more than 50 % is 'unknown'/'insufficient information' (which is then chosen as the outcome and no trend can be established).
- If the classification is equal between two assigned categories, the more conservative (precautionary) classification is taken from this piece of legislation/policy.

For example, underwater noise is reported under the MSFD where no current trend can be established for the Mediterranean Sea, but it is possible to do so for the North East Atlantic Ocean (NEA) (Table 5.38) (and no future trend in this pressure was available in the 2012–2013 MSFD EU-level reporting). Thus, 'the most frequent classification' of the assigned categories is taken as the current trend, i.e. 'insufficient information' for the Mediterranean Sea (meaning that the trend cannot be assessed) and mostly 'stable' for the NEA (as this is the most frequent/common known classification).

Table 5.38 Current trends in the assessment of level of pressure due to underwater noise in the North East Atlantic Ocean and the Mediterranean Sea in the context of the MSFD Descriptor 11, with 'the most frequent classification' highlighted in yellow

Percentage Area (%)					
Regional Sea	Trend increasing	Trend stable	Trend decreasing	Insufficient Information	Area of reported national waters (km^2)
Mediterranean Sea	8	0	0	92	1,411,459
NE Atlantic Ocean	21	34	10	35	2,539,392

Notes:

- Taken from Table AII.37 in Annex II
- Original information from ETC/ICM (2014b)

Steps 5.C.3 and 5.C.4 require a number of decisions to be made about the information to use, hence an assessment of confidence is required, taking into account different factors that may affect the outcome of the service supply capacity assessment. See Annex V for more detail in the confidence assessment linked to these steps, including guidelines to assign the confidence in the different information sources used in the assessment.

Step 5.C.5 Carry out an overall assessment of the future trend in the critical pressure(s) and determine the outlook for (future trend in the state of) the critical ecosystem component(s)

Step 5	**Assess the future state and direction of change in the state of the critical ecosystem component(s), and other parts of the ecosystem where relevant, and use that to determine the future state of and direction of change in the capacity of the ecosystem to supply the service class or type**
5.C	In the absence of outlooks on future trends in ecosystem state and if critical pressure(s) on the critical ecosystem component(s) are not known, identify these and, when basing future changes in service supply capacity on the future trend in the state of the metric(s) identified in Step 2, assess that using future trend(s) in the critical pressure(s).
5.C.1	Identify the critical pressure(s) on the critical ecosystem component(s)
5.C.2	Identify EU (and other) legislation/policy generating information on trends in critical pressures on the critical ecosystem component(s)
5.C.3	Synthesise the information on the critical pressure(s) on the critical ecosystem component(s) from different pieces of EU (and other) legislation/policy
5.C.4	Report the trend (future or current assumed to continue in the future) for each critical pressure from each piece of EU (and other) legislation/policy
5.C.5	Carry out an overall assessment of the future trend in the critical pressure(s) and determine the outlook for (future trend in the state of) the critical ecosystem component(s)

The overall assessment of the future trend in the critical pressure(s) on the critical ecosystem component(s), first delivers a separate future critical pressure trend outcome (future or current assumed to continue in the future) for each piece of relevant EU (and other) legislation/policy used in the assessment. The outcomes are presented as an 'improving', 'stable' or 'deteriorating' future trend in each critical pressure. An overall classification for a single future critical pressure trend per critical component is then determined using the 'majority' aggregation approach (and the 'conservative' aggregation approach) as described below (see also Step 3.4). In the example of the *Recreation and leisure from whale watching* service, where the critical ecosystem components are the populations of whale (and dolphin) species relevant for whale watching, there could be more than one critical pressure on a given whale species. In those cases, the 'majority'/'conservative' approach was first used to aggregate across pieces of EU (and other) legislation/policy and then across critical pressures.

Once the single future critical pressure trend is determined across all pieces of relevant EU (and other) legislation/policy, this is then interpreted in terms of an outlook for the future trend in the state of the critical ecosystem component(s). Expert judgement is used to interpret the future overall trend in critical pressure(s) in relation to the effect this/these may have on a critical ecosystem component (e.g. Table 5.39). This considers whether the future critical pressure trend per piece of legislation/policy represents an 'improvement' or 'deterioration' in the outlook for the trend for the state of the critical ecosystem component(s), i.e. the future direction of change in the state of the component(s). Therefore, the direction of the arrows shown on assessment tables may seem counter intuitive as, e.g., an 'increasing' future critical pressure is represented with a 'downward' arrow (↓). This is done to show that the future pressure trend represents a move towards the future deterioration in the quality of the critical ecosystem components[166] (e.g. the (populations of) whale (and dolphin) species relevant for whale watching in the example of the *Recreation and leisure from whale watching* service shown in Table 5.39).

The confidence in this step of the assessment is measured as the level of agreement between different sources of assessment information. See Annex V for full details on the confidence assessment.

*Applying the 'majority' approach for the aggregation of assessment results **across** different pieces of EU (and other) legislation/policy to determine a single future critical pressure trend on the critical ecosystem component(s):*

- Where there is variation in the classifications, but a majority in favour of one, take the **most common**

  Example (1)

Metric	Legislation /policy 1	Legislation /policy 2	Legislation /policy 3	**Overall Outcome**
Metric 1	↓	↓	↑	**↓**
Metric 2	↑	↑	↔	**↑**

  In the example above, for Metric 1 two out of the three arrows show a 'decrease', thus the overall direction of change is 'deteriorating'.

  For Metric 2, two out of the three arrows show an 'increase', thus the overall direction is 'improving'.

[166] This is in line with Example 4 under sub-step 3.3,

- Where there is insufficient information
  - If there is greater (or equal) 'insufficient information' than any status classification: take the known (status) classification for a metric, discard information from legislation/policy that could not be assessed when there is information that has been assessed.
  - In the overall assessment **across** the different pieces of legislation/policy used as information sources there is an exception to the general rule of taking the majority classification. This part of the assessment takes the majority outcome *from those legislation/policy information sources where a (status) classification has been arrived at* discarding those information sources where the outcome was 'insufficient information'. The value of using information from several sources is the additional information that each contributes, therefore it is considered better to use classified information where available. In the extreme case of a single assessment product, then that value is taken to be that for the overall assessment. This recognises that the assessment product, even if it is the only one available, has resulted from a classification process as required by the relevant legislation/policy and is therefore robust.

Example (2)

Metric	Legislation /policy 1	Legislation /policy 2	Legislation /policy 3	**Overall Outcome**
Metric 1			↑	**↑**

In the example above, for Metric 1, the majority state classification would be 'insufficient information'; however, one source gives a status classification ('improving'). Therefore, this classification is taken forward as the overall outcome.

- If 50-50 'improving'/'deteriorating': Take the <u>least</u> precautionary classification ((i.e. the best outcome for the ecosystem as the other method, 'conservative', demonstrates the precautionary approach, i.e. the worst outcome, see Box 5.2)

Example (3)

Metric	Legislation /policy 1	Legislation /policy 2	Legislation /policy 3	Legislation /policy 4	**Overall Outcome**
Metric 1	↓	↓	↑	↑	**↑**
Metric 2	↑	↑	↔	↔	**↑**

In the example above, Metric 1 shows two 'decreasing' trends while the other two are 'increasing'. The overall outcome is given as 'improving' (as this is the least conservative and 50 % of classifications agree on this).

For Metric 2, 50 % of the classifications show 'improving' and 50 % show 'deteriorating'; therefore 'improving' is taken as the overall classification as this is the least conservative outcome.

Box 5.2 Applying the 'conservative' approach for the aggregation of assessment results across different pieces of EU (and other) legislation/policy

Always take the **most conservative** classification i.e. where conservative means the worst outcome for the ecosystem, even if most classifications are an 'improving' trend and only one shows a 'deteriorating' trend (i.e. a precautionary approach)

Example (1a)

Metric	Legislation /policy 1	Legislation /policy 2	Legislation /policy 3	**Overall Outcome**
Metric 1	↓	↓	↑	**↓**
Metric 2	↑	↑	↔	**↔**

In the example above, Metric 1 shows two out of the three trends 'deteriorating' and this also the most conservative assessment, thus the overall direction is 'deteriorating'.

Metric 2 has two out of the three arrows showing an 'increase', and one showing 'stable'. The overall direction is 'stable' (i.e. not moving 'towards' or 'away' from the legislation/policy objective) because a 'stable' trend is considered more conservative than an 'improving' trend.

If there are some 'known' and some 'insufficient information' classifications: The value of using data/information from several sources is the additional information that each contributes, therefore it is considered better to use classified information (status) where given, even if other pieces of legislation/policy show 'insufficient information' to assess/classify a metric.

Example (2a)

Metric	Legislation /policy 1	Legislation /policy 2	Legislation /policy 3	Legislation /policy 4	**Overall Outcome**
Metric 1			↑	↑	**↑**
Metric 2	↑		↔		**↔**

In the example above, for Metric 1, two trends show an 'improvement' and two show 'insufficient information'. Thus, the overall direction is 'improving'.

In Metric 2 one trend shows an 'improvement' and one show 'stable', while two show 'insufficient information'. Thus, the overall direction is 'stable' (as, of the two classified directions of change, 'stable' is the most conservative).

Table 5.39 Example: The overall future trends and confidence in the assessment of each critical pressure reported under each relevant piece of EU (and other) legislation/policy concerning whale species relevant for the supply of the *Recreation and leisure from whale watching* service in the Mediterranean Sea

Legend

	Unknown
↑	Improving quality
↔	Stable quality
↓	Declining quality

		EU and Other Law and Policy			Majority		Confidence	
Species	Pressure Metric	Marine Strategy Framework Directive	CFP	ACCOBA MS	Pressure	Outlook for Whales	Pressure	Outlook for Whales
Common bottlenose dolphin *Tursiops truncatus*	Removal of target and non-target species		↓		↓	↓	Low	Low
	Loss of prey species							
Cuvier's Beaked Whale *Ziphius cavirostris*	Underwater noise							
Long-finned pilot whale *Globicephala melas*	Pathogens/parasites							
Risso's dolphin *Grampus griseus*	Removal of target and non-target species		↓		↓	↓	Low	Low
Short-beaked common dolphin *Delphinus delphis*	Climate change			↓	↓	↓	Low	Low
	Loss of prey species							
	Habitat Loss							
Striped dolphin *Stenella coeruleoalba*	Pathogens/parasites							
The Fin whale *Balaenoptera physalus*	Ship strikes			↓	↓	↓	Low	Low
	Underwater noise						Low	
The killer whale *Orcinus orca*	Threats outside EU areas					↑		Low
	Hazardous substances			↑	↑		Low	
The sperm whale *Physeter catodon*	Removal of target and non-target species		↓		↓	↓	Low	Low

Notes:

- Taken from Table AII.44 in Annex II – see more on the information sources there. Pressure trends from ACCOBAMS are 'outlooks' for future pressure trends, while those from the MSFD are current pressure trends and those from the CFP are past pressure trends, which, in both cases, are assumed to continue in the future. While the MSFD, in principle, reports future trends for pressures, in reality, future trends were not available for this period (up to 2014) because very few Member States had reported them and there was no consistency at the EU level.
- Pressure outcomes per policy are presented as trends towards a future 'improving' or 'deteriorating' quality of the state of the critical ecosystem components, and so an 'increasing' pressure is represented with a ↓ to show that the future pressure trend represents a future 'deterioration' of that quality. The trend in the future pressure shown is determined using the 'majority' aggregation approach. 'Outlook for whales' refers to the assumed pressure-state relationship between the future trend in a pressure and the effect that will have on the future trend in the state of whales, and so represents the future direction of change in the state of the whales. However, because the critical pressure trends across each relevant piece of legislation/policy is already interpreted in terms of what it means for the future quality of each critical ecosystem component, the classification in the 'Pressure' column equals that of the 'Outlook for whales' column.

5.C.6 Determine the future direction of change in the capacity of the ecosystem to supply the service class or type and, if possible, the future state of this capacity

Step 5	**Assess the future state and direction of change in the state of the critical ecosystem component(s), and other parts of the ecosystem where relevant, and use that to determine the future state of and direction of change in the capacity of the ecosystem to supply the service class or type**
5.C	In the absence of outlooks on future trends in ecosystem state and if critical pressure(s) on the critical ecosystem component(s) are not known, identify these and, when basing future changes in service supply capacity on the future trend in the state of the metric(s) identified in Step 2, assess that using future trend(s) in the critical pressure(s).
5.C.1	Identify the critical pressure(s) on the critical ecosystem component(s)
5.C.2	Identify EU (and other) legislation/policy generating information on trends in critical pressures on the critical ecosystem component(s)
5.C.3	Synthesise the information on the critical pressure(s) on the critical ecosystem component(s) from different pieces of EU (and other) legislation/policy
5.C.4	Report the trend (future or current assumed to continue in the future) for each critical pressure from each piece of EU (and other) legislation/policy
5.C.5	Carry out an overall assessment of the future trend in the critical pressure(s) and determine the outlook (future trend in the state) for the critical ecosystem component(s)
5.C.6	Determine the future direction of change in the capacity of the ecosystem to supply the service class or type and, if possible, the future state of this capacity

The future *direction of change* in the ecosystem capacity to supply the service is based on the outlook for the critical ecosystem component(s), as determined in the previous step (Table 5.39) and using knowledge of the (ecosystem) state-service (generation) relationship (Step 2, see also steps 5.A and 5.B).

The future (state of) service supply capacity should be based on: (1) the current (state of) service supply capacity, (2) the current direction of change in service supply capacity, and (3) the future direction of change in service supply capacity as per steps 5.A and 5.B following Figure 5.7 and Table 5.26. Thus, the same approach is used in this step here. However, in the specific example of the *Recreation and leisure from whale watching* service here, each whale species was assessed separately, rather than as the 'Whales' biotic group, because different pressures affect different whale species differently. Therefore, the method varies slightly to account for this, where the future service supply capacity is firstly determined for each individual whale species, and then an overall capacity is determined based on all the whale species together. In order to do so, this step needs to determine the *individual* whale species current (state of) service supply capacity and its direction of change as these were not determined individually in Step 4. This is done by taking the current state and direction of change in the (current) state (assessed using state trend information) of the individual whale species (i.e. the critical ecosystem component) from Step 3.4 and assessing the current (state of) service supply capacity and its direction of change for each species following a simple, one-to-one (ecosystem) state-service (generation) relationship. The outcomes are then used together with the outlook) for each individual whale species, inferred from future pressure trends, as established in Step 5.C.5 (Table 5.39, i.e. the future direction of change in the state of individual whale species based on the future trend in their state), along with knowledge of the (ecosystem) state-service (generation) relationship and expert judgement. This should allow classifying, where possible, the future (state of the) capacity of each individual whale species towards service supply (Table 5.40).

Examples of how to interpret the input assessment information towards a 'future state and direction of change in service supply capacity'

- Common bottlenose dolphin

  *Future direction of change in service supply capacit*y

  The outlook for the common bottlenose dolphin is 'deteriorating', i.e. the future trend in the state of that critical ecosystem component is 'decreasing' (Table 5.39). Therefore, the capacity of this species to supply the service *Recreation and leisure from whale watching* in the future is expected to 'deteriorate' (Table 5.40) following the established, simple (ecosystem) state-service (generation) relationship.

  Future state of service supply capacity

  The current capacity of the common bottlenose dolphin to supply the *Recreation and leisure from whale watching* service is 'bad'; the (current) direction of change in this capacity is 'deteriorating'; and the outlook for the species is to 'deteriorate' (because the future trend in the state is 'decreasing', Tables 5.39 and 5.40). Therefore, the future (state of) service supply capacity can only be 'bad' because at no time did the direction of change in service supply capacity indicate an improvement that could move the state of this capacity from the current 'bad' to a future 'good' (see scenario C in Table 5.26 and Table 5.40).

- Killer Whale

  Future direction of change in service supply capacity

  The outlook for the killer whale is 'improving', i.e. the future trend in the state of that critical ecosystem component is 'increasing' (Table 5.39). Therefore, the capacity of this species to supply the service *Recreation and leisure from whale watching* in the future is expected to 'improve' (Table 5.40) following the established, simple (ecosystem) state-service (generation) relationship.

  Future state of service supply capacity

  The current capacity of the killer whale to supply the *Recreation and leisure from whale watching* service is 'good'; the (current) direction of change in this capacity is 'deteriorating'; but the outlook for the species is 'improving' (because the future trend in the state is 'increasing', Tables 5.39 and 5.40). Therefore, the future (state of) service supply capacity cannot be established (see scenario K in Table 5.26 and Table 5.40) because there are several potential options. Two examples of these are given here:

  a) The current 'deteriorating' trajectory in the population's service supply capacity stops and switches to 'improving' following the outlook for the species, before (the state of) service supply capacity moves from 'good' to 'bad'. Therefore, (the state of) service supply capacity stays 'good' throughout, i.e. the future (state of) service supply capacity is 'good'.
  b) The current 'deteriorating' trajectory in the population's service supply capacity continues until (the state of) service supply capacity goes from 'good' to 'bad', and the subsequent future 'improving' trajectory is not enough to switch back to a 'good' (state of) service supply capacity. Therefore, the future (state of) service supply capacity is 'bad'.

These examples illustrate that, since the future direction of change in service supply capacity (based on future trend in the state of the metrics of the critical ecosystem components/individual whale species) alone does not indicate by how much the current state of this capacity can change, it is not always possible to determine its future state.

The confidence in this step requires the consideration of the interpretation of the state of the metrics and what this means for the overall capacity to supply the service. In addition, the overall result may be achieved by discarding large amounts on 'unknown' information. See Annex V for full details on the confidence assessment.

Table 5.40 Example: Assessment outcomes for the future (state of the) capacity of each whale species relevant for whale watching in the Mediterranean Sea to supply the *Recreation and leisure from whale watching* service based on the current state and trends in the state of each individual whale species (i.e. the critical ecosystem components) and the 'outlook for whales' (i.e. the forecasted future trend in the state of those whales)

Legend

	Current state of whale species population fails to meet policy objectives	↓	Future state whale species population decreasing (outlook deteriorating)	↑	Improving current state of whale species population, or (current or future) ecosystem capacity to supply service
	Current state of whale species population achieves policy objectives		Good (current or future) ecosystem capacity to supply service	↔	Stable current state of whale species population, or (current or future) ecosystem capacity to supply service
↑	Future state of whale species population increasing (outlook improving)		Bad (current or future) ecosystem capacity to supply service	↓	Deteriorating current state of whale species population, or (current or future) ecosystem capacity to supply service
↔	Future state whale species population stable		Insufficient information (or outcome cannot be determined)		

Species	'Majority' aggregation				
	Current state and direction of change in the state of the critical ecosystem component	**Current state of and direction change in service supply capacity**	**Outlook for whales**	**Future direction of change in service supply capacity**	**Future state of service supply capacity**
Common bottlenose dolphin *Tursiops truncatus*	↓	↓	↓	↓	
Cuvier's Beaked Whale *Ziphius cavirostris*	↔	↔	↓	↓	
Long-finned pilot whale *Globicephala melas*					
Risso's dolphin *Grampus griseus*			↓	↓	
Short-beaked common dolphin *Delphinus delphis*	↓	↓	↓	↓	
Striped dolphin *Stenella coeruleoalba*	↓	↓			
The Fin whale *Balaenoptera physalus*	↓	↓	↓	↓	
The killer whale *Orcinus orca*	↓	↓	↑	↑	
The sperm whale *Physeter catodon*	↓	↓	↓	↓	

Notes: Taken from Table AII.46 in Annex II – see information sources there

In the example shown above, the future state of and direction of change in the capacity of each individual whale species to supply the service needs to be aggregated to provide the overall assessment of the Mediterranean Sea's ecosystem capacity to supply the *Recreation and leisure from whale watching* service. The individual classifications for each whale species can be combined by taking 'the most frequent classification'. The results from doing so are shown in Table 5.41. Future service supply capacity was only classified as being in a 'bad' state, and this was for most species (6 species, 67 % of species assessed), while for the rest it was 'unknown'. The future direction of change in this capacity was forecasted to 'deteriorate' for most species (6 species, 67 % of the species assessed), while it was only forecasted to 'improve' for one species (11 % of the species assessed).

Table 5.41 Example: Summary of assessment results and confidence classifications for the future (state of the) capacity and the future direction of change in the capacity of the Mediterranean Sea ecosystem to supply the *Recreation and leisure from whale watching* service, with 'the most frequent classification' highlighted in yellow

Assessment	Classification	% whale species assigned	Confidence (No. of whale species)		
			High	Moderate	Low
Future state of service supply capacity	Good	0			
	Bad	67	0	0	6
	Unknown	33			
Future direction of change of (the state of) service supply capacity	Improving	11	0	0	1
	Stable	0			
	Deteriorating	67	0	0	6
	Unknown	22			

Notes:

- Assessment outcomes determined using the 'majority' aggregation approach
- Taken from Table AII.49 in Annex II – see information sources there

Applying 'the most frequent classification' means that, overall, the future capacity and the future direction of change in the capacity of the Mediterranean Sea ecosystem to supply the *Recreation and leisure from whale watching* service are expected to be in a 'bad' state and follow a 'deteriorating' trend respectively (Table 5.42).

Table 5.42 Example: Summary of the current and future (state of the) capacity as well as the current and future direction of change in the capacity of the Mediterranean Sea ecosystem to supply the *Recreation and leisure from whale watching* service

<table>
<tr><th>Ecosystem service</th><th>Critical ecosystem component(s)</th><th>Current capacity for service supply</th><th>Future capacity for service supply</th><th>Confidence in the Assessment</th></tr>
<tr><td>Recreation and leisure from whale watching</td><td>Whale species relevant for whale watching</td><td>(Deteriorating)</td><td>(Deteriorating)</td><td><table><tr><th>Step</th><th>Confidence</th></tr><tr><td>Step 1</td><td></td></tr><tr><td>Step 2</td><td></td></tr><tr><td>Step 3</td><td></td></tr><tr><td>Step 4</td><td></td></tr><tr><td>Step 5.C.1</td><td></td></tr><tr><td>Step 5.C.3/4 and 5</td><td></td></tr><tr><td>Step 5.C.6</td><td></td></tr></table></td></tr>
</table>

Notes:

- Assessment outcomes determined using the 'majority' aggregation approach
- The colour in the cells refers to the current and future state of service supply capacity (green = 'good', pink='bad', no colour = 'unable to assess').
- The bracketed words in the cells refer to the current and future direction of change in the state of service supply capacity ('improving', 'deteriorating' or 'stable')
- Confidence is shown for each step of the assessment, where red = low, yellow = moderate, and green = high confidence. The full confidence assessment is described in Annexes II and V.
- Taken from Table AII.50 in Annex II – see information sources there.

5.2 Approach to assess the marine ecosystem capacity to supply multiple marine ecosystem services from a single EU policy-relevant ecosystem component, biotic group, or habitat

The assessment method described above (and applied in full to the test case assessments) considers the ecosystem capacity to supply a single ecosystem service, normally based on the contribution of multiple ecosystem components, i.e. a service-by-service approach. However, each ecosystem component can contribute to the ecosystem capacity to supply multiple ecosystem services (e.g. birds and fish biotic groups in variable salinity water habitats, Table 5.43). A framework is described here for carrying out an assessment of the ecosystem capacity to supply multiple ecosystem based on the contributions of a single ecosystem component, or habitat, i.e. a component-by-component approach.

The input to an assessment of a multi-service situation is to map all the links between the ecosystem component of interest and the ecosystem services to which it contributes (or can supply on its own). In this case, it is not necessary to identify the critical component for any one service. It is, however, necessary to identify/determine the relative contribution of all the component to each service for all service. This is because in order to determine the *relative* contribution of the assessed component, the level of contribution by the other components that contribute to that service needs to be known. For many of the services a given component contributes to, the majority of components may make only a small contribution. For example, fish are likely to make a large contribution to the *Seafood from wild animals* service compared to other ecosystem components, and a smaller relative contribution *to the Global climate regulation* service than some other components.

The remainder of the method mirrors that for a single service (i.e. the one outlined in Section 5.1), although the (ecosystem) state-service (generation) relationship (Step 2, Section 5.1) between the component and each relevant service must be assessed separately.

Table 5.43 Example: Birds and fish biotic groups in the *Variable salinity water* habitat type contribute to multiple ecosystem services

Ecosystem Service	*Variable Salinity Waters*	
	Birds	Fish
2. Seafood from Wild Animals	o	X
3. Plant and Algal Seafood from *in-situ* Aquaculture		
4. Animal Seafood from *in-situ* Aquaculture		X
5. Raw Materials	o	X
6. Materials for agriculture and aquaculture		X
7. Genetic Materials		X
11. Waste and Toxicant Removal and Storage	X	X
12. Mediation of smell/ noise/visual impacts	X	
16. Seed and Gamete Dispersal	X	
17. Maintaining Nursery Populations and Habitats		X
18. Gene Pool Protection	X	X
19. Pest Control	X	X
20. Disease Control	X	X
21. Sediment nutrient cycling	X	X
22. Chemical Condition of Seawater	X	X
23. Global Climate Regulation	X	X
24. Recreation and Leisure	X	X
25. Scientific	X	X
26. Educational	X	X
27. Heritage	X	X
28. Entertainment	X	X
29. Aesthetic	X	X
30. Symbolic	X	X
31. Sacred and/or Religious	X	X
32. Existence	X	X
33. Bequest	X	X

Notes: 'x' refers to a direct contribution of the biotic group in that habitat to the supply of a service and 'o' refers to an indirect link – see Section 4 for further description of linkages

Thus, the steps for this component-by-component assessment are:

Step 1 Identify all ecosystem services to which the given ecosystem component can contribute

This step can be carried out at the Stage 1 linkages (see Section 4 of this Report) with the linkages reviewed and restricted to those applicable to a specific EU marine region, if necessary.

Step 2 For each service, identify the relative contribution of the given ecosystem component to its supply

In order to identify the relative contribution of the focus ecosystem component to the ecosystem capacity to supply each relevant service, it is necessary to identify the relative contribution of all other components contributing to each relevant service.

At this point, all services could be carried forward in the assessment to get a full picture of all the services a component can supply. However, another approach could be to identify those services for which the component is critical, and only carry these forward. It should be noted that the relative contributions of different components to an ecosystem service, may vary by location/assessed area.

Step 3 Establish the (ecosystem) state-service (generation) relationship

The (ecosystem) state-service (generation) relationship between the focus ecosystem component and each service it has the capacity to supply must be determined.

Step 4 Assess the current state and direction of change in the state of the given ecosystem component

The state of the focus ecosystem component should be classified as 'passing' or 'failing' EU (or other) policy objectives and the direction of change in the state of the component should be classified as moving 'towards' or 'away' from such policy objectives.

Step 5 Assess the current state of and direction of change in the capacity of the ecosystem to supply each service

The nature of the (ecosystem) state-service (generation) relationship, the relative contribution of the component to the services it has the capacity to supply, and the current state and direction of change in the state of the component can be used to assess the current state of and the direction of change in the capacity of the ecosystem to supply each relevant ecosystem service.

Step 6 Assess the future state of and direction of change in the capacity of the ecosystem to supply each service

Future changes in the service supply capacity of the ecosystem component of focus should be assessed using forecasted outlooks for the future state and/or future state trend of the component relative to EU (and other) policy obligations, or pressure as a proxy for the potential future trend in the state of the component.

The results of such an assessment can be summarised in a table (e.g. Table 5.44). In this case the relative contribution of the ecosystem component should be specified since this will indicate the importance of the component to the ecosystem capacity for the supply of that service. To note, however, that this assessment option was not feasible at the time the MECSA method (outlined in Section 5.1) was developed (2014). This was due to not only insufficient knowledge on cause and effect within marine ecosystems, but also, and most importantly, because the particular information required to run such a component-based assessment was not available at the EU level.

Table 5.44 Example of the presentation of the potential outcome of the assessment of marine eco-system capacity for service supply when starting from a single EU policy-relevant ecosystem component

Eco-system service	Relative contribution of component to service	EU marine region							
		NEA		Mediterranean Sea		Baltic Sea		Black Sea	
		Current	Future	Current	Future	Current	Future	Current	Future
1	5 %	Im-proving	Deterio-rating	Im-proving	Stable	Deterio-rating	Im-proving	Deterio-rating	Deterio-rating
2	90 %	Stable	Im-proving	Deterio-rating	Stable	Stable	Stable	Im-proving	Im-proving
…	…								

5.3 Summary

Two options have been presented for the assessment of marine ecosystem capacity for service supply in this section, one in detail – a single service assessment method, and the other in outline – starting from an ecosystem component (or biotic group and habitat) and assessing all the services it can supply. The key elements of such an assessment are as follows:

- Identify the critical components for the ecosystem capacity to supply the service or services. Comparable work has referred to the ‘service providing units’ (Kremen, 2005). Here we describe an approach to identify these in any given EU marine region and give an estimate of their relative importance to the ecosystem capacity for service supply.
- Establish the (ecosystem) state-service (generation) relationship. This step is a crucial part of the method here and involves developing a thorough understanding of how the ecosystem can supply a service. This can potentially be the most limiting part of the method due to our limited understanding of the relationship between many services and the ecosystem; thus, it has the potential to lower our confidence in the assessment outputs. However, it is important to elucidate this relationship as much as possible to be able to use ecosystem state information in the most appropriate way and to interpret this information in a way that truly reflects the capacity of the ecosystem to supply services.
- Assess the current state and direction of change in the state of the marine ecosystem (i.e. of the critical component and other parts of the ecosystem where relevant) using EU (and other) policy relevant information. This part of the method presents an approach that can use information that is freely available and is policy relevant, which can then be used for another purpose – to assess the capacity of marine ecosystems to supply ecosystem services. The marine ecosystem assessment is then combined with the understanding of the (ecosystem) state-service (generation) relationship to interpret ecosystem state (and its direction of change) into what it means for service supply capacity (and also for how this can change over time).
- The service supply capacity assessment method presented in detail (section 5.1) includes a confidence assessment at each relevant operational step. This recognises that we are proceeding with an assessment that has a number of assumptions and limitations. These assumptions and limitations are not prohibitive to carrying out the assessment, but we address them through the confidence assigned to each step. Assumptions and limitations of the assessment approach are explored further in Section 6.
- The overall MECSA approach also recognises that society and the marine ecosystem are changing, and recommends adaptive management to integrate these changes into the approach, and related methods, over time.

6 Summary of the Key Assumptions and Limitations of the MECSA Approach

The remit of this study was to provide an EU-level marine ecosystem-based assessment approach (i.e. a concept, framework and method) that considered how ecosystem state affects its capacity for the supply of ecosystem services and used existing EU (and other) policy-based marine ecosystem structures (i.e. species/species groups and habitats) and information to assess this capacity. The ultimate goal of the approach being to assess the sustainability of marine ecosystem capacity for service supply. We, thus, developed and tested a new approach: The Marine Ecosystem Capacity for Service Supply Assessment (MECSA), which involves assessing marine ecosystem state and translating that into an assessment of marine ecosystem capacity for service supply in the present and in the future. Through the process of developing the approach, it became clear that there were a number of key assumptions that need to be made to fulfil its remit; while testing the approach brought forward a series of limitations that influenced what could be achieved.

In this section, we summarise the **key** assumptions and limitations that arose in both developing and testing the MECSA approach. These have been identified at appropriate points throughout the previous sections of this Report, but we return to **key** ones here in order to provide a synoptic overview, organised under the following broad areas:

- Section 6.1: Assumption and limitations of the MECSA concept
- Section 6.2: Limitations of adapting the Common International Classifications of Ecosystem Services (CICES version 4.3) to marine ecosystems
- Section 6.3: Assumptions and limitations of developing marine ecosystem components
- Section 6.4: Limitations of linking marine ecosystem components to marine ecosystem services
- Section 6.5: Assumptions and limitations of the MECSA method
- Section 6.6: Limitations of the test case assessments of the MECSA approach
- Section 6.7: Limitations of the information sources used for the MECSA test case assessments

6.1 Assumptions and Limitations of the MECSA concept

The MECSA concept is based on the connection between the state of the marine ecosystem and the supply of marine ecosystem services. Thus, this connection captures the self-regulating/renewing aspects of the ecosystem. In addition, assessing the state of the marine ecosystem using EU policy-based information means that the resulting assessment of service supply capacity reflects likely changes in this capacity as a result of changes in ecosystem state due to policy interventions. Following from this, there are two key assumptions underpinning the MECSA concept as follows:

- The capacity of the ecosystem to supply ecosystem services is dependent, in some way, on the state of the ecosystem
- The quality classifications of EU-level marine ecosystem assessment products on marine ecosystem state and trends are relevant to assessing the ecosystem capacity to supply ecosystem services

These assumptions are described below, along with their associated limitations.

6.1.1 *The capacity of the ecosystem to supply ecosystem services is dependent, in some way, on the state of the ecosystem*

A fundamental assumption of this work was that the state of the marine ecosystem can inform us on its capacity to supply marine ecosystem services. We defined marine ecosystem capacity for service supply here as: "*the effective capacity (potential) of an ecosystem to supply services, which is that based on its state and so linked to its functioning (rather than pure or total capacity, sensu MA (2005), which is linked to just its extent)"* (see Section 1).

Thus, changes to the state of the biotic parts of the ecosystem (e.g. fish, plankton, macroalgae), influenced by their local habitat condition, could lead to a change in the capacity of the ecosystem to supply ecosystem services. This assumption is limited by our understanding of how the ecosystem can supply services (see Section 4) and of how ecosystem state relates to its capacity for service supply (see Section 5) (*first limitation*). For each service assessment, therefore, establishing the relationship between the state of the components of the ecosystem holding the capacity to supply a particular ecosystem service and (the state of) the ecosystem capacity to supply that service, i.e. the (ecosystem) state –service (generation) relationship, is a key consideration. It is important to note that other parts of the marine ecosystem may also be involved in this relationship, such as certain physico-chemical attributes (e.g. nutrients) (see Step 2 in Section 5). Also, that it is not implicitly assumed that a good state of these components, and other parts of the marine ecosystem where relevant, will mean a good capacity of the ecosystem to supply services, although in many cases this will be true (but there are exceptions).

Establishing the nature of the (ecosystem) state – service (generation) relationship is fairly straight forward in cases where a clear link between them can be made, such as between state of phytoplankton and the state of the ecosystem capacity to assimilate waste nutrients. However, in many cases, the type of relationship may be more difficult to characterise. Limitations in characterising this relationship may arise because either there is a lack of knowledge on the relationship, or, where information exists, it suggests that the relationship is multifaceted, making it difficult to predict how the ecosystem capacity to supply a service will change with a change in relevant aspects (e.g. ecosystem components) of ecosystem state (*second limitation*).

On the first limitation mentioned above, the understanding of the relationship between marine ecosystem functioning and how this leads to the supply of *some* ecosystem services is currently not good enough to allow us to predict how a change in the state of the ecosystem can lead to changes in its capacity to supply (certain) ecosystem services. While understanding of ecosystem functioning and service supply capacity has developed, there are still many gaps in our knowledge. One major gap is for the cultural services. While we intuitively understand that people get many cultural benefits from interacting and experiencing marine ecosystems, we do not always understand the pathways through which the functioning of marine ecosystems specifically lead to those interactions, experiences and benefits. It is clear that there is a need for further work in this area as covered under Section 7.3 of this Report.

On the second limitation mentioned above, in Section 4 of this Report we covered a number of examples where the relationship between (ecosystem) state – service (generation) was particularly intricate. For example, how does the ecosystem capacity to supply an aesthetic interaction/ experience and the related benefit (e.g. the enjoyment provided by a pleasant view of a marine landscape) relate to the condition of the marine biota and habitats experienced? In some cases, such as if the habitats were polluted with litter, then both the ecosystem state and its capacity for service supply (the aesthetic service) would be negatively affected. But in another case, reduced biodiversity in habitats (perhaps indicating poor status), may not have much of an impact on the overall view and experience provided when interacting with these habitats, and so service supply capacity may remain unaltered; whilst the state of the habitats themselves might already be recorded as being degraded. It is certainly the case that the MECSA approach should not be applied based on the assumption that there is always a linear, positive relationship between the state of the ecosystem components, and other parts of the marine ecosystem where relevant, and (the state of) the ecosystem's capacity to supply a specific service.

The assumption that the ecosystem capacity to supply ecosystem services is dependent, in some way, on the state of the ecosystem, is most limiting where it is hard to establish *any* clear relationship between (ecosystem) state – service (generation). For example, the relationship between the state of the ecosystem and the supply of the *Heritage* service can be particularly difficult to characterise, especially where the service type refers to a historic/past state. Thus, the value ascribed to the *Heritage* service may have no relationship with the current (or future) state of the ecosystem. If one takes heritage associated with whaling as an example of this, particular areas or regions may be valued because they were once important for whaling and the current depleted state of many whale populations may have no effect on the perception that an area has this heritage value. This is a form of 'state to capacity' decoupling, which is described in more detail under Section 4. Where this occurs, it is not possible to assess the particular service type using the MECSA approach as it stands, although there would be other approaches to deliver an assessment of the sustainability of the marine ecosystem capacity to supply cultural ecosystem services (see Section 7).

As we did not carry out test cases for (the capacity of the ecosystem to supply) all ecosystem services, we cannot give a definitive list of those services for which this assumption (i.e. that the capacity of the ecosystem to supply ecosystem services is dependent, in some way, on the state of the ecosystem) is particularly limiting. But, as we gather more understanding of ecosystem functioning and the ways that this affects its capacity to supply ecosystem services (see recommendations under Section 7.3), the first limitation described above will reduce. However, it is clear that there is a number of cultural ecosystem services where there is genuine decoupling between ecosystem state and the state of its capacity to supply them (see examples under in Box 4.2, Section 4); a clear takeaway message of this work should be that the MECSA concept will be limited in its application for those services (but see suggestions on what might be done instead under Section 7).

6.1.2 The quality classifications of EU (and other) level assessment products on marine ecosystem state and trends are relevant to assess the capacity of marine ecosystems to supply ecosystem services

Much of the information we set out to use in carrying out the assessment of ecosystem state underpinning the ecosystem service supply capacity assessment actually came from assessment products, namely status assessments, linked to the implementation of EU (and other) legislation/policy. We use ecosystem state as it is defined by Maes et al. (2013), as "the physical, chemical and biological condition of an ecosystem at a particular point in time". This differs to ecosystem status, which they define as "a classification of state among several well-defined categories; it is usually measured against time and compared to an agreed target [in relevant EU environmental directives (e.g. HD, WFD, MSFD)]" (see Section 1). Status assessments, thus, already interpret the state of the ecosystem against reference or target conditions, providing a quality classification that is often interpreted to be equivalent to an assessment of the 'health' of the ecosystem, with 'good' status equating to a 'healthy' ecosystem. The same tends to apply to assessment products from other policy instruments than EU environmental directives.

In a MECSA context, these status, as well state trend or trend in status, quality classifications are the actual input into the assessment of ecosystem state (see Section 5). This means that the overall objectives of the EU policy instruments generating the relevant assessment products are used to determine the state and direction of change in the state of the metrics of, e.g., the critical ecosystem components included in our state assessment, and, thus, the state of and direction of change in marine ecosystem capacity for service supply.

In order fulfil this use, status classifications must be interpreted in terms of how they relate to the relationship between (ecosystem) state – service (generation). For example, how does the difference in status of a biotic group between 'high', 'good', 'moderate', 'poor' and 'bad' under the WFD bear on the ecosystem capacity to supply specific services? We have, therefore, had to assume that the categories used in the relevant status assessments to indicate whether an EU policy objective is being met or not, in absolute terms (i.e. as a 'pass' or 'fail') are indeed differentiated in a way that is meaningful in terms of influencing the marine ecosystem capacity to supply an ecosystem service (see also points 6.5.2, 6.5. 4 and 6.7.1).

6.2 Limitations of adapting CICES (version 4.3) to marine ecosystems

The Common International Classifications of Ecosystem Services (version 4.3, CICES, 2013) is the EU 'reference' typology for ecosystem services adopted by Working Group (WG) MAES (see Section 1) and is the typology for ecosystem services used in the MECSA approach, which had the remit of being based on EU policy. This typology has been designed to work across ecological realms. We, therefore, carried out an initial screening of the services included in it to ensure that they were applicable to marine ecosystems. In doing this, we excluded some of the services as not being relevant for our purposes because they do not originate from marine ecosystems, they are mainly driven by marine abiotic processes, or they are negligible in terms of the supply originating from marine ecosystems when compared to other ecosystems (see Section 2). We also assigned working names to each marine ecosystem service (at the CICES 'class' hierarchical level in most cases but see Section 2) as we found the CICES names to be too inaccessible to be understandable at first glance and to be used regularly throughout this Report. Once this list was established, we looked at each service in greater depth through identifying the linkages with marine ecosystem components. The detailed work on understanding the typology of ecosystem services is covered in Section 2, and how those services are described and supplied by marine ecosystems in Section 4. This work has added great depth to the understanding of the applicability of CICES in a marine context; some of which has been picked up in the more recent developments of CICES (i.e. the production of version 5.1, see Haines-Young & Potschin, 2018 and Section 7).

It is important, therefore, to understand the limitations related to the application of our typology of marine ecosystem services, where key ones have been re-capped below.

6.2.1 A service considered 'final' in CICES (version 4.3) could justifiably be considered to be an 'intermediate' service in other ecosystem service classifications

We defined ecosystem services in this assessment as: '*Ecosystem services represent the flow of ecosystem capital that is realised because of a human active or passive demand. They are thus the final outputs from ecosystems that are directly consumed, used (actively or passively) or enjoyed by people* (see Section 1)'.

Applying this general definition, which is central to the CICES approach, meant that we had to identify final outputs for each ecosystem service. In terms of distinguishing what are 'final' services, we also followed CICES in confining those to the ecosystem outputs *directly* consumed, used (active or passively) or enjoyed by a beneficiary. In contrast, intermediate services are only *indirectly* consumed/used/enjoyed by people; can themselves support many other ecosystem services; and care must be taken to avoid the 'double assessment' of (final and intermediate) services in a services assessment, or the 'double counting' of the benefits from (final and intermediate) services in the economic valuation of service benefits and/or in the monetary accounting of ecosystem services (i.e. the benefit of the final and that/those of the intermediate service/s making it possible). However, as elaborated in Section 1, there is much debate in the field of ecosystem services as to what should be described as a final or intermediate service; although it has been clarified that this is contextual and that CICES should be seen as being about 'potential final services'.

As such, we note that a limitation of the MECSA list and typology of marine ecosystem services is that a service considered 'final' in this list/typology, because it is so in CICES (version 4.3), could justifiably be considered to be an 'intermediate' service in another list/typology. Thus, many of the Regulation and maintenance services included are often considered as intermediate services by other authors, e.g., through maintaining water conditions suitable for producing seafood or for carrying out recreation and leisure activities (see Section 4, Box 4.1 for a list of services that could be considered intermediate elsewhere). At times, we struggled to come up with examples of 'final outputs' for these possibly intermediate-final services. To do so, we included consideration of avoidance costs, e.g., that there would be a cost in treating waste not otherwise treated by the sea under the *Waste and toxicant removal and storage* service; and of very small-scale examples, e.g., rearing sheep on saltmarsh under the *Sediment nutrient cycling* service. On the one hand, the MECSA approach is not likely to be translatable/linked to a subsequent economic assessment. On the other hand, including these services is fully representative of all the ways that the ecosystem contributes to meeting people's basic needs and supporting their well-being and their livelihoods/economy, even if they cannot always be monetised. As described in Section 1, the remit of the MECSA approach was to be as inclusive as possible of the full capacity of marine ecosystems to supply marine ecosystem services. This meant that we did not constrain: (a) our ecosystem services typology to those services that can be easily valued in monetary terms, or (b) our ecosystem components typology to those components covered by *existing* EU (and other) legislation/policy assessment information. We felt that this was an essential standpoint to take because it would reveal what we need to know to have a full picture of how the state of marine ecosystems contributes to people's lives and highlight gaps where information or methodology currently preclude full coverage of this.

6.2.2 There is a 'blurring' of ecosystem functions, services, benefits and goods in our marine ecosystem services typology and list adapted from CICES (version 4.3)

In Section 1, we described the ecosystem services 'cascade' (Figure 1.3, Potschin & Haines-Young, 2011). This outlines the flow from ecosystem structures to the processes and functions they carry out within the ecosystem, the services they can provide and, ultimately, the benefits and values that come from using those services. This cascade has been developed to avoid 'double-counting', i.e. to clearly distinguish separate (final) ecosystem services and only count each once in an assessment or, as mentioned above, in an economic valuation of service benefits. When services are not clearly distinguished from ecosystem processes/functions and goods/benefits, there is a risk that the same service could be counted several times or of confusion between services and good or benefits. In working with CICES, however, we found that there was some 'blurring' across the names used by CICES at all the levels within the hierarchy. Thus, what is being conveyed by the name can, at times, be: (1) an ecosystem process or function (i.e. an intermediate service); (2) a (final) service; (3) a human activity drawing on the service; (4) a service benefit; and/or (5) even a good (according to other assessment approaches). This can lead to confusion when it comes to clearly identifying what parts of the ecosystem contribute to the capacity to supply of a given service. We addressed this by clearly defining what we assume each service represents and identifying at least one beneficiary for each service in Section 4; however, we did not attempt to reclassify and rename services in order to develop a consistent typology and so our services list and typology suffer from the same 'blurring' as CICES (version 4.3).

6.2.3 There are potential overlaps between services in our marine ecosystem services typology and list adapted from CICES (version 4.3)

In considering each service in detail (see Section 4), we found that some services could potentially overlap with others because their descriptions could be open to interpretation (see Table 4.2, Section 4). Throughout Section 4, we tried to clarify what should be included under each service to prevent such overlaps. However, CICES version 4.3 did not provide a detailed enough description of each service and, therefore, if used directly as such, these overlaps could cause confusion and potential 'double-counting'. The new version 5.1 of CICES provides more detail on what each service means, which should help clarify issues of overlap but, when considering very specific examples within service classes, it may still be unclear where something fits within the typology. A user needs to be aware of this and clearly define what he/she intends to assess. In different applications of a marine ecosystem services assessment approach based on CICES, there could be different interpretations of what the services represent. It is important to be clear and consistent on the use of a typology, such as CICES, within an assessment.

6.2.4 Service classes in the CICES (version 4.3) hierarchy are broad and encompass many things

When it came to carry out the service supply capacity assessment, it was found that the service 'class' level of the CICES (version 4.3) hierarchy would be mostly too broad to operationalise using the MECSA approach (and this is before we modified a couple of 'classes' and/or 'groups', see Sections 2 and 4). Thus, in the tests, we further defined service 'types', which would more clearly elucidate the specific parts of the ecosystem that hold the capacity to supply a given service. For example, rather than assessing the extremely broad *Recreation and leisure service '*class', we assessed the *Recreation and leisure from whale watching* service 'type'. A limitation of this approach is that a whole range of detailed assessments would need to be made for each service class (of which we identified 31 classes as being supplied in EU marine regions, see Section 4) in order to carry out a full marine ecosystem service supply capacity assessment.

6.2.5 We had to limit what 'marine' ecosystem services are within the land-sea interface

At the boundary between ecological realms, namely the land-sea interface, there are services supported by marine ecosystems that are not marine ecosystems services. For example, the supply of the CICES (version 4.3) *Reared animals and their outputs* service could be supported by saltmarsh habitats, e.g., sheep grazing there, but we do not include sheep as marine biota in developing marine ecosystem components; thus, we do not include this service as being 'marine'. We do acknowledge the contribution of the marine ecosystem to this service though, which is through sediment nutrient cycling because this supports the nutrition of the sheep and benefits the farmer (see Section 4).

6.3 Assumptions and limitations of developing marine ecosystem components

We developed an EU policy-relevant set of marine ecosystem components built, ultimately, on the MSFD typology of marine habitats and the species groups listed as falling under the scope of this directive. This enabled the link to the ecosystem structures under the scope in EU water, marine and nature directives, as they tend to overlap but across different scales, and the use of assessment information generated by their implementation.

We firstly defined a typology of marine habitats using the MAES marine habitat typology as a starting point. This is included in the MAES marine ecosystem typology (see Table 3 in Maes et al., 2013), which is the EU 'reference' typology for ecosystems. This means that we actually used the MSFD predominant habitat types, which is what WG MAES had used in developing the MAES marine habitat typology, and which are quite broad – corresponding to the Level 2 of the EUNIS marine benthic habitat classification. To note, however, the WG MAES concept and framework for the assessment of ecosystem and services only included habitats (and so a habitat typology), as it is a spatial approach, and not species groups. We considered that this approach would miss important aspects of marine ecosystem capacity for service supply as it is, ultimately, the species groups what hold this capacity and can, thus, supply services upon a demand. We, therefore, defined a list of both sessile, planktonic and highly mobile 'biotic groups'. Marine ecosystems are highly connected and mobile biotic groups, such as whales or fish, can move throughout them. This would not be captured using a habitat typology only. We defined the mobile biotic groups following very closely the MSFD list of functional groups of widely disperse and highly mobile species (in EC, 2011b). We also made explicit the other species groups (e.g. infauna, plankton, etc.), which are considered to be part of the MSFD predominant habitat types, i.e. embedded in benthic and pelagic habitats, both when these have been listed as being under the scope of the directive (in EC, 2011b) and adding to that (e.g. bacteria). This is because the way these groups can supply ecosystem services could differ in different habitats and we wanted to be able to reflect this. We then identified every association between a biotic group (from those in our broad list of groups) and a habitat type (from those within our typology) to create a set of marine ecosystem components.

It is important to consider the assumptions we made when developing this set of marine ecosystem components.

6.3.1 The marine habitat typology we used needed to relate to the ecosystem capacity to supply ecosystem services, which required assuming certain characteristics of these habitats

We made an assumption that some benthic and pelagic habitat types are always photic, even if we know that the natural conditions may mean that this is not always true. We did this to highlight an aspect of the ecosystem that is particularly important to service supply, i.e. whether habitats can be photic or not, because the photosynthetic biotic groups can provide a unique set of services that would, otherwise, not be provided in habitats where they do not occur (as they are aphotic). However, we could only represent the limit of the oligophotic zone across our marine habitat typology, rather than the limit of the euphotic zone (see Section 3 for full discussion on this). This would result in an overestimation of the spatial magnitude of the ecosystem services underpinned by certain photosynthetic biotic groups, which could lead to overestimating the ecosystem capacity to supply the unique 'photic' services across the relevant habitats if this capacity was assessed in a (fully) quantitative manner, which is not the case here (see Section 5). Thus, some biotic groups, e.g. angiosperms, are limited to the euphotic zone, i.e. they do not occur within the oligophotic zone. In addition, in reality, the local characteristics of habitats (e.g. turbidity, depth) mean that photosynthesis does not occur across the full range of that habitat in a region being assessed. We, nevertheless, stand by the fact that this approach represents how ecosystems supply services in the most meaningful way as it includes all services that can be supplied in the 'photic' habitat types overall, and it is the link to services that are important in the MECSA approach. In Section 7, developments in the EU level categorisation and mapping of marine habitat types are described, and it is likely that (with the then required updates to the marine habitats typology used in the MECSA approach) these will lead to a greater potential to apply the MECSA approach respecting the important differences between photic and aphotic habitats.

6.3.2 The individuals of the same population of a particular highly mobile species group can move between all of the habitats they associate with in our habitat typology at different times

A link between a biotic group and a habitat type reflects the potential for a biotic group to spend some or all of its life in that habitat type, be it embedded within it, e.g., sessile benthic invertebrates, or a highly mobile species, such as a seal, feeding temporarily in it. Some highly mobile species, such as whales and dolphins, have been associated with a range of habitat types that they could potentially use in their lifetime. In linking biotic groups and habitat types, therefore, we assume that individuals of the same population of a particular highly mobile species group, e.g. whales, can move between all of these habitats types at different times, i.e. that whales occurring in *coastal waters* at some point in time would belong to the same population as also found in *oceanic waters* at another point in time. This is done to capture the connectivity of the marine system.

6.3.3 Marine biota and their habitats are always associated with each other within our approach, even if we are not always explicit about it

Each marine ecosystem component is made up of a single, specific association between a habitat type and a biotic group (see diagrams in Section 3). We always (implicitly or explicitly) assume that biotic groups are associated with their habitats, and that habitats are associated with the biotic groups that live, or spend time, in them. However, depending on what is relevant, throughout this Report, we have sometimes referred to only a particular habitat or only to a particular biotic group by name, but, in those cases, we implicitly also mean their biotic groups or habitats, respectively. Therefore, we are always consistent in our approach of using marine ecosystem components, as have been defined here.

It is also important to consider the limitations associated with developing the set of marine ecosystem components.

6.3.4 We had to limit what 'marine' habitats are within the land-sea interface

We have excluded habitats at the boundary between ecological realms, namely the land-sea interface, from our habitat typology. These are habitats which do not have a direct connection with the sea (e.g. are above the splash zone). However, they could still have a connection to marine ecosystems, e.g., sand dunes within what we have considered as the supralittoral zone here (see Section 3). This means that both these habitats and their biotic groups can contribute to the supply of marine ecosystem services, like *Flood protection,* alongside the marine ecosystem components included here. They can also support marine biotic groups like (the nesting of) birds or reptiles and so the services these have the capacity to supply or contribute to supply. The habitats we have excluded from the MECSA approach are, nevertheless, accounted for under a terrestrial ecosystem service assessment in a MAES context (see EEA, 2016a) and, therefore, are not missed from a full assessment of the ecosystem capacity for service supply. Notwithstanding, it would be desirable to be able to assess their relative contribution alongside that of marine habitats to a common service in a harmonious way.

6.3.5 We have not included every marine species group explicitly in the list of our biotic groups

Viruses and fungi have not been included in the list of biotic groups (in Section 3). Marine viruses are thought to be the most abundant marine lifeforms and play major roles in marine ecosystem functions, such as in driving biogeochemical cycles (Suttle, 2007). They are also a major source of genetic and biological diversity. Marine fungi are also important as decomposers in marine ecosystems (Hyde et al. 1998). Thus, viruses and fungi are likely to contribute to marine ecosystem capacity for service supply either directly (e.g. bioprospecting for genetic diversity) or indirectly through the process/functions (i.e. intermediate services) they carry out within the ecosystem. Functionally and ecologically, their contributions may be captured under the 'bacteria' biotic group here, but future work should consider their specific contribution to service supply and whether they should be included as separate biotic groups. We are currently limited in doing so by poor understanding of their roles in marine ecosystems as well as lack of information on their state at the EU marine regional level. Current and future research may enlighten us to whether there are any other biotic groups, not included here, that are also important for the supply of ecosystem services.

6.3.6 Aggregating our set of marine ecosystem components up to the 'Level 2' of the MAES marine ecosystem typology (which was an initial requirement of our approach) will lead to repetition

As described in Section 3, whilst it would be possible to nest our 'Level 3a' habitat types and 'Level 4' biotic groups under the four MAES 'Level 2' marine ecosystem types, this would lead to repetition of some of the habitat types and many of the biotic groups. Whilst this is not conceptually a problem when describing a typology for the ecosystem, it could lead to one if that is then used to try to list the ecosystem services supplied by these habitats types and biotic groups (see discussion under Section 6.4.2).

6.4 Limitations of linking marine ecosystem components to marine ecosystem services

We identified both direct and indirect linkages between marine ecosystem components and marine ecosystem services. A direct link indicates that a marine ecosystem component can supply a service directly in the habitat where the service is susceptible of being used by people (i.e. actually supplied). An indirect link indicates that a component supports, in the habitat where it occurs, the supply of a service that can be directly supplied in a different habitat (see Annex I).

In linking marine ecosystem components to the marine ecosystem services they can supply, we took a holistic approach. That is, we identified all the links between the full range of components and services; for example, including links where there was at least one known example of the use of a service in any of the four EU marine regions. It is important to note that service linkages do not indicate the relative contribution of marine ecosystem components towards, or the magnitude of, the ecosystem capacity for service supply[167].

Limitations of establishing these services linkages include that:

6.4.1 The linkages between our marine ecosystem components and marine ecosystem services are limited to those uses that were practiced and legal within the EU at the time they were established

In establishing the linkages between marine ecosystem component and marine ecosystem services, we only considered services that would be used in an EU context. Thus, we did not identify linkages where the services were not used in the EU due to access, cultural relevance, legal or technological reasons (see Section 4). For example, whales could represent seafood in Norway, but not in an EU context where regulations ban whaling. We also considered current (at the time) use and so, in a couple of cases, services were not assigned any link, i.e. marine biofuels (which have been used in the past and could be again in the future but are not currently in use). This means that the validity of the service linkages part of the MESCA approach is limited to the EU context at the time the linkages were established. However, due to changes in management, human activities or scientific research (such as the discovery of currently unknown medicinal properties of a species), the components that are now linked to the ecosystem capacity to supply a given service, may change over time. Thus, in order to remain policy, socio/culturally, economically and scientifically relevant, the overall linkages matrices between ecosystem components and services should be reviewed periodically in light of advances in understanding of the links between them, as these could have changed (see Section 7).

[167] However, the relative contribution of the critical ecosystem components to the supply of a given service is estimated as part of the service supply capacity assessment (in Step 2, see Section 5); meaning that this estimation was, eventually, carried out for the three ecosystem services on which we tested the MECSA approach.

Similarly, if applied to a different marine region, revisions to the services linkages would also need to be carried out. We did not consider the ecosystem capacity to supply services in the marine waters of non-EU countries that share EU marine regions. This was outside of our remit, i.e. an EU context, but we also we do not know enough about the ways, e.g., North African countries use marine ecosystem services from the Mediterranean Sea. Therefore, the MECSA services linkages are likely to underestimate the full way in which the four EU marine regions can supply ecosystem services to all human populations that use them.

6.4.2 Aggregating the links between our marine ecosystem components and marine ecosystem services up to the 'Level 2' of the MAES marine ecosystem typology will be difficult

As already mentioned under Section 6.3, the marine ecosystem components developed for the MECSA would be repeated across some of the MAES 'Level 2' marine ecosystem types because of the repetition of the MAES habitat types making up several of the MAES ecosystem types. In addition, the MAES ecosystem types are very broad and poorly defined in terms of their fit to how the ecosystem can supply ecosystem services (for example, they do not distinguish between pelagic and benthic habitats). Extending from this, and as discussed in Section 4.1 of this Report, although it was an aim of the development of this approach, putting forward the ecosystem services provided by the MAES 'Level 2' marine ecosystem types would be almost meaningless since the repetition of ecosystem components across them would mean that each MAES 'Level 2' marine ecosystem type would be linked to the majority of marine ecosystem services. This would not provide useful information when trying to discern which services are supplied by which habitats for planning or management purposes. We argue, however, that the MECSA ecosystem components are defined at the level required to provide a meaningful representation of the ways in which marine ecosystems hold the capacity to supply ecosystem services. They can, however, be meaningfully aggregated at the level of ecological zones/realms (e.g. water column habitats, ice habitats, photic seabed habitats, and aphotic seabed habitats) as defined in Table 3.4 and we have also shown there how the MAES 'Level 3' habitat types can be aggregated in the same way. Thus, the ecosystem services supplied from the different ecological zones or realms, as opposed to MAES 'Level2' ecosystem types, could be produced as a useful and policy-relevant output.

6.4.3 Having to work at a broad habitat type and biotic group level means that there is little differentiation in the ecosystem capacity to supply ecosystem services in some cases

Some aspects of our marine habitat typology did not seem to make a difference to how services could be supplied in terms of establishing the linkages between marine ecosystem components and marine ecosystem services. For example, there were no differences in the number of services that could be supplied by *variable salinity water* or *coastal water* habitat types, or by *shelf* and *shallow sublittoral* habitat types of different sediment composition. However, we expect that at a more resolved level, these divisions may be important. For example, different benthic communities inhabit muddy sediments compared to coarse sediments. Benthic communities of muddy sediment are better at recycling organic waste than communities of coarse sediment (Doggett *et al*. 2018); thus, these communities would have different relative contributions to the supply of the *Waste and toxicant treatment* via biota service when this relates to organic waste. Knowing the extent of habitats where these communities can exist would, therefore, be advantageous for an assessment of this service. It is also important to note that the ecosystem components are differentiated to also reflect differences in the spatial supply of services; thus, although *variable salinity water* and *coastal water* habitat types may have links that show they can supply the same set of ecosystem services, the differentiation between any components linked to these habitat types will become important when, for example, the assessment is developed to link up with pressures on the ecosystem or demand for/use of the services (see Sections 7.2 and 7.3).

6.4.4 We do not always fully capture the connectivity between benthic and pelagic habitats when linking marine ecosystem components to marine ecosystem services

We did not consider the connectivity between planktonic and benthic life stages of marine fauna when linking marine ecosystem components to marine ecosystem services. We decided to focus on the links between the predominant life stages represented in each habitat type. Thus, as the assessment would be applied for a given time period (see Section 5), it would not be appropriate to try to account for different life stages of the same biotic groups across habitat types as supporting the same service. We do, however recognise that the connection between the pelagic and benthic habitats is important in marine systems, and the MECSA approach misses this connection in this specific instance.

6.5 Assumptions and limitations of the MECSA method

We developed a series of operational steps, i.e. a method (see Section 5), to assess the capacity of the EU marine regions to supply marine ecosystem services through a service-by-service approach. This involved first determining the relative contribution all of the components that can supply a given service as identified during the linkages stage (see Section 4). Critical component(s) (i.e. those with the higher contribution) are then chosen to take forward for the state assessment underpinning the service supply capacity assessment (see Figure 5.2). The current and future state of the (metrics of the) critical component(s), and the direction of change in their state, are assessed using EU (and other) legislation/policy-based information. The same with other parts of the ecosystem that are also involved in the (ecosystem) state- service (generation) relationship, where relevant. The current and future (state of the) ecosystem capacity to supply the service and the direction of change in this capacity is then determined. All parts of this process are informed by an understanding of the (ecosystem) state-service (generation) relationship.

As noted under Section 6.1, there are some key assumptions (and associated limitations) related to the concept of the MECSA approach that should be understood in considering the application of the MECSA method. These are not repeated here, but in brief include that: (i) the capacity of the ecosystem to supply ecosystem services is in some way dependent on the state of the ecosystem (point 6.1.1); and (ii) that the status quality classifications of EU-level (and other) marine ecosystem assessment products are relevant to assessing the ecosystem capacity to supply ecosystem services (point 6.1.2). A number of additional assumptions and limitations of applying the method are, however, outlined below.

Assumptions of applying the MECSA method include:

6.5.1 Using a critical path analysis approach adequately reflects what holds the main capacity to supply the service being assessed in a given EU marine region

We find the relative contribution of all the ecosystem components contributing capacity for the supply of a service and identify the critical one(s) amongst them as that/those with the highest relative contribution. This/these are the only components that go on to be assessed, which assumes that they adequately reflect(s) what is holding the main capacity to supply the service being assessed in a given EU marine region. As shown when establishing the services linkages (see Section 4 and Annex I), many ecosystem components can contribute to the supply of a service and choosing only the critical component(s) ignores, potentially, many others that can contribute capacity to its supply. Nevertheless, assessing only the most important components for the supply of a service is a way of optimising the use of the rather scarce assessment information on any aspect of marine ecosystem state available at the EU-level, by focussing on the most appropriate information to characterise the (ecosystem) state-service (generation) relationship.

6.5.2 Multiple marine ecosystem assessment products from different pieces of EU (and other) legislation/policy can be used together to inform our assessment of ecosystem state because the objectives of these policy instruments are complementary

When assessing a metric (of a critical ecosystem component for the supply of a service or another part of the ecosystem where relevant), we have used the status quality classifications of several assessment products on ecosystem state across several EU water, marine and nature directives, as well as other policy instruments as relevant, *all together* to come up with the overall classification for its state. We have done the same for the classifications of state trend (or trend in status) products to derive the overall classification for the direction of change in the state of the metric. Section 5 explains the reasons for doing so, including the need to use as many information 'sources' together as possible to fill gaps from each where feasible (see Step 3 in Section 5 and point 6.7.1 here). A key reason for this 'joint use' is that we have assumed that all the relevant pieces of EU (and other) legislation/policy cover different but complementary aspects of marine ecosystem integrity, and so that the joint use, of the quality classifications of the status assessment they generate, in the assessment here provides the best possible overall characterisation of marine ecosystem state. We have, therefore, considered that they all carry the same weight in terms of what is meant for both the state of the ecosystem and of its service supply capacity. This is an assumption because we have not investigated the actual comparability of the specific objectives of the different EU environmental directives, and of the other policy instruments, we have used. Thus, these may actually not be different or complementary towards the best characterisation of ecosystem state.

6.5.3 Pressure trends can be used as a proxy for trends in marine ecosystem state when this information is not directly available at the EU- (and other) level to use in our assessment of ecosystem state

In order to assess the direction of change in the ecosystem capacity for service supply, we assessed the direction of change in the state of a metric (of a critical ecosystem component for the supply of a service or another part of the ecosystem where relevant) using information on (current or future) state trend (or trend in status) generated by EU (and other) legislation/policy. However, when this information was not available (see Section 6.7), we used pressure trends as a proxy to indicate how the state of the ecosystem was changing or would change in the future (where possible). In order to conclude on the ensuing (current or future) direction of change in ecosystem state, we needed to know about the pressure-state relationship, but this turned out to be unknown in some cases. We, thus, assumed that a change in pressure would lead to an opposite change in ecosystem state where ecosystem state was known to be sensitive to the pressure being considered, e.g., a decrease in pressure would lead to an improvement in ecosystem state.

Limitations of the assessment method include:

6.5.4 We may have underestimated the ecosystem capacity to supply a service due to the way in which we process the status quality classifications of EU-(and other) level assessment products on marine ecosystem state

As explained in point 6.5.2, we have used all the relevant status quality classifications of assessment products on ecosystem state available at the EU-level *together* to assess the state of (the metrics of) a critical ecosystem component for the supply of a service, and other parts of the ecosystem where relevant. We have, therefore, needed to align the different quality classifications of status from the different EU environmental directives, such as 'good', 'bad', 'moderate', 'not good', 'unfavourable-bad', etc., and also those from other legislation/policy we have brought in for gap filling, in order to use them together in our state assessment. We have done this aligning by considering them to broadly divide into a ‘pass’ or ‘fail’ in achieving the respective overall objective of each directive and followed a similar approach when using other information (see Section 5 and Annexes II-IV). Thus, the status categories that correspond to achieving the respective overall legislative objective are placed under ‘pass’, and all other categories are considered to ‘fail’. In other words, any deviation from achieving the overall policy objective is considered a ‘fail’. The (ecosystem) state-service (generation) relationship is then considered and the capacity for supply of services assessed based on the overall (aggregated) ‘pass’ or ‘fail’ classification of state given. We have done this following a precautionary approach to avoid over-representing the state of marine ecosystem capacity for service supply. However, such a precautionary approach means that we could have underestimated this capacity because if an assessment product has an, e.g., ‘moderate’ classification we have attributed a ‘fail’ to it as if it was ‘bad’, which then means that its contribution to the ecosystem capacity for service supply is ‘bad’.

6.6 Limitations of the test case assessments of the MECSA approach

We carried out test case assessments of the MECSA approach, based on three marine ecosystem services covering various EU marine regions, or parts of regions, in order to help develop the method and evaluate its feasibility (see Annexes II–IV). A summary of these tests is found in Table 6.1 below. It is important to recognise that these are test case studies, and not real assessments, for the following reasons:

1. They did not all consistently cover the four EU marine regions.
2. They were carried out in 2014 (at times using and accessing information that may have been older than that, see Section 6.7) and have not been updated since.
3. The information available at the EU-level with which to carry out the state assessment, underpinning each test service supply capacity assessment, was insufficient (see Section 6.7), which prevented concluding on the current or future direction of change in service supply capacity, or the future state of service supply capacity for some EU marine regions across the tests (see Table 6.1).
4. The information available at the EU-level with which to carry out the state assessment was not always the most appropriate. The method may have aimed at optimising the use of the rather scarce assessment information on any aspect of marine ecosystem state available at the EU-level, by focussing on selecting the most appropriate information to characterise the (ecosystem) state-service (generation) relationship. However, when information was available, this information was not always the most appropriate to characterise that relationship, i.e. to assess the specific metrics that needed to be assessed. Thus, there were instances when more general information had to be used as a proxy, and there was also some ‘forcing’ of the available information and mixing information from different (assessment) time periods (rather than only using information from the same time period).
5. There is insufficient knowledge on cause and effect, i.e. on causal chains, within marine ecosystems. This means that, at times, not enough was known about the pressure-(ecosystem) state and the (ecosystem) state-service (generation) relationships. Assumptions were made regarding the former, but the latter (also) prevented concluding on the future state of service supply capacity for some EU marine regions across the tests (see Table 6.1).
6. All of the test cases completed were done for single services. Section 5.2 describes how the method could be applied for individual ecosystem components across all the ecosystem services each contributes to, but this was not tested.

Section 6.7 below, on the limitations of the information used in the state assessments underpinning the service supply capacity assessments for each test, provides more detail on some of the issues listed above, as well as additional limitations of the assessment information.

Table 6.1 High-level overview of the three test case studies used to develop, evaluate the feasibility of and illustrate the MECSA approach to assess the current state and sustainability of Europe's seas capacity to supply ecosystem services framed by and based on EU policy

Marine ecosystem service tested	Critical ecosystem component	Marine region/ sub-region/part thereof assessed	Reason for choice of marine region/ sub-region/part thereof	Current service supply capacity and direction of change	Future service supply capacity and direction of change	Unable to assess
'*Seafood from wild commercial fish and shellfish stocks*' service type **CICES version 4.3 Section:** Provisioning	Commercial fish and shellfish (epifauna) species making up > 0.1 % of catch in all habitats where commercial fisheries take place	• North Sea • Western Mediterranean Sea	Commercial fisheries are a significant pressure across all marine regions/sub-regions/etc. but method only run in North Sea and Western Mediterranean Sea to represent a relatively information rich, as in other northern areas, and an information poor, as in other southern areas, situation respectively. The test used both data and assessment products generated by CFP implementation	• *North Sea*: 'Moderate' current service supply capacity (*), which had been 'improving' (*) • *Western Mediterranean Sea*: 'Bad' current service supply capacity (*)	Not undertaken	*Western Mediterranean Sea*: Direction of change in service supply capacity
'*Waste nutrient removal and storage*' service type **CICES version 4.3 Section:** Regulation and maintenance	Phytoplankton in all water column habitats	• North East Atlantic Ocean (NEA) • Irish Sea (part of the North Sea sub-region) • Baltic Sea • Mediterranean Sea • Black Sea	Eutrophication is a significant pressure across, or in certain parts of, all regions/sub-regions/etc. Irish sea included to run the method in a relatively information rich situation	• *NEA*: 'Good' current service supply capacity, which had been 'stable' • *Irish sea*: 'Good' current service supply capacity, which had been 'stable' • *Baltic Sea*: 'Bad' current service supply capacity • *Mediterranean Sea*: 'Good' current service supply capacity • *Black Sea*: 'Bad' current service supply capacity, which had been 'improving'	• *NEA*: 'Deteriorating' future trajectory of service supply capacity but future capacity could not be concluded • *Irish sea*: 'Stable' future trajectory of service supply capacity and 'good' future capacity • *Baltic Sea*: 'Improving' future trajectory of service supply capacity but future capacity could not be concluded • *Black Sea*: 'Stable' future trajectory of service supply capacity (*) but future capacity could not be concluded	• *NEA*: Future state of service supply capacity • *Baltic Sea*: Direction of change in service supply capacity, and future state of service supply capacity • *Mediterranean Sea*: Direction of change in service supply capacity, future state of service supply capacity, and future direction of change in service supply capacity • *Black Sea*: Future state of service supply capacity
'*Recreation and leisure from whale (and dolphin) watching*' service type **CICES version 4.3 Section:** Cultural	Whale and dolphin species relevant for whale watching	• North East Atlantic Ocean (NEA) • Mediterranean Sea	Whale (and other cetacean) watching is most significant in these regions (based on Hoyt, 2007, but still the case as per Carwardine, 2016)	• *NEA*: 'Good' current service supply capacity • *Mediterranean Sea*: 'Bad' current service supply capacity, which had been 'deteriorating'	• *NEA:* 'Improving' future trajectory of service supply capacity but future capacity could not be concluded (*) • *Mediterranean Sea*: 'Deteriorating' future trajectory of service supply capacity and 'bad' future capacity	• *NEA*: Direction of change in service supply capacity, and future state of service supply capacity

Notes: Service test case assessments carried out in 2014 and not updated since. Results shown based on the 'majority' aggregation approach for the underpinning state assessments (where relevant, (*) marks exceptions).

6.7 Limitations of the information sources used for the MECSA test case assessments

Assessments of the ecosystem capacity to supply ecosystem services based on EU (or other) legislation/policy have tended to be limited for marine ecosystems due to a lack of, or insufficient, suitable information (e.g. Maes et al, 2014; Mace et al. 2015). More recent developments have achieved spatial assessments and mapping of marine ecosystem capacity for service supply using other information sources, including modelled data (e.g. Liquete et al. 2016, Tempera et al. 2016). However, the remit of the MECSA approach meant that we focussed on using information available from the implementation of EU (or other) legislation/policy. We found that assessments of marine ecosystem capacity for service supply were feasible using this information, i.e. the above-mentioned test case assessments, but that the information available had a series of limitations. In addition, this information was often not spatially resolved at the right scale so that mapping of the assessed marine ecosystem capacity for service supply was not possible.

It should be noted that the limitations we describe below associated with the EU-(and other) legislation/policy information sources used for the state assessment, are only those it was possible to elucidate from carrying out the three test case assessments undertaken. Whilst many of the limitations described below would be true across other applications of the method, it is not possible to rule out there being further limitations of information sources, should a wider selection of assessments be undertaken.
Information used firstly came from EU legislation and policy (i.e. WFD, MSFD, BHD, CFP), but other information sources were used to fill gaps where this was not sufficient, such as assessments and indicators from Regional Sea Conventions, e.g., OSPAR and HELCOM (see point 6.7.3). It should be noted that the limitations relating to the information sources that could finally be used for the assessment were taken into account in estimating the confidence in the assessment (see Section 5 and Annex V).

6.7.1 Multiple marine ecosystem assessment products from different pieces of EU (and other) legislation/policy will often needed to be used together to achieve appropriate spatial coverage in our assessment of ecosystem state across an EU marine region

Different EU environmental directives cover different spatial areas within EU marine regions and the biotic groups under their scope tend to be but are not always the same. For example, the WFD spatial coverage of the ecological status of the marine species groups under its scope is generally limited to 1 nm; while the MSFD covers the environmental status of other marine species groups (than those under the WFD's scope), and also of marine habitats, over that same spatial area. Then, beyond that area, and up to 200nm, the MSFD additionally covers the same species groups as the WFD. The HD protects specific, and normally vulnerable, marine species and habitats, some of which may occur in the supralittoral, e.g. saltmarshes, and so have, most possibly, not being covered by the national implementation of the MSFD (nor by the WFD's, see Section 4). Therefore, no one policy instrument covers the entire spatial range of the MECSA ecosystem components within an EU marine region. This also applies to the spatial coverage of other parts of the ecosystem that needed to be assessed, where relevant. Thus, a further reason we have used the status classification of several assessment products across several different EU (and other) legislation/policy sources together in the state assessment (see points 6.5.2 and 6.5.4) is to be able to include as complete a spatial coverage of the range of these components and other parts of the ecosystem as possible, and so better reflect the state of and direction of change in the service supply capacity of each EU marine region.

6.7.2 There is not always alignment between our marine ecosystem components and the information available at the EU level that could be used to assess them

As explained in Section 3 of this Report and Section 6.3 here, we adapted available marine species and habitat lists/typologies to be more suitable to assess marine ecosystem capacity for service supply. However, the remit of the assessment also called for using typologies that were EU policy-relevant and linked to the WG MAES process and guidance. Thus, the MECSA typology of habitats and list of biotic groups were based on the MAES and MSFD marine habitat typologies as well as the MSFD lists of functional groups and biological communities inhabiting predominant habitat types, respectively. However, when it came to operationalising the assessment and finding policy-relevant information that linked to the MECSA marine ecosystem components (based on the MECSA typology of habitats and list of biotic groups), there were limitations as to what was available in policy-related information at the EU level. Thus, this information did not always align to what needed to be assessed according to our set of marine ecosystem components.

We found that the EU-level information available (where we primarily targeted that resulting from the implementation of EU water, marine and nature directives) did not allow to deliver the actual service supply capacity assessment (see Section 5) at the level of an ecosystem component for the test case assessments we trialled (see Annexes II-IV). Thus, results could only be produced at the level of the whole EU marine region because the information on the state of the (metrics of the) relevant biota tended to only be available at that level, rather than *within their associated habitat types*. For example, under case study 1 (Annex II) the main information used to assess how the state of the ecosystem affected its capacity to supply the *Recreation and leisure from whale watching* service, was the state of relevant whale populations, but this information had not been reported in relation to any particular habitat type at the EU level.

Even then, in some cases, the state of some of the MECSA biotic groups was not represented in the 'pool' of EU level assessment information generated by the implementation of EU (and other) legislation/policy because they are not explicitly under the scope of these policy instruments, e.g., there are no EU-level assessment products on the state of bacteria. This would mean that we could not make an assessment of the services that bacteria can contribute (capacity) to supply based *only* on the state of bacteria. Based on the MECSA method, this would be a major limitation where bacteria are the critical component in terms of the capacity to supply a particular service, but in all other cases, other ecosystem components would be used anyway (see further elaboration on this in Section 4).

In other cases, there were assessment products relating to the state of the MECSA biotic groups, but the information was aggregated at a different resolution to that of these groups. For example, there were EU-level assessment products on the status of the water column, including all its biotic components, which were developed using MSFD reported information; whereas we would require assessment information on phytoplankton and zooplankton separately. This aggregation also applied to the assessment products available to assess other parts of the ecosystem that needed to be assessed, where relevant. As a result, we needed to make an assumption about the available information in order to use it. For example, we did not know the individual status of each biological element included in the ecological status of a WFD water body, only the water body's ecological status, but we could assume it was the same for all of them and equal to that of the aggregated water body status. This would be appropriate with information from the WFD because this applies a 'one-out-all-out' aggregation approach for ecological status assessments (although it could result in an underestimation of status of individual WFD biological elements). However, the MSFD does not use this approach but the related assessment information available at the EU-level tended to also be aggregated (e.g. at the GES Descriptor's *criterion* level), when disaggregated information (e.g. at the GES Descriptor's *indicator* level) is what would be needed for our state assessment.

Where information directly related to the ecosystem components was not available, we used the best available proxies representing them and how they can supply the service (following the (ecosystem) state-service (generation) relationship). For example, to assess the *Waste nutrient removal and storage* service, we used chlorophyll-a concentrations as a proxy of phytoplankton biomass in order to represent phytoplankton productivity in pelagic waters. However, when wanting to obtain an assessment of chlorophyll-a concentrations in marine waters, we still used the MSFD aggregated information (i.e. the status of the related criterion (5.2) on the direct effects of nutrient enrichment under Descriptor 5 on 'Eutrophication'), even if our own rules prevented that. We did it for illustrative purposes (in order to move forward with the assessment) as that was the only information available from an EU environmental directive and we needed to prioritise the use of the information generated by those.

Even with the measures noted above there would still be gaps in what can be achieved in terms of carrying out an assessment of marine ecosystem capacity for service supply using the existing policy reported assessment information (up to 2014). For example, the MSFD is fairly comprehensive in its coverage of the marine environment/ecosystems but this had not translated into the reporting on its first set of assessments; where there were significant gaps in the EU-level assessment products on marine ecosystem state built on it that were available to us (see points 6.6.3 and 6.7.3). However, future rounds of MSFD reporting are likely to be more complete and it may be possible to provide a more complete assessment of marine ecosystem capacity for service supply in the coming years based on those (see Section 7).

6.7.3 When there is alignment with our marine ecosystem components, the information available at the EU level that could be used to assess them is often insufficient

In many cases, the (metrics of the) critical ecosystem components could not be assessed because the information that was supposed to be available at the EU-level with which to do so was not actually available. The components were under the scope of, e.g., EU water, marine and nature directives but the EU-level reporting on these policy instruments had returned, e.g., an 'unknown' rather than a status quality classification. This was also the case for other parts of the ecosystem that needed to be assessed, where relevant. As a result, there was 'insufficient information' (i.e. EU level status assessment products, indicators or datasets) available at the EU level to carry out our state assessment and, thus, the service supply capacity assessment built on it. Information available from reporting on the CFP includes actual datasets and was better but requires a special procedure to be collected (is not reported directly into a central point) as well as some specific processing by, e.g. ICES, which is not often available for the Mediterranean and Black seas (and other sources of fisheries-related information for these regions are not as rich anyway, see Annex IV). To cope with information gaps, our assessment method used a 50 % rule; whereby if over 50 % of the (policy instrument) information source was 'unknown' or 'insufficient information', then an assessment could not be made (see Section 5).

Because the EU-level assessment products built on the reporting on EU water, marine and nature directives and/or on the CFP tended to be insufficient to run the state assessment, other information was brought in to fill gaps and also to provide additional, more specific information from EU marine regions. This other information was from assessments and indicators generated by the implementation of regional (e.g. OSPAR, HELCOM) and international (e.g. ACCOBAMS) conventions, as well as from other EU and global or international organisations (e.g. the EEA, IUCN), governing or covering these regions. Nevertheless, there would still be ecosystem components in large parts of the EU marine regions assessed that are not represented by the status assessments and other information provided by EU (and other) legislation/policy. In addition, many information sources could not be used at all because the 'insufficient information' category exceeded 50 %, which tended to be the case for information on the future state and future state trend of the metrics assessed.

6.7.4 The multiple marine ecosystem assessment products from different pieces of EU (and other) legislation/policy used together to inform our assessment of ecosystem state may overlap, but we have used them as if they were different/complementary

Experience from undertaking the test case assessments (Annexes II-IV) showed that it is not always obvious how complementary the different information sources used as input information for the state assessment are. This was particularly complicated to establish for the test case on the *Waste nutrient removal and storage* service. When it was clear the one piece of EU policy had used the same data and targets for arriving at the relevant assessment product as another, the resulting classification was counted only once. This means that there should not be 'double-counting' of assessments in cases where there was some overlap between them. For example, when assessing the *Recreation and leisure from whale watching* service, assessment products from two pieces of EU policy that partially overlapped, IUCN and ACCOBAMS, were used for the assessment of whale species relevant for whale watching in the Mediterranean Sea because the latter provided specific, additional information to the former for some species, and this information should not be lost. Nevertheless, it was not always possible to verify and account for the possible overlap between, or even full duplication of, EU-level assessment products. For this reason, a lower confidence in the assessment was given in case of a possible overlap compared to when the overlap had been identified and could be managed (see Annex V).

6.7.5 The temporal coverage of the information available at the EU level that could be used in our assessment of ecosystem state is often not aligned

In assessing the state of the (metrics of the) critical ecosystem components, and of other parts of the ecosystem where relevant, it is likely the information collected from EU (and other) legislation/policy does not cover the same time intervals. For example, the assessment products used as input for the test case assessments were a mix of products from different (assessment) time periods, because the information available at the EU-level did not allow using products from the same time period (see Annexes II-III). Therefore, when using all the status quality classifications of assessment products on ecosystem state available at the EU-level together, these classifications may not align in time. This is a limitation imposed by the information available, as none of the policy-relevant information covered the full temporal extent required to carry out the assessment. The MECSA approach defines state as being the ecosystem condition *at a given point in time;* therefore, using information from different temporal scales to fuel the state assessment does not align with our definition of state. Nevertheless, we used a mix of information from different time periods for illustrative purposes (in order to move forward with the assessment).

6.7.6 The MECSA is carried out at the level of EU marine regions but cannot be bio-physically mapped at any level because of the nature of the input information used

The outcomes of the assessment of marine ecosystem capacity for service supply are only spatially applicable/resolved at the level of EU marine regions and are not bio-physically mapped within a region. This is because the EU-level (and other) marine assessment products used as input information for the state assessment tended not to be spatially applicable/resolved at lower scales and neither bio-physically mapped. Thus, the assessment is not expressed – 'spatially' – at the level of the MECSA marine ecosystem components, but at the level of EU marine regions because of the nature of the input information used.

6.8 Next steps

This section has provided an overview of the assumptions which needed to be made in order to undertake the MECSA, and the limitations of the assessment approach. Although several of these are substantial, we have still managed to develop and test the service supply capacity assessment on a number of examples, showing that the assessment can be made with the EU (and other) policy –relevant information that was available at the time the tests were carried out (in 2014), and that the results delivered by the assessment are sensible. The next section (Section 7) describes some of the ways we can further improve the MECSA approach, overcoming some of the limitations outlined here. It also describes the lessons we have learnt in the context of developing this approach, which could help others carrying out assessments of marine ecosystem services, in particular of marine ecosystem capacity for service supply.

7 Conclusions and Recommendations

7.1 Conclusions and 'lessons learnt'

We developed an approach, MECSA (Marine Ecosystem Capacity for Service Supply Assessment), to assess the current state, and sustainability, of the capacity of marine ecosystems to supply marine ecosystem services, which can: (1) make use of the marine ecosystem structures (i.e. species/species groups and habitats) under the scope of existing EU (and other) legislation/policy as well as information on marine ecosystem state generated by these policy instruments (e.g., the MSFD and the HD); (2) use existing knowledge of marine ecosystem functioning to understand how ecosystem state relates to it capacity for service supply; and (3) be applied at an EU marine regional scale. We carried out three tests, each assessing a different marine ecosystem service, in developing the approach (in 2014). These showed that the state of the critical ecosystem components for the supply of those services, combined with our knowledge of how the ecosystem can generate them (including the role of other parts of the ecosystem than these critical components), could tell us how the capacity for service supply was affected (see summary in Table 6.1, Section 6).

Ecosystem services deliver many benefits to people, but the ecosystem's capacity to supply them is decreasing (MA, 2005). The degradation of the capacity of all ecosystems to supply ecosystem services is recognised as a critical issue for sustainable development and in supporting a growing global population (UN, 2015). In the EU, environmental legislation/policies, such as the MSFD and the EU Biodiversity Strategy to 2020, aim at regulating the sustainability of human activities using marine (and other) natural capital in order to ensure that marine ecosystems can self-renew and, thus, continue to supply the ecosystem services on which people rely for meeting their basic needs as well as supporting their well-being and livelihoods/economy. The numerous pieces of EU (and other) environmental and sectoral legislation/policies in place are often there at cost to and effort by the Member States that need to implement them. The effectiveness of these instruments needs to be assessed to ensure they are succeeding.

The approach presented here can facilitate measuring the effectiveness of policy interventions in achieving *sustainabilit*y of service supply capacity at the EU scale, by, firstly, establishing a baseline assessment, i.e. the current state of marine ecosystem capacity for service supply and the direction of change in this capacity; and, secondly, by establishing the future state of and direction of change in this capacity. A key way that this approach can capture the sustainability of marine ecosystem capacity for service supply is through strongly retaining the connection between the state of the marine ecosystem and the supply of services. Thus, this connection captures the self-regulating/renewing aspects of the ecosystem and ensures that the services which are assessed best reflect those which are likely to change as a result of changes in ecosystem state due to policy interventions (given the above-mentioned use of policy-generated information to assess ecosystem state). A high-level assessment such as this can show where improvements towards the sustained supply of ecosystem services are being made and where efforts are paying off, as well as where further effort is required.

We developed marine ecosystem components as meaningful units in which to group marine biodiversity (both species and habitats and their interactions) in relation to how they can supply ecosystem services. These ecosystem components include combinations of all marine taxa (e.g. seabirds, macroalgae, fish) and all marine habitat types (e.g. littoral rock and biogenic reef, oceanic waters) they spend time in, implicitly reflecting the interactions between them. This approach allows managers to fully appreciate which parts of the ecosystems/aspects of biodiversity underpin the sustained supply of ecosystem services. However, we found that it was not possible to apply the MECSA approach at the level of the ecosystem component for the test case assessments we undertook. This was because the information on the state of marine ecosystems used to fuel the assessment was not available for the relevant biotic groups within their associated habitat types, instead it tended to only be available at an EU marine regional level.

Nevertheless, even without assessment information *currently* available at the marine ecosystem component (e.g. seabirds in oceanic waters) level, these components are still key at the first stage of the MESCA approach in setting up the scope of the assessment overall. This is because they allow for the identification of which aspects of the ecosystem need to be included in the assessment in order to assess the sustainability of its capacity to supply any ecosystem service. For example, without making the link between marine habitats and mobile marine taxa like whales and fish, it is likely that habitats that may seem unconnected or remote are missed when considering conservation needs (Culhane et al., 2018). This could lead to a lack of protection of relevant habitats and/or taxa, risking the sustained supply of essential marine ecosystem services. Clearly there is a need to think more on what type of assessment information should be generated and reported by the implementation of EU (and other) legislation/policy in order to underpin an assessment of the capacity of marine ecosystems to supply marine ecosystem services (see Section 7.3).

In future work, the service linkage matrices developed here could also be used in combination with sector-pressure and pressure-component matrices to assess the risk to service supply capacity (Culhane et al., 2019). These other matrices would also serve as to extract information about the pressures (and sectors exerting them) that have the potential to interact with ecosystem component(s), which could lead to changes in ecosystem state and, hence, in its capacity for service supply. For example, the fishing industry (sector) can produce marine litter (pressure), which can impact turtles feeding in the pelagic system (ecosystem component), and this can affect ecotourism underpinned by turtles (ecosystem service). Culhane et al. (2019) found that variable salinity and coastal habitats in the North East Atlantic Ocean had a high capacity to supply ecosystem services and, at the same time, a high risk of the degradation of this capacity due to the impacts of human activities on the state of that ecosystem. They also found that the ecosystem components that would be the most important, i.e. critical, for the supply of a given service would also be those most at risk. Adding to this, however, they found that protecting the capacity for the supply of ecosystem services alone would not protect all parts of the ecosystem that are at high risk from human impacts. Consequently, even if assessments of the marine ecosystem capacity for service supply have many uses (see reviews in Ivarsson et al, 2017; Veretennikov, 2019 (in prep.)), they are complementary to marine ecosystem and biodiversity monitoring and assessment, i.e. do not replace them (Culhane et al., 2019).

Thus, biodiversity is vital for the self-renewal of ecosystems and the sustained supply of ecosystem services, but the scale of an ecosystem services assessment can mean that (the state of) biodiversity gets lost amongst the drive to assess these services. For example, the assessment of the ecosystem's capacity to supply the *Seafood from wild animals* service could mean that all fish and shellfish stocks are considered together (as done in Annex IV here). The assessment outcome could be that the ecosystem capacity to supply this service is in a 'good' state, which may be true overall but individual stocks could be in a 'poor' state within this broader classification. Therefore, applying the natural capital and ecosystem services approach and, because it is based on it, the MECSA approach does not necessarily lead to the protection of individual (vulnerable or not) species. This is a key reason why specific marine biodiversity assessments are still needed. See Section 7.3.2.4 for an example of why separate marine ecosystem assessments are also still needed.

As described in Section 1, we set out to structure our MECSA approach in a way that was inclusive of the full capacity of marine ecosystems to supply marine ecosystem services. This meant that we did not constrain: (a) our marine ecosystem services typology to those services that can be easily valued in monetary terms; or (b) our marine ecosystem components to those components that can be assessed using *existing* information from EU (and other) legislation/policy. Assessing the capacity to supply this inclusive range of ecosystem services is important because, in a changing world, ecosystem services are key to adaptation and building societal resilience to threats such as climate change (Munang et al., 2013; Allison and Bassett, 2015). Thus, even where ecosystem services are not currently in demand, the ecosystems capacity to supply them is often crucial to the long term sustainability of our society.

Many factors can affect the ecosystem capacity to supply ecosystem services and the potential sustainability of this capacity. For example, we found that the Mediterranean Sea ecosystem capacity to supply the *Recreation and leisure from whale watching* service was in a 'bad' state and 'deteriorating' when we ran this test in 2014, and that it would stay this way in the future (see, e.g., Table 6.1). We also identified multiple pressures that affected different whale and dolphin species leading to these species being in such a 'bad' state. In line with our findings, Notarbartolo di Sciara (2016) indicated that most of the marine mammals found regularly in the Mediterranean Sea were classified as 'threatened' by the IUCN. However, the whale watching industry in the Mediterranean Sea was, at the time, relatively underdeveloped, and had the potential, and was expected, to expand (Elejabeitia et al., 2012; IUCN-ACCOBAMS, 2016). Thus, while the Mediterranean Sea ecosystem's capacity for whale watching may not have been fully exploited at the time, the 'bad' state of whale populations there (including those relevant for whale watching) already indicated that possibilities for the expansion of activities using the service would be limited. This would then have implications regarding how much the whale watching industry could really expand. Whale watching can bring numerous benefits to society, but there is also evidence that it can have negative impacts on the cetacean populations they seek out (New et al., 2015). This is already thought to be a problem in the Mediterranean Sea, where irresponsible and unregulated whale watching activities can occur, or where enforcement of regulations is not implemented (Notarbartolo di Sciara, 2014). Exploring this test case assessment highlighted how the expansion of any industry needs to be commensurate with an understanding of the sustainability of the ecosystem's capacity to supply the services on which it depends. However, a well-managed whale-watching sector can actually help in the conservation effort of cetaceans, in regions where populations are highly threatened (García-Cegarra and Pacheco, 2017).

Some ecosystem services in EU marine waters are overexploited (see examples in EEA, 2015). For example, we found that the current capacity of the Baltic Sea to sequester waste nutrients to be in a 'bad' state when we ran this test in 2014 (see, e.g., Table 6.1). The Baltic region is reliant on the service of *Waste nutrient removal and storage* with, e.g., only around 70 % of the population in Poland serviced by wastewater treatment plants in 2012 (Kiedrzyńska et al., 2014); meaning that there was most probably a significant proportion of untreated waste that reached marine waters and was reliant on the ecosystem for its breakdown. This type of waste is in addition to nutrient runoff from agriculture and atmospheric deposition (HELCOM, 2014). A 2014 report from HELCOM indicated that most of the Baltic Sea was affected by eutrophication and that this was one of the biggest threats to biodiversity there (HELCOM, 2014). We found there was insufficient information to assess whether the *current* (at the time) capacity to supply this service was 'improving' or 'deteriorating' due to the 'unknown' direction of change in the state, including any potential recovery, of the benthic system (see, e.g., Table 6.1). There were general indications of improvement of eutrophication-related parameters 'though reported by others'; where nutrient inputs to the Baltic Sea had generally decreased and concentrations of chlorophyll had mostly stabilised (HELCOM, 2014). However, at the time, the Baltic Sea had the largest hypoxic area, i.e. 'dead zone', in the world (Diaz and Rosenberg, 2008). According to the latest assessments from HELCOM, despite nutrient land inputs having decreased considerably, and decreases in chlorophyll-a concentrations being observed in some parts of the Baltic Sea, over 97 % of the region still suffers from eutrophication (HELCOM, 2018); although the record for the largest 'dead zone' now resides elsewhere. Whilst management interventions have not yet succeeded in achieving 'good' status for eutrophication, ongoing and agreed reductions of nutrient inputs according to the HELCOM Baltic Sea Action Plan are foreseen to be effective in decreasing the eutrophication symptoms in the long term (HELCOM, 2018). This is consistent with our conclusion that the *future* capacity to supply the service *Waste nutrient removal and storage* could be 'improving'. However, we acknowledge that the long retention time in the Baltic Sea means that phosphorus can only be removed from the system very slowly and gets re-released from anoxic sediments, inhibiting recovery (HELCOM, 2014; 2018). Furthermore, since nutrient input from waste water and other sources is often exacerbated during flood events; climate change scenarios suggest that the nutrient load could increase in the Baltic Sea in the future with more extreme weather events (Kiedrzyńska et al., 2014).

Consequently, while there are some indications of an improvement of eutrophication-related parameters in the Baltic Sea, issues relating to hydro-morphology, climate change, and the social context of the region introduce uncertainty. This test case assessment demonstrated that a range of interacting environmental and social factors contribute to the unsustainable use of marine ecosystem services.

As reported in Sections 5 and 6, there were limited possibilities to assess marine ecosystem capacity for service supply when having to prioritise information streams from certain pieces of EU legislation/policy to fuel the assessment. Nevertheless, even in a relatively information-rich situation as provided by the reporting on the CFP, there would still be uncertainty with assessing this capacity. For example, we found that the capacity of the North Sea to supply the *Seafood from wild animals* (fish and shellfish) service was in a 'moderate' state when we run this test in 2014 (see, e.g., Table 6.1). In addition, we indicated that the direction of change in this capacity was probably 'improving', but the future of it was uncertain due to climate change impacts on marine ecosystems. According to the latest assessments, many of the assessed commercial fish and shellfish species in the North Sea are at or below a fishing mortality capable of producing the Maximum Sustainable Yield, which is part of fulfilling 'good environmental status' under the MSFD (EEA, 2019a), although their reproductive capacity is not yet good for all of these (EEA, 2019a). Reductions in fishing mortality are attributable to successful management interventions in reducing fishing pressure in the North Sea. The *trends* in reproductive capacity of the assessed North Sea stocks currently appear to be stabilising or even improving overall (EEA, 2019a). However, European shelf seas, including the North Sea, are warming faster than the global average (MacKenzie and Schiedek, 2007). Recent predictions have found that fisheries productivity may increase in the North Sea region under certain climate change scenarios (Barange et al., 2014). However, evidence has been found for large-scale changes to North Sea fish stocks, likely due to warming, including a shift of stocks to greater depths (Engelhard et al., 2014) and to northward colder waters (EEA, 2019b). This change in fish species distribution relies on the availability of suitable habitats in, e.g., deep waters, and, without this, many species are likely to be exposed to warmer temperatures with unknown consequences (Rutterford et al., 2015). Changes to North Sea fisheries require adaptation by the fishing industry and associated management (Rutterford et al., 2015). Exploring this test case assessment demonstrated that uncertainty and the need for adaptive management are essential to sustaining marine ecosystem capacity for service supply into the future.

7.2 Future direction of work

Future work on the assessment of the current state, and sustainability, of marine ecosystem capacity for service supply should move from assessing single services, as done here (Section 5.1), to assessing multiple services (see, e.g., Section 5.2). This would make it explicitly possible to consider the likely co-benefits and/or trade-offs in trying to maintain and/or restore marine ecosystems and, thus, achieve a continued supply of *all* marine ecosystem services. As noted, to date the MECSA approach has been applied as single-service assessments; this by definition limits the approach by preventing the explicit consideration of the relationship between services and, hence, neither of the synergies that may exist in their generation nor of the trade-offs in their supply/use. For example, the *Waste nutrient removal and storage* service (type) involves the removal, i.e., sequestration, of anthropogenic waste inputs (e.g. excess dissolved nutrients from agriculture) from circulation in the marine environment by certain marine biota. This service is related to the *Waste nutrient treatment* via biota service (type), involving waste bioremediation, as bioremediation by marine biota can release dissolved nutrients into the water column from solid organic waste, which are then sequestered by those biota involved in the *Waste nutrient removal and storage* service (which may actually partially overlap). It is clear that there will be interdependencies in the ecosystem capacity to supply these, and other, services, but the relationships between different services may be quite complex. Hence, there may be trade-offs or synergies associated with objectives for the protection of (the capacity to supply) one marine ecosystem service, through protecting relevant parts of the marine ecosystem, versus another. Applying the MECSA method per single *marine ecosystem component* (see Section 5.2), rather than per service, would lead to assessing all the services that could be supplied by a given component altogether at the same time, which would make those interlinkages obvious. However, such an alternative assessment option was not feasible at the time the MECSA method was developed (2014). This was due to not only insufficient knowledge on cause and effect within marine ecosystems, but also, and most importantly, because the particular information required to run such a component-based assessment was not available at the EU level.

Future work would also need to add in further elaboration to explain how the MECSA method can be applied where there is more than one critical ecosystem component for a given ecosystem service assessment. As it stands, the approach has only been explored under three test cases, and for each of these it was possible to focus on a single critical component. It may, however, be the case that two or more components have equal importance. In those cases, the application of the method outlined in Section 5 of this Report could develop as indicated in Box 7.1 in order to conclude on the classifications for the state of and direction of change in marine ecosystem capacity for service supply.

Box 7.1 How to conclude on the classifications for the state of and direction of change in current and future marine ecosystem capacity for service supply when there is more than one critical ecosystem component involved in the supply of a service

If the (ecosystem) state-service (generation) relationship is simple, what happens would depend on the actual service and whether the critical ecosystem components all have the same relative contribution to its supply or not, where:

If the relative contributions are all the same, it may be possible to just aggregate the overall outcome classifications of the service supply capacity assessment across all ecosystem components per service and EU marine region. This would be done by determining what is 'the most frequent classification' across the overall classifications for the state of service supply capacity of all the components and for the direction of change in service supply capacity of all the components. 'The most frequent classifications' would then be assigned as those for the state of and for the direction of change in the region's service supply capacity;

If the individual contributions are different, it may be appropriate to use the relative contribution from each component to weight its classification before determining what are 'the most frequent classifications', i.e. to make each component's classifications count a certain fixed amount, or percentage, towards determining 'the most frequent classification', which would depend on what is its relative contribution, rather than all the classifications counting the same.

If the (ecosystem) state-service (generation) relationship is complex, some type of aggregation would also be needed. However, this would depend on the actual service being assessed and how the relationship is characterised, i.e. what/how many are the exact metrics used in the state assessment.

The assessment stage of the MECSA approach can be improved in the future as more information on the state of marine ecosystems generated by EU (and other) legislation/policy becomes available. Improvements in the availability of some of this information should come through the updated assessments and reporting driven by the implementation of the relevant EU legislation/policy. For example, updates were made to the WFD national assessment products in the 2016 reporting; and updated national assessment products from the MSFD and/or the HD started to become available in 2018 with more reported in 2019 (and also the BD's). In addition, the EC Decision defining the

MSFD's 'good environmental status' (EC, 2010) was revised as EC (2017), which would bring about changes to the marine ecosystem structures used in the MECSA approach (see below), and this was accompanied by a revision of the MSFD Annex III on ecosystem elements, anthropogenic pressures and human activities in marine waters. This 'package' should have had, or will soon have, a big impact on MSFD national assessments and, thus, what should be available as assessment information at the EU level from their current, or future, reporting. This reporting may indeed improve on the currently poor situation regarding the availability of MSFD assessment information at the EU level (see Sections 5 and 6); thus facilitating a more robust assessment of the state of the marine ecosystem and of its capacity to supply ecosystem services following the MECSA approach (providing that the reporting is strong on aspects relating to marine ecosystem state and integrity). However, we will not know more about possible improvements until the actual MSFD EU-level reporting has been fulfilled and reviewed (reporting started in October 2018 but most Member States had not reported by end 2018 and reporting was still not complete by mid-2019; then the analysis of this reporting, by the EEA and its ETC/ICM, can only be carried out afterwards, once the reported is completed).

As there have been recent developments and updates to the relevant EU legislation/policy (over 2015–2018), the MECSA approach would require updates to some of its 'structural elements' such as the characterisation and classification of marine ecosystem components and marine ecosystem services to keep on being one-to-one EU policy-relevant. The main changes are:

(1) **A revision of the MSFD predominant habitat types** in EC (2011) (the ones used here) into pelagic and benthic broad habitat types took place over 2015- 2017 as part of the revision of the EC Decision defining 'good environmental status' (EC, 2017)[168]. This has resulted in a very different typology for the seabed habitats, which is fully aligned to and uses the EUNIS-based biotope nomenclature (e.g. infralittoral, circalittoral), instead a bio-physical typology as used here (e.g. sublittoral), and is almost equivalent to the Level 2 revision of the EUNIS benthic habitats (see below). This new MSFD habitat typology, through its alignment to the revised EUNIS Level 2, includes the delimitation of photic seabed habitats from non-photic ones, where the former are not only discriminated as oligophotic, but also as euphotic (see discussion in Box 3.1, Section 3). In addition, the new MSFD benthic broad habitat typology, again following from its alignment to EUNIS, considers that littoral habitat types can occur in the supralittoral zone. It follows that the benthic habitat typology used here would need to be cross-walked to the updated MSFD benthic broad habitat typology in order for them to remain policy relevant (see discussion around Table 3.3, Section 3, and also Condé et al, 2018). However, the general alignment between them is obvious given that the typology used here already discriminates oligphotic habitat types and considerers the possible 'extension' of littoral habitat types to the supralittoral zone as done by the new MSFD benthic broad habitat types. Changes to the MSFD pelagic 'predominant' into 'broad' habitat types are not so significant, and have all already been considered in the pelagic habitat typology used here (e.g. the deletion of the *reduced salinity water* pelagic habitat type, see Section 3). Thus, for both pelagic and benthic habitat types, the information that should become available in the updated MSFD reporting, now or in the future, should be more suitable for a marine ecosystem capacity for service supply assessment, such as that provided by the MECSA approach.

[168] The revised Decision defining 'good environmental status' does not change the MSFD grouping of species used here (Section 3), but assessments of sub-groupings as needed, at times, to run the MECSA (e.g. of whales within marine mammals) may be available through their reporting. However, we cannot be sure as the updated MSFD (2018) reporting is still ongoing in 2019, and also because Member States may not have chosen to report in line with EC (2017) and related EU-level guidance yet.

(2) **A revision of the Common International Classification of Ecosystem Services (CICES)**. A revision of CICES version 4.3, on which the typology and list of marine ecosystem services used here is based, into version 5.1 took place during 2016 to the end of 2017 following consultations with the CICES expert and other communities (see https://cices.eu/). The revised CICES, as version 5.1, was released in 2018 and included changes to the hierarchy, the service names and their descriptions. It also provided an indication of which services could be supplied by marine ecosystems (as well as by the abiotic part of the marine environment, although the latter would not be services, but marine abiotic outputs according to the services definition used in this Report). Many of these changes have resulted in the 'new' CICES classification being more in line with the adapted typology of (marine) ecosystem services we have used here (see Section 2). In fact, they reflect many of the issues we picked up in Sections 2 and 4, regarding the identification of the marine ecosystem services from CICES and the description of those services respectively; where the latter were summarised in Section 4.3.4. However, a crosswalk would still be required between the typology used in Section 2 here with CICES version 5.1, in particular the marine ecosystem services in this new version. This need has been fulfilled via a customisation of this new version of CICES for its (improved) application to marine ecosystems and developing an updated list of marine ecosystem services based on that typology, which are provided in Annex VI to this Report. This Annex also includes:

i. A short description of each of the new services (building on those provided in Section 4).
ii. A crosswalk between the marine ecosystem services list based on CICES v.4.3, as used in the MECSA approach (see Table 2.2 in Section 2), and this updated list based on CICES v.5.1, as well as an in-depth comparison between them.
iii. Updated linkages matrices between biotic groups and the updated list of services based on CICES v.5.1 (building on that provided in Section 4), and between these services and habitats (building on that provided in Annex I), where the habitats are based on the (new) MSFD broad habitat types

Annex VI was developed in early 2019 as part of the Report's publication process. For this reason, the updated list of marine ecosystem services based on CICES v.5.1 is not integrated in the MECSA approach as described in sections 1–7 (and Annexes I–V) of this Report. Nevertheless, Annex VI shows that CICES v5.1 is indeed quite aligned with the typology and list of marine ecosystem services used in the MECSA approach, which was based, but improved, on CICES v.4.3. However, there are some differences between the updated typology and/or list of marine ecosystem services based of CICES v.5.1 and the MESCA's. The main ones are that: 1) the updated list of provisioning services is longer because CICES v.5.1 includes more services relating to the use of marine biota as 'genetic materials'[169]; and 2) the updated classification of a few cultural services keeps the additional support or contributions of the marine ecosystem towards people's wellbeing included in the MESCA services typology and definitions, which is not included in CICES v.5.1.

(3) **A revision of the marine component of the EUNIS habitat classification**. The version of 'marine EUNIS' used here (see Section 3) has changed. A revision of the Level 2 of the classification, i.e. the European level, was completed in 2016 (see Evans et al, 2016), which, *inter alia,* follows what has been noted above for the MSFD regarding the delimitation of photic seabed habitats (since the revised MSFD benthic broad habitat typology is based on the revised EUNIS

[169] This is because, compared with CICES v.4.3, CICES v.5.1 has considered the differences in the biota (e.g. plants or animals) providing the genetic material, whether they are used in part (e.g. genes) or as whole organisms, as well as their origin (e.g. the wild versus in situ aquaculture).

Level 2). An update of the marine habitat definitions, and other changes, at lower levels of the classification was completed by mid-2019 (see also Condé et al., 2018). The new 'marine EUNIS' should also allow for an improved regionalisation of habitat descriptions per EU marine region.

(4) **A revision of EUSeaMap 2012** (EUSeaMap 2012, Cameron & Askew, 2011) **into EUSeaMap 2016** (Populus *et al*., 2017). To note that this consistent modelling approach for broad scale seabed habitat mapping at the EU level is relevant to model the discrimination of the photic zone across MSFD benthic predominant habitat types (e.g. falling between the MSFD shallow and shelf sublittoral habitat types for the euphotic limit, see Section 3). The revision extended the approach developed by EUSeaMap 2012 (for the North, Celtic, Baltic and Western Mediterranean marine (sub) regions) to all EU marine (sub)regions (i.e. adding the Black and Eastern Mediterranean seas and the Macaronesian region). However, EUSeaMap 2016 is less suitable than EUSeaMap 2012 to model the 'photic limit' across MSFD habitat types as other variables have been used for the modelling the MSFD shallow/shelf sublittoral limit (or the circalittoral/offshore circalittoral limit under the new MSFD benthic broad habitat typology and the revised EUNIS Level 2), in particular energy (choosing wave base ratio as a proxy) or temperature (see variables in 'Thresholds appendix' of Populus et al., 2017). Nonetheless, the extension of EUSeaMap should allow spatial assessments of the state and service supply capacity of benthic habitats following the MESCA approach; but this is once a crosswalk has been made between the benthic habitat typology used here (Section 3) with the EUSeaMap seabed habitat classification (see also Condé et al., 2018).

A future assessment of marine ecosystem capacity for service supply could be more integrated and be able to combine: (1) the improved EU policy based information coming through, in particular the seabed mapping of EU marine regions and better ecosystem state information; (2) improved understanding, and spatial delineation, of the risk to service supply capacity, and the human activities and pressures that contribute to that risk; and (3) continued improved understanding of the ecosystem functioning underpinning service supply capacity through on-going small scale studies that are complementary to high level assessments such as this. This integrated approach could involve:

(1) A spatial approach to assess multiple pressures leading to their combined effects on broad scale seabed habitats (using EUSeaMap[170]) *inter alia* to account for the lack of sufficient (biodiversity) state/status information available at the EU level. A similar approach was taken by the HELCOM HOLAS (HOLAS I and II, HELCOM 2010 and 2018) and HARMONY (Andersen & Stock (eds.), 2018) projects, which supported Member State initiatives to implement or support the implementation of the MSFD during its 1st cycle.

(2) Combining the ensuing bio-physically mapped combined pressure effects assessment with biodiversity status/state information (wherever available and feasible) following the approach in, for example, Andersen et al. (2015).

(3) Testing the resulting bio-physically mapped approach to assess the state of broad scale seabed habitats through case studies until Member States' marine pressure and biodiversity spatial datasets become available at the EU level (as part of, e.g., implementing the MSFD's Article 19.3), rather than the currently reported assessment products.

[170] To stress that EUSeaMap applies to the seabed, i.e. cannot map pelagic habitats, and so cannot be used to spatially represent all the MECSA's biotic groups/ecosystem components. Further, EUSeaMap does not apply to the littoral zone either, but this may be partially addressed by using, where feasible, Corine Land Cover (CLC). Noting that the correspondence between the CLC classes in the land-sea interlace and the assessment 'units' used by relevant EU environmental legislation, e.g. the WFD's water bodies, is not very good and cannot currently be systematically established.

(4) Combining the ensuing bio-physically mapped assessment of the state of broad scale seabed habitats for each EU marine region with the MECSA services linkages (Section 4) and applying aspects of the assessment method (e.g. the (ecosystem) state-service (generation) relationship, Section 5) should deliver a (bio-physically mapped) assessment of marine ecosystem capacity for service supply. This would be relevant to both EU-level marine ecosystem service supply capacity assessment and accounting exercises in the context of Action 5 under Target 2 of the EU Biodiversity Strategy to 2020 and its post-2020 follow-up. To note that the EEA and its ETC/ICM have planned to explore such an assessment in the near future.

7.3 Recommendations

In this concluding sub-section, we put forward 11 recommendations for future assessments of marine ecosystem capacity for service supply, which have been grouped as information and knowledge for and scope of the assessment. These recommendations are based on the conclusions drawn herein and our understanding of likely future developments in this area. These recommendations could be applied in the context of marine ecosystem and marine ecosystem services assessments that may be required under any post-2020 follow up of Action 5 under Target 2 of the Biodiversity Strategy to 2020.

7.3.1 Information for the assessment

1. **Make best use of what is currently available**
   Successful application of the MECSA approach to the test case assessments showed that it is possible to carry out an assessment of marine ecosystem capacity for service supply making best use of what is already available. For example, the assessment was limited to the critical ecosystem components for the supply of a service as a way of optimising the use of the rather scarce policy-based assessment information on any aspect of marine ecosystem state available at the EU-level, focussing on the most appropriate information to characterise the (ecosystem) state-service (generation) relationship. Although the assessments will improve as more and better information becomes available, it was still possible to make reasonable assessments. These assessments can then form a baseline and indicate where there are potential problems in the sustainability of human activities using marine ecosystem services, marine abiotic outputs, and other natural capital because of their impact on marine ecosystems. They should, thus, be valuable in going forward to manage human uses of Europe’s seas sustainably.

2. **Harmonise EU (and other) marine environmental and sector legislation/policy monitoring and reporting obligations**
   We found overlaps in reported policy-based information, which meant that some EU-level (and other) assessment products on marine ecosystem state duplicated each other in part or in full. We also found misalignment of timings of monitoring and reporting across relevant pieces of EU (and other) legislation/policy, which meant that not all the EU-level (and other) assessment products we wanted to use at a given time were available at that time. Harmonising and rationalising the different obligations for, at least, EU water, marine and nature directives as well as the CFP would create more useful information flows (and/or datasets where relevant) on marine ecosystem state that could be used for several types of assessments, as well as being more efficient for Member States to report on. Better still, harmonisation of reporting obligations should also happen between EU and Regional Sea Convention assessments.

3. **Improve the suitability of and fill important gaps in policy-based information relating to the assessment of marine ecosystem capacity for service supply**
   The policy-based information available at the EU level with which to assess marine ecosystem state and, thus, service supply capacity was not always the most suitable for the assessment, or was insufficient, or had other problems. First and foremost, it was not possible to complete the test case assessments at the level of marine ecosystem components. We made a strong argument under Section 3 for why this set of components (i.e. biotic groups associated with their habitats) was most suitable for assessing the capacity of marine ecosystems to supply ecosystem services. We stand by these points, yet appreciate the significant changes required to provide EU-level (and other) assessment products where the status of biotic groups is reported separately (individually) for each major ('Level 3a') habitat type within a marine region. This is more achievable perhaps for those component that include embedded biotic groups. Even when working with just ('Level 4') biotic groups, or with just ('Level 3a') habitats, rather than with their combination into ecosystem components, we found very significant gaps in information that should have been reported, which meant that certain EU-level (and other) assessment products that should have been available simply were not. We also identified several instances in which the information was not appropriate for an ecosystem service supply capacity assessment, because it was too aggregated. For example, aggregated marine mammal assessment products from MSFD reporting, rather than a split into whales/dolphins and seals as needed to assess the *Recreation and leisure from whale watching* service. Furthermore, we identified several gaps, where there were no assessments of certain marine biotic groups because those groups do not explicitly fall under the scope of any piece of EU (and other) legislation/policy, such as bacteria.

   If full assessments of marine ecosystem capacity for service supply are to be made, these inadequacies in the information need to be addressed and these information gaps need to be filled. Some of these inadequacies, such as explicitly specifying if a habitat can be photic or not, are actually already being addressed at the EU level (see Section 7.2). However, further changes are needed, including: (1) making disaggregated Member State information more easily accessible; (2) making the coverage of all marine biotic groups explicit in an assessment of marine ecosystem state; (3) supporting Member States so they can monitor and, thus, report on how ecosystems function (which is key to them supplying services), and which is included under MSFD reporting but hardly ever fulfilled; (4) collecting on, reporting and making available spatially explicit data for all EU marine regions; and (5) developing relevant regional thresholds for GES or other relevant policy objectives so that spatially explicit datasets can be used in assessments because there would be a way to classify the state of marine ecosystems and, thus, the state of their capacity for service supply per EU marine region.

7.3.2 Knowledge for the assessment

4. **Understand each individual (ecosystem) state-service (generation) relationship and the difference between marine ecosystem services assessments and straight marine ecosystem assessments**
   We found that understanding the specific (ecosystem) state –service (generation) relationship linked to the ecosystem capacity to supply a given service was fundamental to most aspects of the MECSA approach. These included *inter alia* identifying the ecosystem components that are critical to the supply of the service, because they hold most of the capacity; selecting the most appropriate assessment metrics; and concluding the assessment by translating ecosystem state into the state of this capacity. In addition, the (ecosystem) state –service (generation) relationship is also the key factor that separates this service supply capacity assessment here from an assessment of ecosystem state. Thus, we note that 'good' ecosystem state does not always equal a 'good' capacity to supply ecosystem services, and vice versa. For example, the *early* stages of eutrophication

(nutrient enrichment) imply a ‘not good’ state of the ecosystem *sensu* the MSFD (and similarly under the WFD), but a ‘good’ state of service supply capacity. Therefore, ecosystem service assessments, such as the one here, do not replace assessments of ecosystem state (and neither of biodiversity as explained in Section 7.1) when assessing progress towards meeting EU legislation/policy objectives for the *conservation* of Europe’s seas – it is essential that these are seen as complementary.

5. **Use small scale studies on causal chains within marine ecosystems to support assessments carried out at the level of EU marine regions**

   This assessment was carried out at a high level, covering the four EU marine regions. However, a lot of the knowledge behind the expert judgement and evidence used to establish the links between marine ecosystem components and marine ecosystem services, and also to elucidate (ecosystem) state-service (generation) relationships was gleaned from small scale, focussed, ecological studies on how specific habitats and species hold the capacity to supply specific ecosystem services (see examples in Section 4). More of these studies are needed to improve our understanding and our confidence in the underlying assumptions of high-level assessments such as the one here.

6. **Consider the association between all the biotic groups and their habitats as well as the link between biota state and habitat state**

   The MECSA approach not only makes it explicit which marine biotic groups are embedded (i.e. benthic and planktonic biota) in which habitats, but also making the link between highly mobile marine biotic groups (e.g. fish, whales) and the habitats they can be associated with. This serves to highlight the importance of all habitats where services can be supplied to people, as well as the habitats that are remote for people but support the species and species groups that can supply the services they use elsewhere. In order to fully protect the ecosystem capacity to supply services, we need to consider all of the relevant habitats (Culhane et al., 2018). Thus, there will be aspects of the state of certain habitats that are important for, e.g., seabird foraging and the health of the seabird population that uses them – and there is a need to make a link between those aspects and the state of seabird populations in order to fully understand how the capacity to supply services varies per habitat. However, we had difficulties in establishing this link because there was hardly any information available at the EU level on the state of biotic groups *in* specific habitats, and neither on the state *of those* habitats. As a result, we have not managed to rank the importance of each habitat towards service supply capacity, only whether the capacity to supply a given service is held by a habitat, or not (knowing which biotic groups can occur, or not, there, see Section 4 and Annex I).

   For example, there was insufficient reporting on the individual status of the MSFD predominant habitat types (in the 2012/1st cycle reporting on the MSFD; noting this is the most widespread set of marine habitats under the scope of EU legislation), and so there were no assessment products on each of these habitat types at the EU level. The reported status of those habitats would be that of the habitat overall, but other reported information should include aspects of the state of the biological communities embedded in them (as is the case under the HD). This would have helped to link the state of each benthic and pelagic habitat and the state of the relevant benthic and planktonic biota respectively. The reverse was applicable for the assessment of the highly mobile biotic groups, where what was reported was their status, but other reported information should include aspects of the state of their habitats. However, the latter was not sufficiently fulfilled across the EU.

7. **Recognise where global marine assessments are needed**
   Following on from point 6 above, marine ecosystems and the biota within them are connected globally, or at least to regions greater than EU marine regions. For some marine ecosystem services, EU-level information will never be adequate to fully characterise the ecosystem capacity to supply them, as factors external to EU marine regions will impact on services supplied within these regions. For example, for some cetacean species, such as the harbour porpoise, minke whale and white-beaked dolphin, the North East Atlantic Ocean EU marine region is at the edge of their wider North Atlantic range. Spatial variation in prey availability may lead to redistribution of animals and, thus, the distribution and abundance of these species in the North East Atlantic Ocean EU marine region may vary as a result of this (Hammond et al. 2017).

7.3.3 Scope of the assessment

8. **Consider all of the direct contributions that marine ecosystems make to people**
   We followed the approach taken by the CICES (version 4.3) in developing and using a broad and encompassing set of marine ecosystem services. This set recognises all of the ways in which marine ecosystems directly contribute to meeting our basic needs as well as supporting our wellbeing and livelihoods/economy. It is important to recognise all ecosystem services – even those that do not seem to have an obvious market value, e.g., most Regulation and maintenance services (although there may be avoidance, or other, costs involved in their use). This is because, ultimately, all ecosystem services contribute to the long-term sustainability of our society. It is possible to detect whether these contributions could generally change by using a supply-side approach as demonstrated by the MECSA approach here. However, as discussed in Sections 4 and 6 of this Report, for cultural services, the capacity of the ecosystem to supply the service can be decoupled from its state contravening one of the basic premises of our approach. Nevertheless, this was not the case for the one cultural service we explored as a test case, where it was possible to link ecosystem state to its capacity for service supply. However, for many other cultural services the decoupling of ecosystem state and capacity would make it difficult to fully apply the MECSA approach.

   We, therefore, recommend that further work is undertaken to explore alternative complementary approaches to assessing the sustainability of the ecosystem capacity to supply cultural services. These may include approaching the assessment from a risk to service supply capacity perspective (e.g. see approach described in Culhane et al., 2019; also see Mace et al., 2015) where the impact risk to a given ecosystem component is coupled with the service supply potential of that component to provide an overall risk to service supply capacity. In this case, where risk to supply is low, one might assume that the sustainability of supply is high. This alternative approach does not require that the relationship between the ecosystem component state and ecosystem service capacity is tightly coupled; still, it would need to be fully explored across a range of cultural services to see if it was fitting for the broad aims of what a MECSA-type approach is trying to achieve. A further alternative approach is to consider that a past, or alternative, state of a culturally and historically important species, and/or habitat, relates the most to what would be required to fulfil the capacity expected by humans for the supply of a given service. In this case, the historic/alternative state may be used as the objective against which to consider the current state of the relevant ecosystem components in terms of that being most fitting to the capacity to supply such a service.

9. **Establish who are the beneficiaries of marine ecosystem services**
   In order to recognise and understand all the contributions of marine ecosystems to meeting our basic needs as well as supporting our wellbeing and livelihoods/economy (see point 8 above), we also need to explicitly identify all of the beneficiaries of marine ecosystem services. This would not only help to establish how/in which contexts these services are 'final' (see Sections 1 and 4), but also to establish how we might best measure specific contributions to different parts of our

society. For example, while the *Pest control* service tends to be 'intermediate' (see Section 4), for the owners of situ salmon aquaculture farms this service is 'final'. This is because they directly use, although passively, and benefit from natural mechanisms to control those species that can become a nuisance for humans (including non-indigenous, invasive species; proliferating native species; and nuisance algae), and which are underpinned by a balanced food web. In this case, the service would prevent, or minimise, invasions of jellyfish small enough to enter salmon cages and damage, or destroy, the farmed salmon stocks – incurring in economic losses.

10. **Acknowledge the need for an adaptive response to marine ecosystem services assessment**
    Ecosystem services are embedded in the current social/cultural, ecological, economic and political context. As this context changes, the approach/methodologies to assess ecosystem services/ecosystem capacity for service supply also need to change in order to keep up (i.e. remain valid, see Section 7.2 above). This is so the outcomes of these assessments can still inform management about the need to change and adapt in response to, e.g., changes in the ecosystem capacity for service supply.

11. **Link multiple human activities and pressures to marine ecosystem capacity for service supply**
    Increasing, multiple human activities and pressures in the marine environment, alongside anthropogenic climate change, require urgent combined assessment to gauge how the likely subsequent impacts on marine ecosystems affect their capacity for service supply and, thus, what this will mean for long-term sustainability of both the activities themselves and the supply of ecosystem services. The next step for this type of assessments must, thus, be to link to those activities and pressures. As mentioned under point 8 above, it may be necessary to take a 'risk to service supply capacity' approach for services where the relationship between ecosystem state and their supply is complex, and establishing the links between multiple human activities, pressures, ecosystem components and the services they supply would enable moving towards this (see also Section 7.2).

8 References

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