What can indicators of Good Environmental Status tell us about ecosystem services?: Reducing efforts and increasing cost-effectiveness by reapplying biodiversity indicator data

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Abbreviations

ES: ecosystem services, MSFD: Marine Strategy Framework Directive, GES: good environmental status, EU: European Union, NIS: Non-indigenous species

ABSTRACT

The EU Marine Strategy Framework Directive (MSFD) requires member states to manage their marine ecosystems with the goal of achieving Good Environmental Status (GES) of all European Seas by 2020. Member states assess GES according to 11 descriptors set out in the MSFD, and their associated indicators.

An ecosystem service approach is increasingly being advocated to ensure sustainable use of the environment, and sets of indicators have been defined for ecosystem service assessments. We considered whether a selection of GES indicators related to biological descriptors, D1 Biodiversity, D2 Non-indigenous species, D4 Food webs and D6 Seafloor integrity, may provide information relevant to ecosystem services, potentially allowing use of collected environmental data for more than one purpose. Published lists of indicators for seven selected marine ecosystem services were compared to 296 biodiversity-related indicators included within the DEVOTOOL catalogue, established for screening marine biodiversity indicators for the MSFD. We concluded that 64 of these biodiversity indicators are directly comparable to the ecosystem service indicators under consideration. All 296 biodiversity indicators were then reassessed objectively to decide which of them could be useful as ecosystem service indicators. To carry out this step in a consistent and transparent manner, guidelines were developed among the co-authors that helped the decision

making process for each individual indicator. 247 biodiversity indicators were identified as potentially useful ecosystem service indicators. By highlighting the comparability between ecosystem service and biodiversity indicators it is hoped that future monitoring effort can be used not only to ensure that GES is attained, but also that ecosystem service provision is maximised. It is recommended that these indicators should be tested across EU regional seas to see if they are useful in practice, and if ecosystem service assessments are comparable across regional seas.

1.1 INTRODUCTION

Biodiversity is closely linked to ecosystem functioning, which in turn underpins the provision of ecosystem services on which humanity depends, such as Food provision and Climate regulation (Heiskanen et al., 2016; Liquete et al., 2016). According to the Convention on Biological Diversity (CBD, 1992), biodiversity is defined as "the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems". Yet, biodiversity is threatened worldwide by pressures such as habitat loss, overexploitation and pollution (Halpern et al., 2008; Knights et al., 2013). International environmental agreements, such as the Aichi Biodiversity Targets for 2020 in the Convention of Biological Diversity (CBD, 1992), the EU Biodiversity Strategy 2020 (BD; COM/2011/0244), and recent European Union legislation (e.g. the EU Marine Strategy Framework Directive (MSFD; 2008/56/EC)) are placing increasing emphasis on halting biodiversity loss (Laurila-Pant et al., 2015; Liquete et al., 2016).

The MSFD "establishes a framework for community action in the field of marine environmental policy", which promotes the preservation and protection of marine waters in European member states (European Commission, 2008). One aim of the MSFD is for each member state to take measures to achieve and maintain Good Environmental Status (GES) in all four European Seas (i.e. Baltic Sea, Black Sea, Mediterranean and North East Atlantic) by the year 2020, through country-specific programmes of measures (Börger et al., 2016). The MSFD defines GES as: "the environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive within their intrinsic conditions, and the use of the marine environment is at a level that is sustainable, thus safeguarding the potential for uses and activities by current and future generations." This definition implies that ecosystem services and societal benefits should be taken into consideration when measuring GES but at the same time these aspects are not mentioned in either the descriptors or associated criteria (Borja et al., 2013). Recently, changes were suggested to some elements of the MSFD, including criteria and Annex III, these are now awaiting acceptance. Among these changes is the acknowledgement that member states may also assess ecosystem services under MSFD. These changes demonstrate the importance of comparing ecosystem service indicators and biodiversity-related indicators (from now on biodiversity indicators).

To assess the status of the seas and to be able to monitor changes in environmental status, each member state has to carry out regular assessments addressing 11 descriptors that describe a state, or a pressure, or both. These are: Descriptor (D) D1 – Biological diversity, D2 – Non-indigenous species (NIS), D3 – Commercial fish and shellfish, D4 – Food webs, D5 – Eutrophication, D6 –Sea floor integrity, D7 – Hydrological conditions, D8 – Concentration of contaminants, D9 – Contaminants in fish and other seafood, D10 – Litter, D11 – Energy and noise. These 11 descriptors are further defined by a set of 29 criteria and 56 indicators. Indicators are variables that provide information on complex phenomena and if properly selected can show changes of such phenomena (Kandziora et al., 2013; Hattam et al., 2015). A requirement of the MSFD is that indicators focus on essential biological components of the ecosystem, from taxonomic groups through habitats to ecosystems (Borja et al., 2014; Berg et al., 2015). Member states considered the different criteria and indicators, and for those of relevance to their seas they defined a series of indicators to be used to describe a baseline, and then in regular monitoring programmes to assess the success of their programmes of measures.

The biological components relevant for biodiversity assessments are described by Cochrane et al. (2010), and specifically listed in the Table 1 of the Annex III of the MSFD. The biodiversity components include predominant seabed and water column habitat types, as well as specific habitats that have biodiversity conservation importance. Biological communities associated with those seabed and water column habitats, such as phytoplankton and zooplankton communities, angiosperms, macro-algae and invertebrate bottom fauna, or species belonging to groups such as fish, marine mammals and reptiles, and seabirds are also included in the biodiversity components. Currently there are a number of operational indicators available for the assessment of GES (Teixeira et al. 2016), and more are being developed to be used in robust and cost-efficient monitoring and assessments (Heiskanen et al., 2016).

Besides monitoring the status of marine waters, the MSFD dictates that member states shall adopt an ecosystem-based management approach in their programmes of measures to “enable the sustainable use of marine goods and services” (Paragraph 8 of the MSFD preamble). Ecosystem-based management is focused on ecosystems and human interactions within these systems, and thus necessitates an understanding of the linkages within and between the biological components of the ecosystems as well as with social and economic systems (McLeod et al., 2005; Atkins et al., 2011). Furthermore, it is stated in the MSFD Article 1, Paragraph 3.: “*Marine strategies shall apply an* *ecosystem-based approach to the management of human activities, ensuring that the collective pressure of such activities is kept within levels compatible with the achievement of good environmental status and that the capacity of marine ecosystems to respond to human-induced changes is not compromised, while enabling the sustainable use of marine goods and services by present and future generation*". This anticipates that there is a link between GES and the sustainable use of ecosystem goods and services. Although many of the GES indicators are well described and used by EU member states, there is no operational example describing how these could also be used in the assessment of ecosystem services, although some regional (Hasler et al., 2016) and EU-level (Maes et al., 2016) suggestions have been made. Here we conceptualise 'sustainable use' in the sense of 'weakly sustainable use' (sensu Rossberg et al., 2017) i.e. usage that can be continued indefinitely in its current form. The key concept to assess status and trends of potential uses of an ecosystem, particularly relevant in local and regional settings, is that of ecosystem services (Maes et al., 2012; O'Higgins and Gilbert, 2014). Ecosystem services are the direct and indirect contributions of ecosystems to human well-being (TEEB, 2010) and are increasingly being considered in marine policy and planning (Fisher et al., 2009; Börger et al., 2014; Pendleton et al., 2016).

In the Millennium Ecosystem Assessment (MEA, 2005) ecosystem services were split into four groups: i. provisioning, such as food and timber; ii. regulating, for example regulating climate or water flows; iii. cultural, such as aesthetic experience derived from being in nature; and iv. supporting, for example supply of larval fish (in this example supporting the service of Food provision). This approach was criticised as it did not differentiate between processes and services or services and benefits, potentially leading to double counting (Fisher et al., 2008). Since then several alternative classifications have been proposed (Liquete et al., 2013), including a more hierarchical approach as defined by Fisher et al. (2009) which renamed the supporting services as intermediate services or processes. CICES (Common International Classification of Ecosystem Services) is another classification example, which merges regulating and supporting ecosystem services into a new category of "regulating and maintenance" ecosystem services and also includes a separate framework for abiotic services (Haines-Yong and Potschin, 2013). Within this study, seven ecosystem services (Table 1) were chosen that included examples from the MEA ecosystem service groups.

While the scientific literature on ecosystem services continues to grow it is still a challenge to apply this concept in practice (Kandziora et al., 2013). To assess ecosystem services, it is important to understand and quantify the link between biodiversity; i.e. species or communities or traits of species and the flow of services they supply or to which they contribute. However, this challenging task is hampered because biodiversity-ecosystem function relationships are still subject of ongoing research, particularly in the marine environment (Liquete et al., 2013; Gamfeldt et al., 2015; Strong et al., 2015). Yet, some biological components of the ecosystem do play clear roles in the provision of ecosystem services (Kandziora et al., 2013). For example, charismatic species attract visitors for ecotourism and therefore contribute to the service of Leisure and Recreation (Uyarra and Côté, 2007). In this way ecosystem services can be linked to MSFD biological components. Another example is the invasive macrozoobenthic polychaete genus *Marenzelleria* which, in the Baltic Sea, enhances retention of phosphorus in sediments and so promotes the Bioremediation of waste service (Norkko et al., 2012). Effects of biodiversity on ecosystem services may be explained by functional traits of species, so identification of "key functional traits," that have the capacity to influence the provision of multiple ecosystem services, is promising (Hevia et al., 2017). Table 2 lists examples of how each component contributes to the provision of particular ecosystem services.

Links between ecosystem components and ecosystem services can help to identify suitable ecosystem service indicators. The biodiversity indicators used to monitor GES could then also be used to assess ecosystem services, providing a cost-effective approach to support the management of regional seas and the services they provide. Several ecosystem service indicator lists have been published although none claims to be complete (Böhnke-Henrichs et al., 2013; Liquete et al., 2013; European Commission, 2014; Atkins et al., 2015; Hattam et al., 2015). Currently there are no accepted operational practise nor guidelines for the development or selection of useful marine ecosystem service indicators (Hattam et al., 2015; Hasler et al., 2016). Therefore, in this study, we have considered the applicability of biodiversity indicators for assessing the seven selected marine ecosystem services, to support the practical application of ecosystem services as a management tool within the framework of the MSFD implementation or other biodiversity assessments.

2.1 METHODS

2.1.1 Marine ecosystem service indicators

It was deemed efficient to concentrate on a broad selection of ecosystem services rather than all services, because each service indicator had to be cross checked against each biodiversity indicator, which is more manageable with a smaller number of services. This approach resulted in seven ecosystem services being selected for this study (MEA category in brackets): Food provision (provisioning), Climate regulation (regulating), Disturbance prevention and moderation (regulating), Bioremediation of waste (regulating), Biological control (supporting), Leisure and Recreation (cultural) and Aesthetic experience (cultural). Several studies have classified ecosystem services and prepared indicators for marine ecosystem services (Böhnke-Henrichs et al., 2013; Liquete et al., 2013; European Commission, 2014; Atkins et al., 2015; Hattam et al., 2015). We selected the three most comprehensive descriptions of marine ecosystem services (European Commission, 2014; Atkins et al., 2015; Hattam et al., 2015), and then used these to revise the descriptions of the seven services (Table 1). Published definitions of the Biological control service were particularly difficult to reconcile. Some encompass the concept of resilience, for example through food web dynamics, but also as disease and pest control, but we lack understanding of the connections between resilience and biodiversity, and how such knowledge can be used to inform management (Oliver et al., 2015). Our narrower description of this service therefore focused on pest, disease-bearing and harmful species. The terms nuisance species and pest species are currently used interchangeably in the ecological literature and are mostly aimed at invasive species. Here, by combining definitions of pest (Daily (2003) and nuisance (Hall-Spencer and Allen, 2015) species, we consider pest species to include humanity's competitors for food and other natural products and any other organisms that have undesirable effects from a human perspective, including invasive and native organisms, harmful algal blooms, opportunistic macro-algal blooms, and jellyfish swarms. We collated the three indicator lists into one, as examples of published ecosystem service indicators (Appendix 1). This provided a concise selection of published indicators that were well described in the respective sources, giving us information on metrics and units for each.

2.1.2 Comparability of biodiversity and ecosystem service indicators

The MSFD-relevant biodiversity indicators were taken from the freely available software DEVOTOOL (Version 0.64, http://www.devotes-project.eu/devotool/). DEVOTOOL provides a catalogue of biodiversity indicators from a wide range of countries, including some non-EU countries. The database focuses on indicators of the following descriptors: D1 Biodiversity, D2 Non-Indigenous Species, D4 Food webs and D6 Seafloor integrity (Teixeira et al., 2016). For each indicator, information is provided on data requirements, geographical coverage, relevance to habitats and biodiversity components as well as human pressures (Teixeira et al., 2016). At the time of access (09/06/2015, database version 6), 558 indicators were catalogued, of which 292 were operational, 200 under development, 46 conceptual and for 30 no status was given. Only the operational indicators for the biodiversity descriptors (D1, D2, D4 and D6) were included in this analysis.

Firstly, the published ecosystem service indicators were compared to the biodiversity indicators, to assess which of the latter are suitable for ecosystem service assessment. Biodiversity indicators had to fit the descriptions and metrics as well as units of published ecosystem service indicators to be selected. This assessment revealed that there is only a small overlap between the biodiversity and ecosystem services indicators and, as a result, information that is collected in biodiversity assessment may be not be directly used for ecosystem service assessment using published indicators. Yet, the biodiversity indicators may provide useful information on ecosystem services in addition to biodiversity status. For example, biodiversity indicators of distributional ranges of fish and top predators can also provide information on the ecosystem services of Food provision and Leisure and recreation.

2.1.3 Evaluation of biodiversity indicators for ecosystem service indicators

Further investigation was undertaken to determine whether biodiversity indicators could be useful for ecosystem service assessment. To be useful as an ecosystem service indicator, a biodiversity indicator has to link to a service in a direct and plausible manner. For example, phytoplankton biomass is not deemed suitable as an indicator for Food provision because, while phytoplankton is at the base of the food chain, and therefore important for Food provision, humans do not consume phytoplankton directly rendering it less useful in direct ecosystem service assessment. According to the MEA (2005), primary production would be a supporting service and phytoplankton biomass could be deemed in the same way as it has only an indirect impact on people (Liquete et al., 2016).

Guidelines were developed to evaluate if biodiversity indicators are useful for ecosystem service assessment (Table 3). Using these rationales, we considered each of the biodiversity indicators to assess its potential in ecosystem service assessments.

3.1 RESULTS

3.1.1 Comparability of biodiversity and ecosystem service indicators

In total, of the 296 operational DEVOTOOL indicators, 64 were directly comparable to published ecosystem service indicators while 232 indicators were not (Figure 1). Twenty indicators were useful for Food provision. Climate regulation could be measured with two indicators, Disturbance prevention with one, Bioremediation with eight and Biological control with eleven. Biodiversity indicators were most applicable for cultural services Leisure and recreation (35) and Aesthetic experience (30). Of those indicators that were directly comparable to ecosystem service indicators, 29 could be used for one ecosystem service only, 33 could provide information for two ecosystem services owing to similar data requirements, while two biodiversity indicators provided information on three different ecosystem services (Figure 1, Appendix 2).

3.1.2 Evaluation of all biodiversity indicators for ecosystem service assessments

Rationales were established to assess the relevance of biodiversity indicators for ecosystem service assessments in a consistent and plausible manner (Table 3). For example, while there is agreement in the ecological literature that zooplankton and fauna in general take up carbon, there is not enough evidence to show that this take-up leads to improved Climate regulation because organisms also respire carbon dioxide and may not remove any of it from the system (Legendre and Michaud, 1998; Turley et al., 2010). Therefore, indicators such as biomass of zooplankton or other faunal groups were rejected as indicators for Climate regulation.

Of the 296 GES indicators assessed using these rationales, 49 were found not to be useful for ecosystem services assessment, while 247 were considered suitable. Of these, 18 indicators additional to those already published could be used for Food provision, 36 for Climate regulation, 27 for Disturbance prevention, 35 for Bioremediation of waste, 12 for Biological checks and balances, 66 for Leisure and recreation as well as 50 for Aesthetic experience. Ninety-four biodiversity indicators were useful for one ecosystem service while 163 could be useful for two or more ecosystem services (Figure 1, Appendix 2). Multimetric indicators were often rejected as the integration of several types or sources of information made their interpretation in relation to ecosystem services rather complex; nevertheless, it is recognized that the datasets necessary to calculate these could contain useful information for ecosystem services assessment.

4.1 Discussion

This paper identifies potential indicators for seven selected ecosystem services from a list of biodiversity indicators prepared for the GES assessment of the MSFD. Ecosystem services are generated from many interactions in complex systems and not all links between ecosystem components and ecosystem services are fully understood (Balvanera et al., 2013; Liquete et al., 2016). For some services the role of the contributing components is clear. For others, relationships between ecosystem components and services (examples provided in Table 2) can help to conceptualise the links and to identify indicators for such services. This can also help with defining rationales for accepting or rejecting indicators as being useful for ecosystem service assessment.

Combining three lists of published ecosystem service indicators showed that they complemented each other well in terms of information on indicators. It also showed that each ecosystem service needs several indicators to be measured effectively, as has also been demonstrated by Atkins et al. (2015). For instance, for Food provision, abundance or biomass of edible species is important but so is the quality of fish and shellfish stocks, and so indicators such as the length profile of a fish community (abundance/biomass of large fish versus small fish) are insufficient on their own to measure service provision.

The comparison of biodiversity indicators for MSFD GES assessment with published indicators for ecosystem service assessment showed that there was little overlap of the conceptual approaches underpinning these assessments (Figure 1). However, biodiversity indicators do provide valuable information on ecosystem services, and the indicator lists could be updated to include biodiversity indicators identified as useful in this study. For the taxa and components for which links between their environmental status and ecosystem services are clear, the indicators used to assess GES of such components could also be used as ecosystem service indicators. For example, the abundance and distribution of marine mammals could be a useful indicator of the ecosystem service of Leisure and Recreation but further information such as proximity to the shore would be needed to assess if marine mammals could be watched from the shore or from small boats. Further ecological and ecosystem service research could advance our understanding of relationships between components and ecosystem services. For instance, a better comprehension of the key species, and functional traits, and habitats involved in services such as Bioremediation of waste or Biological control would improve the choices of indicators as well as management measures to keep this service sustainable. Such species and habitats will differ regionally. For example, one ecosystem service indicator for Biological control is ‘Quality of pest control species’, but pest species and the species that control them will differ regionally and this should be taken into consideration in each study area.

The application of functional traits in ecosystem services assessment may be a promising way forward, linking biodiversity to ecosystem services (Hevia et al., 2017 and references therein). This would enable connection between ecosystem structure and functioning and ecosystem services. However, there is lack of biological trait data to derive ecological indicators, as those are not currently included in marine monitoring (Beauchard et al., 2017). To date trait-based indicators are rarely used in marine systems (Teixeira et al., 2016) and were thus excluded from this analysis.

Other biodiversity indicators are only useful if target species (or functional trait) data are measured and can be extracted from available data sets. ‘Biomass of zooplankton’ may be useful for Leisure and Recreation if data on jellyfish blooms can be extracted, as jellyfish blooms may have a negative effect on beach goers. Some biodiversity indicators may inform us of potential declines in services. For example ‘Areal extent of opportunistic macroalgae’ can indicate a reduction in the Leisure and recreation service if rotting mats of macroalgae cover beaches. Similarly, ’Extent of dead seagrass beds’ is an indicator of reduced Climate regulation as dead or degraded seagrass beds no longer sequester carbon at the same rate or, even worse, can turn from a carbon sink to a carbon source (Pendleton et al., 2012; Macreadie et al., 2014).

Several multimetric indices are listed in DEVOTOOL. Many of these have been developed for the Water Framework Directive and some are applied to derive Ecological Quality Ratios for the assessment of the ecological status of surface waters. The principles of the development of multimetric indices and their use in the ecological assessments are summarized by Hering et al. (2006). They are also proposed, and in some cases adapted, for use in assessing GES. Some multimetric indices integrate several ecological and biological parameters reflecting the status of a biological community or Water Framework Directive 'quality element'. They are used to assess of the current status of the biological community addressing different stressors or different ecological or biological components (Hering et al., 2006). The combination of several parameters or several functional groups into a single index or series of indices using simple to complex statistics hinders the assessment of the link between ecosystem processes or components and the services they provide, particularly if the index is unit-less and/or a ratio. These indices were therefore largely rejected as being unsuitable for assessment of ecosystem services. An exception was made for benthic diversity indices which can be useful for Bioremediation of waste regarding diversity as an index and this is in agreement with Atkins et al. (2015) and Hattam et al. (2015). Higher diversity may indicate that functioning Bioremediation of waste is taking place although further studies are needed to confirm this. There may also be potential for their usefulness for ecosystem service bundles (sets of ecosystem services that repeatedly appear together across time and space (Raudsepp-Hearne et al., 2010), though to assess this was beyond the scope of this study.

For two services, Bioremediation of waste and Biological control, it was difficult to identify suitable indicators. For both services, the absence of pollutants or nuisance species can indicate a functioning service but it can also simply indicate the lack of pollutants or nuisance species in the first place, making these services difficult to define. Also, in the case of Bioremediation of waste, it is difficult to assess at which level the service fails if there is a lot of pollution. The service may still be there and functioning but be overwhelmed by the amount of pollutants in the environment (for example in an industrial harbour). In that case, pollution levels would be high even though the ecosystem service is functioning and working at high level and rate. The same problem can occur in Biological control and the indicator "Trends in arrival of non-indigenous species (NIS)" is a good example of this problem. If there are no pathways for NIS to arrive then this indicator would appear to demonstrate a functioning service while, in reality, there simply are no NIS arriving but if NIS do arrive, the ecosystem may not be able to cope with their numbers if the service was so far not "used". Therefore, an additional indicator that would show the degree of pressure from a particular NIS would be necessary to then demonstrate that the service is working.

4.2 Limitations of this assessment

Here, a list of new ecosystem service indicators based on biodiversity indicators is suggested. Our assessment was based on expert judgement rather than quantifiable criteria. To help overcome this limitation, rationales were created to reduce the subjectivity of the expert judgement approach.

The practical application of these indicators for ecosystem services assessment now needs to be tested using actual data. Ideally, this could be done in regional studies comparing ecosystem service assessment results across regional seas based on these indicators. It should be combined with evaluation of the general applicability of the rationales for selecting indicators for ecosystem service assessment. Indicators should be gauged as being useful if they show policy-relevance and sensitivity to changes within policy-relevant time frames. Additionally, this study did not look for appropriate target ranges for each indicator that would provide useful information on potential changes to the ecosystem. Target setting for ecosystem service indicators should be related to the sustainability definition of the resource in questions taking ecological, economic and social sustainability into account (e.g. Rossberg et al., 2017).

This study concentrated on biodiversity indicators for D1, D2, D4 and D6, which were the focus of the DEVOTOOL catalogue, on which we based our research. Indicators for other descriptors could also provide information on ecosystem services and should be considered for ecosystem service assessments. For instance, D3 (Commercial fish and shellfish stocks) is solely concerned with commercial species and therefore D3 indicators would clearly provide much information that is useful to assess Food provision and other services such as Biological control and Leisure and Recreation. Other examples are indicators for D8 (Concentration of contaminants) and D9 (Contaminants in fish and other seafood) which may be more informative for Bioremediation of waste and Food provision than the indicators addressed here, but such indicators were not included in this study.

A large number of contributors added indicators to DEVOTOOL and this led to some limitations in the catalogue (Teixeira et al., 2016). Chiefly these were: heterogeneity in the amount and type of information reported for each indicator, some indicator titles occur multiple times, not all fields were filled in correctly and some were left with gaps. Although they were addressed as far as possible by Teixeira et al. (2016), these limitations also led to issues in this assessment of indicators for ecosystem services. One problem was that not enough information was given on all indicators found in DEVOTOOL to be able to readily understand the information that would be collected and hence its relevance to ecosystem services. Although some indicators have a similar or even the same title, the underlying data requirements may differ amongst indicators, therefore all indicators were assessed in this study.

4.3 Recommendations and conclusion

Managing the marine environment of the European Union in a sustainable manner is a key aim of the MSFD (Borja et al., 2013). Ecosystem services are a useful management tool to complement traditional conservation measures (Luck et al., 2009; Maes et al., 2012). Therefore applying data which were originally collected to carry out biodiversity assessments for ecosystem service assessments would be a cost-effective way to facilitate management of the EU seas within an ecosystem service framework. Data for further ecosystem service indicators would be needed because not all biodiversity indicators can be connected with ecosystem service indicators. This study demonstrates that the majority of biodiversity indicators could also be useful for ecosystem service assessment. To help member states identify which biodiversity indicators are useful for the selected seven ecosystem services, appendix 2 of this study has been incorporated into DEVOTOOL Version 8 (http://www.devotes-project.eu/devotool/).

Although acknowledging the value that information on GES has for the assessment of ecosystem services, this study also highlights the need to refine available biodiversity indicators for the measurement of ecosystem services, recognising they are often too imprecise. This is in line with other authors that have shown the importance of the specificity of indicators, particularly within complex causal-link frameworks with many stages (e.g. Böhnke-Henrichs et al., 2013; Hattam et al., 2015). Furthermore, the choice of indicators should attend to the context of the assessment, including whether there is a requirement for both, GES and ecosystem service assessment (Hooper et al., 2014; Liquete et al., 2016).

Internationally, it is up to individual EU member states and other countries to choose biodiversity and ecosystem service indicators as needed. However, a systematic approach to assess biodiversity and how that relates to the status of ecosystem services would support coherent mapping and assessment of ecosystem services , as required by e.g. the EU Biodiversity Strategy 2020 (Maes et al., 2016). That way, across a regional sea, data can be compared and management aligned more effectively. This would also help fulfil the requirement of the MSFD for member states to "ensure the coordinated development of marine strategies for each marine region or subregion" due to the transboundary nature of the marine environment (MSFD, Article 13). Using these indicators for ecosystem services where appropriate on a global scale will also allow development of robust and comparable ecosystem service assessments worldwide which would also help achieve a convergence of theoretical and practical approaches to ecosystem service management. The approach demonstrated here could now be extended to all ecosystem services because we have shown in this study that an objective approach can be used.

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Tables, Figures and Appendices - Headings

Table 1: Descriptions of the seven ecosystem services addressed in this study, adapted from: Böhnke-Henrichs et al. (2013), European Commission (2014), Atkins et al. (2015) and Hattam et al. (2015)

Table 2:

Ecosystem	**Description**

service	
Food provision	The availability of marine flora and fauna for human consumption that can be caught from the wild
Climate regulation	The contribution of the marine environment to the maintenance of a favourable climate
Disturbance prevention or moderation	The dampening of the intensity of environmental disturbances such as storm floods, tsunamis and hurricanes and including the prevention of coastal erosion
Bioremediation of waste	The removal of waste input from humans into the marine environment, e.g. excess nutrients, and chemicals, as well as hazardous substances
Biological control	Control of pest species such as sea lice, invasive species, harmful algal blooms, blooming macro-algae, disease bearers such as *Escherichia coli*
Leisure, recreation	The provision of opportunities for tourism, recreation and leisure that depend on a particular state of marine ecosystems, in particular abundance of charismatic species, species targeted by anglers, species and habitats visited by snorkelers and divers, also water is of sufficient quality to serve as bathing water
Aesthetic experience	The contribution of the marine environment to the existence of a seascape that generates a noticeable emotional response within an individual observer

Table 2: Biodiversity components (species and taxonomic groups; Cochrane et al. (2010)) listed in Table 1 of Annex III of the MSFD as indicative biological features. For each component an example of their contribution to a particular service is given. Table is split to increase legibility.

Table 2a

Ecosystem services	Biodiversity components (species and taxonomic groups) listed in Table 1 of Annex III of the MSFD				
	Phytoplankton	**Zooplankton**	**Angiosperms**	**Benthic macroalgae**	**Benthic invertebrate fauna**
Food provision				Agar production for gelatine	Shellfish for human consumption
Climate regulation	Removal of carbon dioxide from the water column		Removal of carbon dioxide from the water column		Burial of carbon during bioturbation
Disturbance prevention			Reduce erosion by providing root structures in the sediments and reduce wave force and current strength	Reduce erosion by reducing wave force and current strength	Reduce wave force through bioengineering that creates obstacles for currents such as oyster beds and reefs
Bioremediation	Take up of nutrients from the water column for growth	Remove wastes from seawater	Remove wastes from seawater	Take up of nutrients from the water column for growth	Remove wastes from seawater through filter feeding
Biological control		By feeding on phytoplankton blooms	Remove bacteria from seawater		As predators of invasive species

Ecosystem services	Biodiversity components (species and taxonomic groups) listed in Table 1 of Annex III of the MSFD				
	Phytoplankton	**Zooplankton**	**Angiosperms**	**Benthic macroalgae**	**Benthic invertebrate fauna**
Food provision				Agar production for gelatine	Shellfish for human consumption
Climate regulation	Removal of carbon dioxide from the water column		Removal of carbon dioxide from the water column		Burial of carbon during bioturbation
Leisure/recreation	Diving/swimming/kayaking in bioluminescent water	Diving/swimming/kayaking in bioluminescent water	Snorkelling, diving	Snorkelling, diving	Angling bait, snorkelling, diving, crab catching
Aesthetic experience	Diving/swimming/kayaking in bioluminescent water	Diving/swimming/kayaking in bioluminescent water	For snorkelers, divers	For snorkelers and divers	For snorkelers and divers

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584 Table 2b

Ecosystem services	Biodiversity components (species and taxonomic groups) listed in Table 1 of Annex III of the MSFD				
	Fish	**Elasmo-branches**	**Marine mammals and reptiles**	**Seabirds**	**Non-indigenous species (NIS)**
Food provision	Wild fish catches and aquaculture	Sharks and rays caught for human consumption	Grey seals are hunted in the Northern Baltic Sea, Finland	Common eiders are hunted in Denmark, Sweden and Finland	NIS can be introduced for their aquaculture qualities for example Pacific oysters or Manila clams

Ecosystem services	Biodiversity components (species and taxonomic groups) listed in Table 1 of Annex III of the MSFD				
	Fish	**Elasmo-branches**	**Marine mammals and reptiles**	**Seabirds**	**Non-indigenous species (NIS)**
Climate regulation					
Disturbance prevention					Reduce wave force through bioengineering that creates obstacles for currents such as oyster beds
Bioremediation					Some NIS can remove waste from seawater through bioturbation and filtration
Biological control	As predators of invasive species	As predators of invasive species	As predators of invasive species	As predators of invasive species	*
Leisure/recreation	Angling	Angling/diving	Whale/seal/dolphin watching	Bird watching	
Aesthetic experience	For snorkelers and divers	Basking shark watching	Whale/seal/dolphin watching	Bird watching	

Table 3: Guidelines developed in this study to help deciding which biodiversity indicators may be useful for ecosystem service assessments

	Indicator type	Example	Rationale	Decision	Example reference
General criteria	Distributional range of a component	Distributional range of cephalopods	Useful to know where a particular service may be found but further information needed, such as abundance to give complete information. Also useful to show trends over time.	Accept, but not useful on it's own	

	Indicator type	Example	Rationale	Decision	Example reference
	Ratios	Biomass ratio of opportunistic macroalgae	Useful but further information needed, such as abundance to give complete information. Useful to show trends over time.	Accept, but not useful on it's own	
	NIS related indicators	Trends in arrival of new NIS	Depending on the particular species, NIS may change services for example reduce bioremediation by reducing filter feeder abundance but this link is indirect	Reject as too vague, need to know the species and how they affect a particular service	
	Management indicators	Bag size of hunted species	Such indicators show a management measure set in response to other ecosystem indicators and are therefore too indirect	Reject	
	Pressure indicators	Ratio of area affected by dredging proposal	Can indicate a reduction in a service, for example carbon sequestration may be reduced through dredging, but it is human made pressure rather than the effect of the pressure on the ecosystem that is measured here	Reject	
	Multimetric indicators	Cymoskew	Data required to calculate the majority of multimetric indicators is useful but most multimetric indicators, particularly EQR indicators which are unitless do not provide direct information about service provision	Reject, but some might be useful if simple to interpret (for example species diversity for leisure and recreation)	
Food provision	Biomass/abundance of groups that contain edible species	Biomass of cephalopods	Useful, if edible species are measured and data for these species can be extracted from available data	Accept	
	Size ratios	LFI - Large Fish indicator	Useful to assess status of fish communities containing commercial species	Accept	Hall et al. 2006

	Indicator type	Example	Rationale	Decision	Example reference
	Reproduction indicators	Fecundity rate of fish, Sex ratio of fish	This is a group of indicators that is classed into process indicators by Hattam et al. (2015) and Atkins et al. (2014) for Food provision. However, for top predators such as white tailed eagle reproduction is a useful indicator for the state of the ecosystem (Biological control in the wider sense)	Reject for food provision but accept if top predator health status can be used as an indicator of Biological control	
Climate regulation	Abundance or biomass of phytoplankton or macrophytes	Biomass of phytoplankton	Autotrophs take up carbon, which is good for climate regulation but the carbon needs to be removd from the system (e.g. through burial or export to the deep ocean) for it to be effectively a climate regulating service	Accept, but further information needed such as export rates	
	Depth limits of photic habitats such as seagrass beds	Depth limit of macrophytes	Greater depth range of a seagrass bed or of macroalgae potentially leads to larger area covered with such species which allows more uptake of carbon	Accept, but should be revisited in ecology	
	Zooplankton biomass/abundance etc	Biomass of selected zooplankton species and taxa groups	Heterotrophs do take up carbon, for example by eating phytoplankton, and some do move it down through the water column, particularly during dial vertical migration. They also excrete cells in faecal pellets which allows faster sinking rates, enhancing the organic pump	Reject as too indirect, further information on faecal matter and feeding rates needed to measure the service	Turley et al. 2010
	Fish and other fauna biomass	Biomass of demersal fish	Fish store carbon but also respire it, it does not lead to burial and removal of carbon	Reject as too indirect, further ecological study needed	Beaugrand et al. 2010
	Opportunistic macroalgae	Abundance of opportunistic macroalgae	Rafts of opportunistic macroalgae can wash up on shores, particularly after storms but are not buried, therefore carbon is not removed from the system	Reject	

	Indicator type	Example	Rationale	Decision	Example reference
	Distributional range of phytoplankton	Distributional range of phytoplankton	Indicator does not inform on how much carbon the phytoplankton take up or how much of that carbon is taken out of the system by burial or export therefore the link between the ecosystem service and the indicator is tenuous	Reject	
	Seagrass abundance, depth, biomass	Biomass of seagrass	Seagrass sequesters carbon and through the root system aids burial of carbon	Accept	Macreadie et al. 2014
	Bioengineering species	Biomass (per unit of surface) of structuring/engineering species (per habitat)	Species dependent: certain bioturbators aid the removal of carbon and nutrients from the system while others recirculate carbon and nutrients back through the system. Also, macrophytes can aid the removal of carbon (but see above indicators on macrophyte distribution and abundance) and biogenic reefs can aid carbon sequestration	Accept if bioturbators or macrophytes such as seagrass are measured	Norkko et al. 2012
Disturbance prevention	Extent of rocky habitat or sandy habitat	Areal extent of rocky habitats	Abiotic feature which does not inform on an ecosystem service	Reject	
	Macrophytes: biomass	Biomass of *Cystoseira barbata*	Species dependent and also dependent on where the species are in relation to the coast, a small-growing species of seaweed such as *Cystoseira* spp. may not reduce wave energy enough to provide a significant service, but large kelps may	Reject, further research needed	
	Depth limit of macrophytes	Depth limit of macrophytes	Distribution relative to coastline may be more important; greater depth will potentially reduce the service as it will not reduce wave and tidal strength	Reject, further research needed, but may be useful if seagrass is measured as seagrass roots hold substrate in place, reducing erosion	

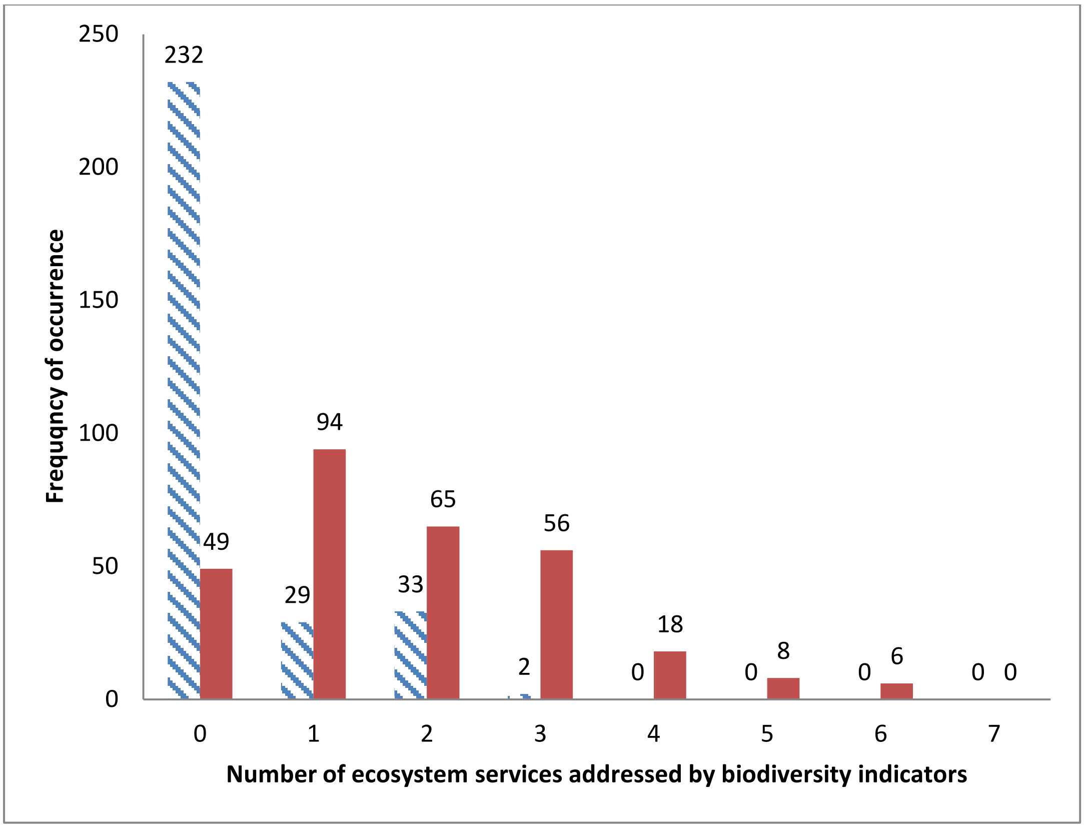
	Indicator type	Example	Rationale	Decision	Example reference
	Bioengineering species	Biomass (per unit of surface) of structuring/engineering species (per habitat)	Species and biological trait dependent	Accept if species or biological trait that aid sedimentation, reduce erosion, reduce wave strength	
Bioremedia tion	Depth distribution of habitats	Depth distribution of *Posidonia oceanica* meadows	This indicator can inform on where habitats are that aid bioremediation but it does not provide enough information to assess the service	Reject, as it does not provide enough informatio on the function of the service	
	Depth limit of macrophytes	Depth limit of *Fucus vesiculosus*	Can inform on the water clarity (similar to Secci depth) but is a very indirect indicator, as water clarity also depends on physical and hydrological factors such as currents and waves	Reject	
	Distributional range of habitats, areal extent of habitats	Distributional range of circalittoral and bathial soft bottom habitats	Informs on where the service may take place	Accept	
	Benthic invertebrates	Abundance of selected benthic invertebrate species	Abundance of bioturbators may be useful to assess this service but further information would be needed	Accept	Watson et al. 2016
	Abundance, composition of functional groups	Abundance and composition of functional groups in selected habitats	May inform on different types of organisms that can contribute to Bioremediation of waste	Accept	

	Indicator type	Example	Rationale	Decision	Example reference
	Structuring/engineering species	Areal extent of biogenic/vulnerable habitats	Several engineering groups are involved in bioremediation: bioturbators, filter feeders, seagrass and knowing the areal extent of their occurrence may help assess where bioremediation takes place	Accept	Norkko et al. 2012
Biological control	Communities diversity indices	Abundance or biomass of key species in the coastal waters	This indicator, particularly if observed over time may inform on changes to communities and thereby if a service can improve or be reduced with time	Reject	
	Bird indicators	Reproduction capacity of white tailed eagle	These indicators can show if an ecosystem as a whole is able to support top predators but a change in such an indicator would need further investigation to understand why bird populations are stressed or declining	Reject	
	Abundance, composition of functional groups	Abundance of phyto- and zooplankton	This indicator on its own does not inform on the stressors that may lead to a lack of biological control	Reject	
	Extent of opportunists, dead/dying seagrass	Areal extent of intertidal opportunistic green algae Areal extent of dead *Posidonia oceanica* meadows	These indicators may show where the service has failed but further information on the cause would be needed (for example mortality of *Posidonia* may also be due to non-biological reasons such as mechanical stress)	Accept	
Leisure/recreation	Depth distribution of habitats	Depth distribution of selected habitats	This information is important for divers, snorkellers, anglers as it can inform on the accessibility of the habitat for recreational activities	Accept	

	Indicator type	Example	Rationale	Decision	Example reference
	Diversity indices	Species diversity of benthic communities	Diverse benthic communities are important for snorkelling, diving and rockpooling	Accept	
	Biomass of charismatic species	Biomass of demersal elasmobranches	While charismatic species may attract visitors, for example on boat tours or for diving, abundance would be a better measure as these beneficiaries are more interested in knowing how many charismatic species are likely to be around than in their biomass	Reject	
	Breeding success, mortality of seabirds, reproduction in marine mammals	Productivity of seabirds (annual breeding success)	Can inform on the immediate future of the service	Accept	
	Biomass/abundance of zooplankton/phytoplankton	Abundance of phyto- and zooplankton	If taxa can be distinguished in the data, then this can be a negative indicator for nuisance species, such as jellyfish, HABs	Accept, if nuisance species are measured	
	Opportunistic macroalgae	Abundance of opportunistic macroalgae	Negative indicator, as it may indicate beaches are covered in macroalgae	Accept	Davenport and Davenport, 2006
Aesthetic experience	Depth distribution of habitats	Depth distribution of selected habitats	This information is important for divers, snorkellers, anglers as it can inform on the accessibility of desirable habitat for recreational activities	Accept	
	Diversity indices	Species diversity of benthic communities	Diverse benthic communities are important for snorkelling, diving and rockpooling	Accept	
	Breeding success, mortality of seabirds, reproduction in marine mammals	Productivity of seabirds (annual breeding success)	Can inform on the immediate future of the service	Accept	

Indicator type	Example	Rationale	Decision	Example reference
Opportunistic macroalgae	Abundance of opportunistic macroalgae	Negative indicator, as it may indicate beaches are covered in macroalgae	Accept	Davenport and Davenport, 2006

Figure 1: Assessment of biodiversity indicators as a potential source of information on ecosystem services. Hashed bars: compared to published ecosystem service indicators, most biodiversity indicators (232 of 296) are not directly comparable. Full bars: biodiversity indicators reassessed using guidelines developed in this study



Appendix 1: Indicator list collated from Atkins et al. (2015), Hattam et al. (2015) and Commission (2014b)

Ecosystem service	**Generic marine ecosystem service indicator**	**Metric (unit)**	**Additional or changed measurements - general comments**	Hattam	Atkins	Commission
Food provision - Wild capture sea food	Fish and shellfish populations, seaweed stock	Biomass (tonnes km^{-2}) or abundance (no. km^{-2}) of fish and shellfish; area (m^2) or biomass (tonnes km^{-2}) of seaweed		√	√	
	Quality of the fish, shellfish, seaweed stock	Species composition, age profile; length profile; % affected by disease; mortality rates		√	√	
Food provision - Farmed sea food	Fish and shellfish populations, seaweed stock	Biomass (tonnes km^{-2}) or abundance (no. km^{-2} of fish and shellfish; area (km^2) or biomass (tonnes km^{-2}) of seaweed		√		
	Quality of the fish, shellfish, seaweed stock	% affected by disease; mortality rates		√		
Climate regulation	Air-sea and sediment water fluxes of carbon and CO_2	mg C $^{-2}$ d $^{-1}$		√		
	Air-sea fluxes of other green house gases	µg green house gases m^{-2} d^{-1}		√	√	

Ecosystem service	Generic marine ecosystem service indicator	Metric (unit)	Additional or changed measurements - general comments	Hattam	Atkins	Commission
	Levels of carbon in different components of the marine ecosystem	biomass of carbon (gm^{-2}), dissolved organic and inorganic carbon (mg C m^{-3}, burrier particulate organic or inorganic carbon (mg C m^{-2})		√	√	
	Permanence of carbon sequestration	% of annual carbon turnover from sediments		√		
	Carbon stock	ton C				√
	C sequestration	ton C $year^{-1}$			√	√
	Blue C	ton C				
	Primary production	ton C $year^{-1}$				√
	Assimilative and recycling capacity	No units given			√	
	pH	Change in units	Time frame and spatial extent not identified			√
Disturbance prevention or moderation	Capacity of water storage of habitat	Water storage capacity (m^3/area) for different intertidal habitats (e.g. sediment, saltmarsh, mangrove)		√	√	
	Reduction of wave energy by near shore and intertidal habitats	Change in wave energy (Joules m^{-2}) attributed to different intertidal and near shore habitats	Width or area of salt marsh, reed bed, mudflat, sand dunes etc providing natural hazard protection (m, % cover, sediment	√	√	√

Ecosystem service	Generic marine ecosystem service indicator	Metric (unit)	Additional or changed measurements - general comments	Hattam	Atkins	Commission
			stabilisation properties			
	Changing shoreline	Change in beach profile (slope (gradient) and width (m) and stability) over time determined empirically from photos, satellite, LiDAR, ARGUS camera and modelled	Sediment stability	√	√	
Bioremediation of waste	Absolute levels of waste in the water column and within species	Chemical analysis (contaminant concentrations) and visual analysis	Water quality indicators (N mgl^{-1}, P mgl^{-1}), total dissolved solids (mgl^{-1})	√	√	√
	Amount of heavy metals in water and sediment	mgl^{-1}			√	
	Number of shellfish area closures	No units given		√		
	Presence of pathogens; outbreaks of *E.coli* infections; hospital admissions	Total coliforms or other pathogens (mgl^{-1})		√	√	
	Benthic biodiversity levels/ratios/no. of sensitive species	Different biodiversity indices		√	√	

Ecosystem service	Generic marine ecosystem service indicator	Metric (unit)	Additional or changed measurements - general comments	Hattam	Atkins	Commission
	Harmful algal bloom outbreaks	Remote sensing, water sampling to detect frequency and extent; modelling to determine future frequency and extent		√	√	
	Assimilative capacity	No unit given			√	
	Biological oxygen demand	mg O_2 l^{-1} day^{-1}			√	
	Oxyrisk	No unit given			√	√
	Amount of organic matter in water and sediment	mgl^{-1}			√	
Biological control	Presence/absence/frequency of pests (e.g. algae blooms, foam, sea lice on farmed salmon)	Count data		√	as an intermediate service	√
	Pest control	Distribution (km^{-2}) of alien species				√
	Quality of pest control species	Abundance, health status			√	
Leisure, recreation and tourism	Sea space available for recreation	Number of km^2 of sea with safe water quality available for recreational use		√	√	
	Number of designated sites	N			√	
	Number per area of specific seascape features	N/area			√	

Ecosystem service	Generic marine ecosystem service indicator	Metric (unit)	Additional or changed measurements - general comments	Hattam	Atkins	Commission
	% of total natural seascape	% of natural area in a specified area			√	
	Number and quality of beaches	Number and size of blue flag beaches		√	this is under benefits in Atkins	
	Water quality	Chemical analysis (contaminant concentrations) and visual analysis; total coliforms or other pathogens (quantity per ml of water)		√	this is under benefits in Atkins	
	Abundance and diversity of key species of recreational interest	Count data		√	this is under benefits in Atkins	
	Area of biotopes of key interest to recreational users	For example, extent of seagrass, maerl or kelp beds (km^2)		√	this is under benefits in Atkins	
Aesthetic experience	Uniqueness of a site	1/(Number of sites with similar features)		√	this is under benefits in Atkins	
	Abundance of key species of individual interest	Count data		√	this is under benefits in Atkins	
	Area of biotopes of key interest to individuals	For example, extent of seagrass, maerl or kelp beds (km^2)		√	this is under benefits in Atkins	

Appendix 2: Biodiversity indicators have been identified as useful (yes) or not useful (no) for the assessment of the selected ecosystem services. Published: those that also occur on the published ecosystem service indicator list created for this study

Biodiversity Indicator	**Food provision**	**Climate regulation**	**Disturbance prevention or moderation**	**Bioremediation of waste**	**Biological control**	**Leisure and recreation**	**Aesthetic experience**
Abundance of selected (coastal) fish species	no	no	no	no	no	published/yes	no
Trends in arrival of new non-indigenous species	no	no	no	no	yes	no	no
State of benthic communities	no	no	no	published/yes	no	no	no
Abundance or biomass of key species in the coastal waters	no	no	no	no	yes	no	no
Depth limit of macrophytes	no	yes	no	yes	no	yes	yes
Trends in the arrival of new invasive species	no	no	no	no	yes	no	no
Trends in the abundance of settled invasive species	no	no	no	no	yes	no	no
Reproduction capacity of white tailed eagle	no	no	no	no	no	yes	yes
Number of endangered marine species and populations	no	no	no	no	no	no	no
Bag size of hunted species	no	no	no	no	no	no	no
Number of species mentioned in birds directive and habitat directive that are on the suitable protection level	no	no	no	no	no	no	no
Number of hunted seals (grey seal, ringed seal)	no	no	no	no	no	no	no

Biodiversity Indicator	Food provision	Climate regulation	Disturbance prevention or moderation	Bioremediation of waste	Biological control	Leisure and recreation	Aesthetic experience
Mortality of white-tailed eagles	no	no	no	no	no	yes	yes
Breeding success of kittiwake	no	no	no	no	no	yes	yes
Species composition	no	no	no	published/yes	no	no	no
Abundance of phyto- and zooplankton	no	yes	no	no	yes	no	no
Abundance of phyto- and zooplankton	no	no	no	no	no	no	no
WFD SHWAP - Schleswig-Holstein Wadden Sea Assessment of Phytobenthos	no	yes	yes	yes	no	no	no
WFD BALCOSIS - Macrophyte index	no	yes	yes	no	no	no	no
WFD ELBO - German Macrophyte index	no	published/yes	yes	no	no	no	no
MarBIT - Marine Biotic Index Tool	no	no	no	published/no	no	no	no
Areal extent of intertidal opportunistic green algae	no	no	no	yes	yes	yes	yes
WFD German Ecological phytoplankton assessment with Chl *a* and Phaeocystis blooms	no	no	no	no	published/yes	no	no
WFD German Ecological phytoplankton assessment with Chl *a* and biovolume	no	yes	no	no	no	no	no
Depth limit of spermatophytes	no	yes	yes	no	no	yes	published/yes
Depth limit of	no	no	no	no	no	no	no

Biodiversity Indicator	Food provision	Climate regulation	Disturbance prevention or moderation	Bioremediation of waste	Biological control	Leisure and recreation	Aesthetic experience
charophytes							
Depth limit of *Fucus spp*.	no	yes	yes	no	no	yes	yes
Biomass ratio of opportunistic macroalgae	no	no	no	no	yes	no	no
Macrophyte species reduction (reduced species list)	no	no	no	no	no	no	no
TSI - Taxonomic Spread Index	no	no	no	published/no	no	no	no
WFD HPI - GermanMacroalgae index	no	no	no	no	no	no	no
Species diversity and landscape quality index	no	no	no	no	no	published/yes	published/yes
Ratio of area of protected area/total area	no	no	no	no	no	no	no
Ratio of surface water bodies in good ecological status	no	no	no	no	no	no	no
AETV - German Estuary Typology Procedure	no	no	no	published/no	no	no	no
Distributional range of cephalopods	yes	no	no	no	no	yes	no
Distributional range of demersal elasmobranchs	yes	no	no	no	no	yes	no
Distributional range of pelagic fish	yes	no	no	no	no	yes	no
Distributional range of phytoplankton	no	yes	no	no	no	no	no
Distributional range of sea-turtles	no	no	no	no	no	yes	yes
Distributional range of zooplankton	no	no	no	no	no	no	no

Biodiversity Indicator	Food provision	Climate regulation	Disturbance prevention or moderation	Bioremediation of waste	Biological control	Leisure and recreation	Aesthetic experience
Distributional range of selected demersal fish	yes	no	no	no	no	yes	no
Distributional range of selected benthic invertebrate species	no	no	no	no	no	no	no
Distributional range of whales	no	no	no	no	no	yes	yes
Distributional range of birds	no	no	no	no	no	yes	yes
Distributional pattern within the distributional range of sea-turtles	no	no	no	no	no	yes	yes
Distributional pattern within the distributional range of demersal fish	yes	no	no	no	no	yes	yes
Distributional pattern within the distributional range of demersal elasmobranchs	yes	no	no	no	no	yes	no
Distributional pattern within the distributional range of phytoplankton	no	yes	no	no	no	no	no
Distributional pattern within the distributional range of zooplankton	no	no	no	no	no	no	no
Distributional pattern within the distributional range of birds	no	no	no	no	no	yes	yes
Distributional pattern within the distributional range of cephalopds	yes	no	no	no	no	yes	yes

Biodiversity Indicator	Food provision	Climate regulation	Disturbance prevention or moderation	Bioremediation of waste	Biological control	Leisure and recreation	Aesthetic experience
Abundance of cephalopds	published/yes	no	no	no	no	yes	published/yes
Ratio of fish species in good ecological status	no	no	no	no	no	yes	no
Abundance of demersal fish - representation for georeferenced data (GIS)	published/yes	no	no	no	no	published/yes	no
Abundance of demersal elasmobranchs - representation for georeferenced data (GIS)	published/yes	no	no	no	no	published/yes	published/yes
Abundance of toxic phytoplankton taxa	yes	no	no	published/yes	published/yes	yes	yes
Biomass of zooplankton	no	no	no	no	no	no	no
Abundance of whales	no	no	no	no	no	published/yes	published/yes
Breeding population size of birds	no	no	no	no	no	yes	yes
Abundance of bird colonies	no	no	no	no	no	published/yes	published/yes
Abundance of demersal fish	published/yes	no	no	no	no	published/yes	yes
Biomass of demersal fish	published/yes	no	no	no	no	published/yes	no
Biomass of demersal elasmobranchs	yes	no	no	no	no	published/yes	no
Body length distribution of fish	published/yes	no	no	no	no	published/yes	no
Body length distribution of sea-turtles (longest shell)	no	no	no	no	no	yes	yes
Abundance rank of phytoplankton species	no	no	no	no	no	no	no

Biodiversity Indicator	Food provision	Climate regulation	Disturbance prevention or moderation	Bioremediation of waste	Biological control	Leisure and recreation	Aesthetic experience
Presence rank of phytoplankton	no	no	no	no	no	no	no
Abundance rank of zooplankton species	no	no	no	no	no	no	no
Presence rank of zooplankton taxa	no	no	no	no	no	no	no
Demographic characteristics of mammals	no	no	no	no	no	yes	yes
Productivity of seabirds (annual breeding success)	no	no	no	no	no	yes	yes
Breeding failures (widespread colony abandonment of birds)	no	no	no	no	no	yes	yes
Survival rate of birds	no	no	no	no	no	yes	yes
Number of introduced predating birds	no	no	no	no	published/yes	no	no
By-catch of seabirds	no	no	no	no	no	yes	no
Light pollution for sea birds	no	no	no	no	no	no	no
Body length distribution of fish	published/yes	no	no	no	no	published/yes	no
Distributional range of selected species	no	no	no	no	no	no	no
Body length distribution of pelagic invertebrates	published/yes	no	no	no	no	no	no
Depth distribution of selected habitats	no	no	no	no	no	yes	no
Depth distribution of circalittoral and bathial soft bottom habitats	no	no	no	no	no	no	no

Biodiversity Indicator	Food provision	Climate regulation	Disturbance prevention or moderation	Bioremediation of waste	Biological control	Leisure and recreation	Aesthetic experience
Distributional range of circalittoral and bathial soft bottom habitats	no	no	no	no	no	no	no
Distributional range of circalittoral and bathial soft bottom habitats	no	no	no	no	no	no	no
Number of lagoons	no	no	no	no	no	no	no
Depth distribution of *Posidonia oceanica* meadows	no	yes	yes	no	no	yes	yes
Number of rocky habitat polygons	no	no	no	no	no	no	no
Areal extent of rocky habitats	no	no	no	no	no	no	no
Depth distribution of selected habitats	no	no	no	no	no	yes	no
Distributional range of selected habitats	no	no	no	no	no	yes	no
Depth distribution of circalittoral and bathial soft bottom habitats	no	no	no	no	no	no	no
Ratio of area of infralittoral soft bottom habitats	no	no	no	no	no	no	no
Index of shape complexity	no	no	no	no	no	no	no
Perimeters (mean) of rocky habitats	no	no	no	no	no	no	no
Number of patches or polygons of rocky habitats (0-50 m depth)	no	no	no	no	no	no	no
Ratio perimeters/areal extent of rocky habitats	no	no	no	no	no	no	no

Biodiversity Indicator	Food provision	Climate regulation	Disturbance prevention or moderation	Bioremediation of waste	Biological control	Leisure and recreation	Aesthetic experience
Patch size standard deviation	no	no	no	no	no	no	no
Perimeters (sum) of rocky habitats	no	no	no	no	no	no	no
Distribution changes of established biocenosis	no	no	no	no	no	no	no
Ratio of area of selected habitats	no	no	no	no	no	no	no
Ratio of area with selected habitat in a bathymetric stratum	no	no	no	no	no	no	no
Areal extent of selected rocky habitats	no	no	no	no	no	yes	no
Areal extent of infralittoral rocky biogenic habitats	no	no	no	no	no	yes	no
Areal extent of infralittoral rocky habitats	no	no	no	no	no	yes	no
Ratio of area of lagoons	no	no	no	no	no	no	no
Areal extent of dead *Posidonia oceanica* meadows	no	no	yes	yes	no	yes	yes
Frequency of occurrence of habitats per square (in those cases without spatial continuity in cartography)	no	no	no	no	no	no	no
Areal extent (volume) of pelagic habitats	no	no	no	no	no	no	no
Species diversity (Shannon index)	no	no	no	no	no	no	no
Species diversity (Shannon index) of selected habitats	no	no	no	no	no	no	no

Biodiversity Indicator	Food provision	Climate regulation	Disturbance prevention or moderation	Bioremediation of waste	Biological control	Leisure and recreation	Aesthetic experience
Number of biocenosis/facies	no	no	no	no	no	no	no
CYMOX Index for lagoons	no	no	no	no	no	no	no
Abundance and composition of riparian vegetation	no	no	no	no	no	no	no
Abundance, composition and age structure of fishes in lagoons	published/yes	no	no	no	no	published/yes	no
Abundance of selected benthic invertebrate species	yes	no	no	yes	no	yes	yes
Flowering index of seagrass	no	no	no	no	no	no	no
Spatio-temporal variation of structural descriptors of *Posidonia oceanica* seagrass	no	yes	yes	yes	no	published/yes	published/yes
Abundance of functional groups	no	no	no	no	no	no	no
Abundance and composition of functional groups in selected habitats	no	no	no	yes	no	no	no
Abundance of keystone species or associated species	no	no	no	no	no	no	no
Hydrological condition of infralittoral rocky bottom habitats	no	no	no	no	no	no	no
Biomass of functional groups	no	no	no	yes	no	no	no
Body length distribution of fish	published/yes	no	no	no	no	published/yes	no

Biodiversity Indicator	Food provision	Climate regulation	Disturbance prevention or moderation	Bioremediation of waste	Biological control	Leisure and recreation	Aesthetic experience
Species richness of birds (in the Important Bird Areas network)	no	no	no	no	no	yes	yes
Biomass or functional groups of demersal biota (fishes and invertebrates)	published/yes	no	no	no	no	published/yes	no
Biomass or functional groups of demersal biota (fishes and invertebrates)	published/yes	no	no	no	no	published/yes	no
Abundance of planktonic copepods	no	no	no	no	no	no	no
Ratio of area of biogenic/vulnerable habitat	no	no	no	no	no	no	no
Areal extent of biogenic/vulnerable habitats	no	no	yes	yes	no	yes	yes
Ratio of area of selected habitats	no	no	no	no	no	no	no
Areal extent of selected habitats	no	no	no	no	no	published/no	published/no
Biomass (per unit of surface) of structuring/engineering species (per habitat)	no	no	yes	yes	no	published/yes	published/yes
Ratio of area potentially affected by changes in the sedimentation rate	no	no	no	no	no	no	no
Ratio of area potentially affected by selective extraction of substrate	no	no	no	no	no	no	no

Biodiversity Indicator	Food provision	Climate regulation	Disturbance prevention or moderation	Bioremediation of waste	Biological control	Leisure and recreation	Aesthetic experience
Ratio of area potentially affected by discharge of materials	no	no	no	no	no	no	no
Ratio of area potentially affected by changes in the seafloor topography	no	no	no	no	no	no	no
Ratio of area affected by each type of fishing gear	no	no	no	no	no	no	no
Species diversity of benthic communities	no	no	no	published/yes	no	yes	no
Areal extent of alterated Posidonia oceanica meadows	no	no	yes	yes	no	published/yes	published/yes
Ratio of area affected by aquaculture	no	no	no	no	no	no	yes
Ratio of area affected by cables and pipelines	no	no	no	no	no	no	yes
Ratio of area affected by human highly modified coast	no	no	no	no	no	no	yes
Ratio of area affected by harbor dredging activities	no	no	no	no	no	no	yes
Ratio of area affected by anchorage	no	no	no	no	no	no	yes
Ratio of area affected by dredging disposal	no	no	no	no	no	no	yes
Ratio of area affected by port infrastructure	no	no	no	no	no	no	yes

Biodiversity Indicator	**Food provision**	**Climate regulation**	**Disturbance prevention or moderation**	**Bioremediation of waste**	**Biological control**	**Leisure and recreation**	**Aesthetic experience**
Ratio of area affected by artificial beaches or beach nourishment	no	no	no	no	no	no	yes
Depth limit of eelgrass	no	yes	yes	no	no	published/yes	published/yes
Macroalgae-diversity indices	no	no	no	yes	no	no	no
Zoobenthos-diversity indices	no	no	no	yes	no	no	no
Fish-diversity index (Shannon)	no	no	no	no	no	yes	no
Areal extent of marine angiosperms	no	yes	yes	yes	no	published/yes	published/yes
Abundance of perennial seaweeds	no	yes	yes	yes	no	no	no
Abundance of seaturtle spawning population	no	no	no	no	no	yes	yes
Survival rate of *Posidonia oceanica*	no	no	no	no	no	no	yes
Biomass ratio of demersal fish (at higher trophic levels in the total catch)	yes	no	no	no	no	yes	no
Trends in populations of large pelagic fish	yes	no	no	no	no	yes	yes
Presence of particularly sensitive and/or tolerant species	no	no	no	no	no	no	no
Biomass ratio of benthic invertebrates above specified length	published/yes	no	no	no	no	no	no
Community Trophic Index	no	no	no	no	no	no	no

Biodiversity Indicator	Food provision	Climate regulation	Disturbance prevention or moderation	Bioremediation of waste	Biological control	Leisure and recreation	Aesthetic experience
Fish community size index	yes	no	no	no	no	no	no
Fish community abundance index	no	no	no	no	no	no	no
Abundance and composition of intertidal macroalgae	no	published/yes	yes	yes	no	no	no
Biomass ratio of opportunistic macroalgae/total	no	no	no	yes	yes	no	no
Depth of sediment redox potential discontinuity	no	no	no	yes	no	no	no
Biomass of benthic invertebrate species in sediment habitats	no	no	no	yes	no	no	no
Bathymetry	no	no	no	no	no	no	no
Accumulation of contaminants in sediment	no	no	no	yes	no	no	no
Marine Biological Valuation Methodology	no	no	no	no	no	no	no
Abundance ratio of opportunistic/sensitive species	no	no	no	no	no	no	no
Biomass of Cystoseira barbata	no	yes	no	no	no	no	yes
Biomass of Phyllophora crispa	no	yes	no	no	no	no	no
Biomass of seagrass	no	yes	yes	yes	no	no	no
Abundance of seagrass	no	yes	yes	yes	no	no	published/yes
Evenness (Sheldon) of phytoplankton	no	no	no	no	no	no	no
IBI - Integrated Biological Index	no	no	no	no	no	no	no

Biodiversity Indicator	Food provision	Climate regulation	Disturbance prevention or moderation	Bioremediation of waste	Biological control	Leisure and recreation	Aesthetic experience
Abundance ratio of selected dinoflagellates (C-strategy species)	no	no	no	yes	no	no	no
Abundance of selected phytoplankton species and taxa groups	no	yes	no	no	yes	no	no
Biomass ratio of diatoms/dinoflagellates	no	no	no	no	no	no	no
Spatial distribution of non-indigenous species	no	no	no	no	published/yes	no	no
Trends in arrival of new non-indigenous species per pathway	no	no	no	no	published/yes	no	no
Abundance ratio of bleached coral colonies	no	no	yes	no	no	yes	yes
POSWARE	no	yes	no	no	no	no	no
CymoSkew	no	yes	no	no	no	no	no
EPI - Estonian Phytobenthos Index	no	no	no	no	no	no	no
WFD Swedish Assessment of Biological Quality Elements in coastal and transitional waters - macrovegetation	no	no	no	no	no	no	no
WFD Polish Assessment system for coastal and transitional waters using macrophytes	no	no	no	no	no	no	no
WFD Dutch Eelgrass index	no	no	yes	no	no	no	no

Biodiversity Indicator	**Food provision**	**Climate regulation**	**Disturbance prevention or moderation**	**Bioremediation of waste**	**Biological control**	**Leisure and recreation**	**Aesthetic experience**
BEQI - Benthic Ecosystem Quality Index	no	no	no	no	no	no	no
BBI - Brackish water benthic index	no	no	no	no	no	no	no
WFD ZKI - Estonian Multimetric macrozoobenthos community index	no	no	no	no	no	no	no
BAT - Benthic Assessment Tool	no	no	no	no	no	no	no
ITI - Trophic index	no	no	no	no	no	no	no
NQI - Norwegian Quality Index	no	no	no	no	no	no	no
MAB Macroalgal Bloom Assessment (OpportunisticMacroalgae)	no	no	no	no	published/yes	no	no
WFD RSL - Macroalgae - Rocky Shore Reduced Species List	no	no	no	no	no	no	no
Depth limit of *Fucus vesiculosus*	no	no	no	no	no	no	no
Depth limit of *Furcellaria lumbricalis*	no	no	no	no	no	no	no
RSL - Rocky Intertidal macroalgae - Reduced Species List (RSL)	no	no	no	no	no	no	no
MarMAT - MarineMacroalgae Assessment Tool	no	no	no	no	no	no	no
The Elevated Phytoplankton (Single Taxa) Counts Tool	no	no	no	no	published/yes	no	no
Abundance of waterbirds in the	no	no	no	no	no	published/yes	published/yes

Biodiversity Indicator	Food provision	Climate regulation	Disturbance prevention or moderation	Bioremediation of waste	Biological control	Leisure and recreation	Aesthetic experience
breeding season							
Abundance of waterbirds in the wintering season	no	no	no	no	no	published/yes	published/yes
Distributional range of marine mammals	no	no	no	no	no	yes	yes
Nutritional status of marine mammals	no	no	no	no	no	yes	yes
Population growth rate, abundance and distribution of marine mammals	no	no	no	no	no	yes	yes
Pregnancy rates of marine mammals	no	no	no	no	no	yes	yes
Productivity of white-tailed eagle	no	no	no	no	no	yes	yes
Abundance of sea trout spawners and parr	no	no	no	no	no	yes	no
Abundance of salmon spawners and smolt	no	no	no	no	no	yes	no
WFD German Eelgrass index (intertidal)	no	no	no	no	no	no	no
AMBI - AZTI Marine Biotic Index	no	no	no	no	no	no	no
BOPA - Benthic Opportunistic Annelida Amphipoda Index	no	no	no	no	no	no	no
CARLIT-BENTHOS - Cartography of littoral and upper-sublittoral rocky-shore communities	no	no	no	no	no	no	no
DKI - Danish Quality Index	no	no	no	no	no	no	no
Depth limit of eelgrass	no	yes	yes	no	no	published/yes	published/yes

Biodiversity Indicator	Food provision	Climate regulation	Disturbance prevention or moderation	Bioremediation of waste	Biological control	Leisure and recreation	Aesthetic experience
M-AMBI - Multivariate AZTI Marine Biotic Index	no	no	no	no	no	no	no
POMI - Posidonia oceanica Multivariate Index	no	no	no	no	no	no	no
Biomass of cephalopods	published/yes	no	no	no	no	yes	no
Biomass of demersal elasmobranchs	yes	no	no	no	no	yes	no
Biomass of selected zooplankton species and taxa groups	no	no	no	no	yes	no	no
Age-frequency distribution of fish	yes	no	no	no	no	yes	no
Fecundity rate of fish	no	no	no	no	no	yes	no
Sex ratio of fish	no	no	no	no	no	no	no
Survival rate of fish	published/yes	no	no	no	no	yes	no
Biomass of phytoplankton	no	yes	no	no	no	no	no
Fecundity rate of sea turtles	no	no	no	no	no	yes	yes
Mortality rate of seaturtles	no	no	no	no	no	yes	yes
Biomass of zooplankton	no	no	no	no	no	no	no
Age-frequency distribution of *Pinna nobilis*	no	no	no	no	no	published/yes	published/yes
Biomass of zooplankton	no	no	no	no	no	no	no
Biomass of phytoplankton	no	yes	no	no	no	no	no
Biomass ratio of opportunistic/sensitive species	no	no	no	no	yes	no	no
Blubber thickness of seals	no	no	no	no	no	yes	yes

Biodiversity Indicator	Food provision	Climate regulation	Disturbance prevention or moderation	Bioremediation of waste	Biological control	Leisure and recreation	Aesthetic experience
PREI - Posidonia oceanica Rapid Easy Index	no	no	no	no	no	no	no
Abundance of benthic invertebrates	no	no	no	yes	no	no	no
Abundance of fish	published/yes	no	no	no	no	yes	no
Biomass of phyto- and zooplankton	no	yes	no	no	no	no	no
Biomass of phyto- and zooplankton	no	no	no	no	no	no	no
Areal extent of maerl-type biogenic sediments	no	no	yes	no	no	published/yes	published/yes
Abundance ratio of benthic invertebrates above specified length	no	no	no	no	no	no	no
WFD German Saltmarsh index	no	no	no	no	no	no	no
WFD German Eastern Baltic Phytoplankton index	no	no	no	no	no	no	no
Abundance of bioengineering species	no	no	yes	yes	no	published/yes	published/yes
Catch per unit effort (CPUE) of selected fish species	yes	no	no	no	no	no	no
CFR - Multimetric CFR index (Quality of Rocky Bottoms)	no	no	no	no	no	no	no
Concentration of Chl *a*	no	yes	no	no	no	no	no
Concentration of oxygen at the bottom	no	no	no	yes	no	no	no
Conservation status of fish	no	no	no	no	no	no	no

Biodiversity Indicator	**Food provision**	**Climate regulation**	**Disturbance prevention or moderation**	**Bioremediation of waste**	**Biological control**	**Leisure and recreation**	**Aesthetic experience**
Eveness (Pielou) of selected biological components	no	no	no	no	no	no	no
Genetic population structure of selected biological components	no	no	no	no	no	no	no
Index of phytocoenoses ecological activity (S/Wph)	no	no	no	no	no	no	no
MEDOCC	no	no	no	no	no	no	no
Secchi depth	no	yes	no	no	no	no	no
Abundance of Macroalgae (total cover)	no	yes	no	no	no	published/yes	published/yes
Abundance of demersal elasmobranchs	published/yes	no	no	no	no	published/yes	published/yes
Areal extent of selected Macroalgae species	no	yes	no	no	no	yes	yes
Species diversity (Shannon index) of benthic invertebrates	no	no	no	yes	no	no	no
Surface area/biomass ratio of selected macroalgae species	no	no	no	no	no	no	no
Species richness of fish	no	no	no	no	no	yes	yes
Species richness of Macroalgae	no	no	no	yes	no	no	no
Species richness of plankton	no	no	no	no	no	no	no
Species diversity (Shannon index) of plankton	no	no	no	no	no	no	no
Species diversity (Shannon index) of macroalgae	no	no	no	no	no	no	no

Biodiversity Indicator	Food provision	Climate regulation	Disturbance prevention or moderation	Bioremediation of waste	Biological control	Leisure and recreation	Aesthetic experience
Species diversity (Shannon index) of fish	no	no	no	no	no	yes	yes
Mortality rate of fish	published/yes	no	no	no	no	no	no
MTI - Marine Trophic Index	no	no	no	no	no	no	no
IQI - Infaunal Quality Index	no	no	no	no	no	no	no
Abundance of populations of selected bird species (winter)	no	no	no	no	no	published/yes	published/yes
Abundance ratio of selected phytoplankton taxa groups	no	no	no	no	no	no	no
WFD British Seagrass index	no	no	no	no	no	published/yes	published/yes
Species richness of selected habitats	no	no	no	no	no	no	no
Species richness of benthic invertebrates	no	no	no	yes	no	no	no
Species diversity (Menhinick) of plankton	no	no	no	no	no	no	no
Abundance (per unit of surface) of structuring/engineering species (per habitat)	no	yes	yes	yes	no	published/yes	published/yes
Substrate condition	no	no	no	no	no	no	no
Abundance of selected zooplankton species and taxa groups	no	no	no	no	yes	no	no
Abundance of functional groups of fish	published/yes	no	no	no	no	no	no
Abundance of phytoplankton	no	yes	no	no	yes	no	no

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Abundance of seals	no	no	no	no	no	published/yes	published/yes
Abundance of selected phytoplankton species and taxa groups	no	yes	no	no	yes	no	no
Abundance of zooplankton	no	no	no	no	no	no	no
Areal extent of eelgrass	no	yes	yes	yes	no	published/yes	published/yes
Areal extent of *Posidonia oceanica* meadows	no	yes	yes	yes	no	published/yes	published/yes
Abundance of shade-adapted, slow growing calcareous species	no	yes	no	no	no	no	no
Abundance of opportunistic macroalgae	no	no	no	yes	yes	no	no
EEI - Ecological Evaluation Index	no	no	no	no	no	no	no
BENTIX	no	no	no	no	no	no	no
Biomass of engineering species	no	yes	yes	yes	no	no	no
Biomass of *Mnemiopsis leidyi*	no	no	no	no	published/yes	no	no
Biomass of structuring species	no	yes	yes	yes	no	no	no
Biomass ratio of ESG IA species	no	no	no	no	no	no	no
LFI - Large Fish indicator	published/yes	no	no	no	no	yes	no
Body length distribution of demersal fishes, elasmobranchs and invertebrates	yes	no	no	no	no	yes	no

Biodiversity Indicator	**Food provision**	**Climate regulation**	**Disturbance prevention or moderation**	**Bioremediation of waste**	**Biological control**	**Leisure and recreation**	**Aesthetic experience**
Body length distribution of demersal fishes, elasmobranchs and invertebrates	yes	no	no	no	no	yes	no
BQI - Benthic Quality Index	no	no	no	published/yes	no	no	no
Sum "yes"	18	37	27	35	15	68	50
Sum published/yes	20	2	0	5	8	33	26
Sum all accepted	**38**	**39**	**27**	**40**	**23**	**101**	**76**