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Experimental Seagrass Ecosystem Accounts: A pilot study for one component of marine ecosystem accounts

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Executive Summary

Natural capital underpins the provision of many essential services that humans depend on, yet making the link between healthy ecosystems and the direct and indirect services they produce is often difficult. For instance, healthy seagrasses are vital to sustaining biodiversity, and to the provision of many marine ecosystem services in Europe. Seagrasses, particularly *Posidonia oceanica*, are important indicators of the quality of the marine environment, and are considered *biological quality elements* in the implementation of the Water Framework Directive (WFD, 2000/60/EC) and the Marine Strategy Framework Directive (MSFD, 2008/56/EC) (Marba et al., 2013). To date, 515 Natura 2000 sites have been designated for *Posidonia* beds[1], while numerous ecosystem services are noted to derive from seagrasses (see **section 3.4**). These demonstrate the importance of tracking the extent and condition of seagrasses within Europe to ensure their ongoing capacity to contribute to ecological functioning, and to human wellbeing through the many services they provide.

To meet the ambitious targets set out in the 7th Environmental Action Programme of the European Union (EU) and the *EU Biodiversity Strategy to 2020*, a shared initiative—or Knowledge Innovation Project (KIP)—was established at the EU level to develop an Integrated system for Natural Capital and ecosystem services Accounting (INCA). KIP INCA builds on the first phase of the EU initiative on *Mapping and Assessment of Ecosystems and Services* (MAES), which aimed to map and assess ecosystems and their services in the EU, and supports the second phase of MAES, which aims to value ecosystem services and integrate them into accounting and reporting systems by 2020.

To this end, this experimental review explores options for developing integrated seagrass accounts, primarily focusing on ecosystem extent accounts and ecosystem condition accounts, while briefly reviewing how these accounts could be linked to 'ecosystem production' and 'service supply-use' accounts.

Here, we identified available data reported under EU directives and remote or *in situ* surveys to determine the feasibility of developing seagrass ecosystem extent accounts. Key challenges associated with reported data included: (1) raw data used to inform assessments were often not available, or were not available at a resolution necessary to detect spatially-explicit change over time; (2) only one round of reporting had been conducted, preventing comparison between timeframes (not including the Habitats Directive), and/or (3) data were—in the case of Article 17—focused on one species in one location. In contrast, regional projects and studies provided helpful overviews of available information on the location of seagrasses, but were frequently developed using methods that would limit long-term comparability and use in accounts (see **section 3.2.1** for more details). Studies also often proposed multi-dimensional indicators for seagrass condition, with the sheer number of metrics making standardised application across regions unfeasible (see **sections 3.3.1** and **3.3.2**).

A number of short- and long-term options are available to overcome these challenges. In the short-term, accounts may be informed by high-level assessments like the European Red List of Habitats and the HELCOM Red List, yet these provide limited spatial understanding of the extent and

[1] More information available at: http://eunis.eea.europa.eu/habitats/10004#sites.

condition of seagrasses and their capacity to provide services (section 3.3.3). Comprehensive, project-based reviews of the regional or national extent and trends of seagrasses could be used in the short-term to trial the development of accounts, including 'ecosystem production' and 'service supply-use' accounts (e.g. Telesca et al., 2015) (see section 3.2.2). Conversely, pressures could be explored as proxies for seagrass condition, particularly in data-rich regions or countries with time series of pressures and data on seagrass extent (e.g. Northeast Atlantic) (see sections 3.3.4 and 3.3.6), while protected areas and other forms of spatial management (e.g. marine spatial planning initiatives) could be used to gauge the level of protection of seagrasses (section 3.3.5). However, each of these approaches is dependent on the baseline used for comparison, and does not necessarily indicate a current state/condition (i.e. "protected" seagrasses may be degraded, in recovery, or healthy).

In the long-term, subsequent rounds of reporting are expected to lead to greater access to underlying data that could be used to inform seagrass accounts, while the continued and expanded implementation of standardised, long-term, and country-led monitoring initiatives—both *in situ* and remotely sensed—could lead to higher-quality data. In particular, three basic metrics were noted as being relevant across EU policy frameworks and monitoring initiatives: taxonomic composition; spatial extent of seagrass beds; and annual mean shoot density (see section 3.3.2 for more details, and alignment with the WFD's Ecological Quality Ratios). A combination of existing initiatives, such as the Copernicus Marine Environment Monitoring Service, the CORINE Land Cover dataset, EUSeaMap, and Global Ocean Observing System (GOOS), could be adapted/used to complement *in situ,* country-level surveys, and thereby generate more complete and comparable accounts (further details available in the 'Key messages' section, and summarised in Table 16).

This experimental review represents a step toward the development of integrated seagrass accounts that would help track progress toward multiple European policy objectives, including Ecological Objectives under UN Environment / Mediterranean Action Plan's (UNEP/MAP's) Integrated Monitoring and Assessment Programme of the Mediterranean Sea and Coast and related Assessment Criteria (IMAP) and multiple descriptors of 'Good Environmental Status' under MSFD, while assisting with the implementation of the Water Framework Directive through seagrasses' use as indicators of the quality of the marine environment. Moreover, seagrasses are one of the habitats listed in Annex 1 of Article 17 of the Conservation of Habitats, Flora and Fauna Directive (92/43/EEC), or "Habitats Directive", which seeks to maintain or restore natural habitats and associated species at a favourable conservation status. Natural capital accounts such as these are an important way of tracking the changing extent and condition of such habitats, along with their capacity to deliver the services upon which humans depend.

1. Introduction

To establish the knowledge base necessary to meet the ambitious targets set out in the 7th Environmental Action Programme of the European Union (EU) and the *EU Biodiversity Strategy to 2020*, a shared initiative—or Knowledge Innovation Project (KIP)—was established at the EU level to develop an Integrated system for Natural Capital and ecosystem services Accounting (INCA). KIP INCA builds on the first phase of the EU initiative on Mapping and Assessment of Ecosystems and Services (MAES), which aimed to map and assess ecosystems and their services in the EU, and supports the second phase of MAES, which aims to value ecosystem services and integrate them into accounting and reporting systems by 2020.

The work presented herein explores one example of the development and application of a natural capital accounting framework for a marine ecosystem at the regional sea and European level. Specifically, this report examines the feasibility of establishing an integrated marine pilot account for seagrasses, as one of the identified priority ecosystem areas, highlighting potential methods and current gaps in knowledge. The report focuses primarily on ways of tracking the extent and condition of seagrasses across Europe, based on existing knowledge, while briefly discussing corresponding services and benefits and how these might be linked to changes in extent and condition.

This work is informed by the outcomes of a horizon scan of the current state of knowledge with regards to the status of and pressures facing Europe's seas, conducted between May and June 2017 as part of the same contract, and the "Developing an EU Ecosystem Accounting System: Focus on marine ecosystems" workshop held in March 2016 (10-11 March 2016, Paris, convened by the European Environment Agency [EEA] and the French Ministry for the Environment). The work also draws on data derived from recent reporting under European legislation and work completed by the EEA and others towards marine accounts and relevant data assessments and synthesis for the marine realm (e.g. the EEA's "State of Europe's Seas" report[2] and the European Topic Centre on Inland, Coastal and Marine Waters (ETC/ICM) Reports that will be released in 2017[3] and other synthesis work by the Joint Research Council (JRC) and the EEA).

Existing terrestrial and marine pilot accounts, including those at the case study level, are referenced to determine where methodologies could be transferred or adapted, or where new methodologies are required. Related and existing ecosystem service accounts (e.g. Integrated Marine Fish Accounts[4]) are also reviewed to see how these could be used to inform the methodology, while aligning with the System of Environmental-Economic Accounting Experimental Ecosystem Accounting (SEEA-EEA) framework (UN et al., 2014; see **Figure 1**) and recent, associated, draft Technical Recommendations (UN Environment et al., unpublished). This report takes into account the characteristics and sustainability of the data, including the feasibility of long-term monitoring and the quality of the data

[2] EEA. (2015). State of Europe's seas. EEA Report No 2/2015. URL: http://www.eea.europa.eu/publications/state-of-europes-seas.

[3] 2017 ETC/ICM Report No. 1 ("Development of EU-policy based marine (ecosystem) services assessments") and 2017 ETC/ICM Report No. 2 ("Further development of marine ecosystem typologies").

[4] Piet et al. (2016) Integrated marine fish accounts. Copenhagen, Denmark: European Topic Centre on Inland, Coastal and Marine Waters, European Environment Agency.

(i.e. spatial resolution; level of detail, such as species names and condition; accuracy). The scientific literature is also reviewed to identify the current state of knowledge with regards to seagrasses, including extent and indicators of condition within European waters.

This work aligns with Target 2 of the *EU Biodiversity Strategy to 2020* (COM(2011 244), which specifies that "by 2020[,] ecosystems and their services are maintained and enhanced by establishing green infrastructure and restoring at least 15% of degraded ecosystems", and with multiple Marine Strategy Framework Directive (MSFD) criteria[5]. This review offers experimental examples of how a seagrass extent account and a seagrass condition account could be constructed using available information, and is intended for use in identifying gaps in knowledge and priorities for establishing comprehensive seagrass accounts that integrate extent, condition and services.

[5] Criteria include: "Habitat extent" (1.5); "habitat condition" (1.6); "abundance of perennial seaweeds and seagrasses adversely impacted by decrease in water transparency" (5.3.2)

2. Methodology

2.1 Data and information requirements

Ecosystem assets, such as seagrasses, are "*spatial areas comprising a combination of biotic and abiotic components and other characteristics that function together,*" and are measured from two perspectives: *ecosystem condition* and *ecosystem extent*, along with *ecosystem services* (UN et al., 2014). Here, *ecosystem extent* refers to the size or 'stock' of an ecosystem asset in surface area (typically land cover in terrestrial examples) or biomass, whereas *ecosystem condition* refers to the overall quality of an ecosystem asset in terms of its characteristics (i.e. those related to its health), which can be measured through associated indicators (direct or indirect) that represent ecosystem function, resilience and integrity and are responsive to change over time (UN et al., 2014).

To develop comprehensive environmental-economic accounts, spatially-explicit datasets at the appropriate scale and quality are required, with time series of appropriate lengths to capture status and trends of ecological change. Data on the following four components, in accordance with the SEEA-EEA framework, are used to develop an integrated seagrass account:

- Extent (i.e. measure of the extent of an ecosystem asset(s));
- Condition (i.e. measure of ecosystem condition, or state/health);
- Services (i.e. measure of flow of ecosystem services); and
- Benefits (i.e. measure of value of benefits) (see **Figure 1**).

While this represents an ideal set of information requirements that could be used to establish an integrated seagrass account at the EU- or member state-level, it is difficult to obtain suitable data at a consistent spatial resolution and quality, and that use consistent metrics and timeframes. Thus, this review seeks to identify different approaches that could be used to overcome these data gaps, where possible, and to identify priority areas for development.

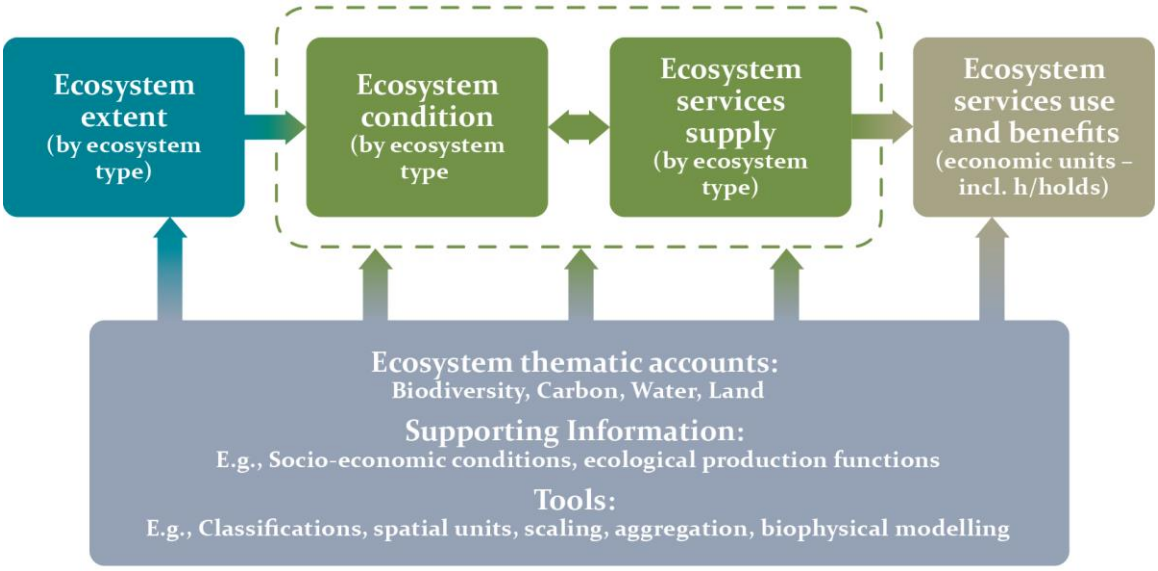

Figure 1. Relationship between thematic accounts and other SEEA-EEA accounts (adapted from Chow, 2016).

This experimental review focuses primarily on the first two components noted above—the **ecosystem extent account**, and the **ecosystem condition account**—while briefly touching on associated services and how these might be measured. This approach aligns with European classifications of seagrasses, specifically focusing on those of the European Nature Information System (EUNIS) and Annex 1 of the EU Habitats Directive (EC Directive 92/43/EEC) (see Annex 1, **Table A2**), and version 5.0 of the Common International Classification of Ecosystem Services (CICES) framework (Roy Haines-Young and Jan-Erik Petersen, unpublished).

Aligning with the recent 2017 draft Technical Recommendation for the SEEA-EEA framework (UN Environment et al., unpublished), units that could be used to define the spatial areas for which information is collected and organised include:

- A **basic spatial unit (BSU)** of 1 km^2 or 10 km^2 grid cells[6]. This is not an accounting unit, *per se*, but provides a consistent underlying spatial infrastructure (or resolution) for data integration;
- **An Ecosystem Asset unit (EA)**, representing an individual, contiguous area of the same ecosystem type); and an
- **Ecosystem Accounting Area (EAA)**, which defines the scope of the accounts, or the area to which all contributing data are aggregated. For the purpose of this review, the spatial focus (i.e. area of interest) was on the Marine Strategy Framework Directive's regions and subregions[7], where applicable, and the HELCOM region (entire Baltic Sea) (*EU Strategy for the Baltic Sea Region*; European Commission, 2009).

2.2 Seagrass ecosystem extent account

As indicated in the SEEA-EEA, an understanding of the spatial extent of an ecosystem asset (in this case, seagrasses) is essential to measuring the corresponding stock and associated services. Available geospatial datasets were therefore identified and reviewed for inclusion in the seagrass extent account, identifying the current known extent of seagrasses within Europe. These datasets were evaluated based on their resolution, completeness, and frequency of updates.

It is important to note that 'seagrass extent' in this instance functions as a proxy for identifying the extent of the entire ecosystem, and forms just one component of an integrated seagrass ecosystem account.

2.3 Seagrass ecosystem condition account

A literature review was conducted to identify indicators commonly used to assess seagrass condition within Europe. This information was considered in light of the metrics collated and used

[6] It is important to note that 1 km^2 is a higher resolution than that used for Article 17 reporting under the Habitats Directive and MSFD reporting (10 x 10 km^2 grid cells). The corresponding difference in the scale of change documented can be quite large (see Table 3 for examples). However, the appropriate scale would need to be determined based on the quality of the data available, and the sensitivity of the results to the scale selected. It should be noted that other BSUs (including polygons) could also be used but are unlikely to align with the spatial infrastructure used by the EEA.

[7] Additional information available here: https://www.eea.europa.eu/data-and-maps/data/msfd-regions-and-subregions-1.

under Article 17 of the Habitats Directive, the Water Framework Directive (specifically, Ecological Quality Ratio metrics), and the Marine Strategy Framework Directive. In the absence of spatially-explicit data, ecosystem assessments of health were also reviewed to assess whether it would be feasible to use them to inform condition accounts, including the European Red List of Habitats (Gubbay et al., 2016) and the HELCOM Red List (HELCOM Red List Biotope Expert Group, 2013). Indirect proxies for seagrass condition were also discussed briefly, reviewing possible pressures and available data that could be used to construct an account.

2.4 Exploration of seagrass ecosystem services account

This section begins with a discussion of the biophysical measurements of seagrass ecosystem services and their use in physical terms, as the first step in the general SEEA-EEA approach. Accordingly, 'Ecosystem Production Accounts' and ecosystem service 'Supply-Use Accounts' are illustrated, focusing primarily on the final services that are used directly by humans.

The section concludes with the outcomes of a high-level literature review that was conducted to explore methods of valuation for seagrass services, focusing on examples found primarily within Europe. The aim of this review was to provide an initial discussion related to next steps, specifically in relation to linking seagrass extent and condition with ecosystem service supply, use and valuation.

3. Results

3.1 Literature review: Building integrated seagrass ecosystem accounts

A review of the scientific literature revealed a set of commonly used metrics for assessing the extent and condition of seagrasses, and corresponding ecosystem services across Europe, with corresponding information outlined in **Table 1**.

Table 1. Examples of information that can be used to complete a full seagrass account.

Component	Sub-component	Description, and examples of information	Ref.
Extent	N/A	• Known seagrass extent (area) by regional sea, including estimates for opening and closing stocks; • Known seagrass extent (area) by species, including estimates for opening and closing stocks; • Above-ground biomass (direct variables); • Depth limit	[2, 6]
Condition	State	• Estimates of shoot density and cover (direct variable); • Estimates of canopy height (direct variable); • Estimates of photosynthetic efficiency (direct variable); • Below-ground biomass (direct variable); • Carbohydrate content (direct variable); • Abundance of associated species, such as waterfowl (indirect variable);	[2, 3, 4, 6]
	Pressures	• Fouling load (nutrient runoff); • Sea surface temperature; • Sea surface salinity; • Water clarity (light availability); • Eutrophication; • Chlorophyll *a* concentration	[2, 3, 7, 12]
Ecosystem services	Carbon sequestration	Seagrasses regulate the chemical composition of the atmosphere through carbon sequestration (CICES v. 5.0, 2.2.6.1). • Estimates of carbon storage rates; • Estimates of costs associated with climate mitigation.	[3, 10, 11]
	Food provisioning	Seagrasses contribute to food provision by supporting commercially- and nutritionally-important species (indirectly supports CICES v. 5.0, 1.1.1.4, as the final service). • Value to commercial fishing industry; • Value to aquaculture industry supplier	[1, 9]
	Water flow stabilisation	Seagrasses contribute to regulating hydrological flows (CICES v. 5.0, 2.2.1.3).	[3, 10]
	Nurseries for populations of	Seagrasses function as nurseries for commercially-important species in Europe, such as Atlantic cod (*Gadus morhua)* (CICES v.	[5, 13]

Component	Sub-component	Description, and examples of information	Ref.
	fish	5.0, 2.2.2.3). • Fish biomass; • Number of juveniles (nursery grounds)	
	Mass stabilisation and erosion control	Seagrasses contribute to mass stabilisation and control of erosion rates (CICES v. 5.0, 2.2.1.1). • Estimates of avoided costs associated with erosion damage.	[3, 8]
[1] Cole and Moksnes, 2016; [2] Duffy E., 2017; [3] Marba et al., 2013; [4] Berg et al., 2016; [5] Lilley and Unsworth, 2014; [6] Collier et al., 2016; [7] Zucchetta et al., 2016; [8] Ondiviela et al., 2014; [9] Christianen et al., 2013; [10] Duarte et al., 2013; [11] Fourqurean et al., 2012; [12] Leoni et al., 2008; [13] Tuya et al., 2014			

3.2 Seagrass ecosystem extent account

3.2.1 State of knowledge

Seven seagrass species are known to occur in Europe (*Halophila decipiens, Cymodocea nodosa, Posidonia oceanica, Zostera marina* [*Z. angustifolia* in the UK]*, Zostera Noltii, Ruppia maritima* and *Halophila stipulacea*), three of which are native—*Z. marina* (sublittoral)*, Z. noltii* (littoral)*, P. oceanica*—and one of which, the *H. stipulacea,* is considered invasive, having originated in the Red Sea (Ondiviela et al., 2014; IUCN, 2017) (see **Figure 2**). IUCN also records the presence of *Ruppia cirrhosa* in the southern half of the Mediterranean (IUCN, 2017).

To date, spatially-explicit, consistent and accessible datasets on the extent of seagrasses are still limited globally, even within Europe. Geospatial data reported under Article 17 of the Habitats Directive (habitat class 1120, 'Posidonia beds (*Posidonion oceanicae*)'), HELCOM, OSPAR and the MSFD were reviewed first, forming the basis from which to conduct an analysis of data and information gaps with regards to seagrass extent in European waters. While these data were able to offer contextual assessments of the location and condition of seagrasses, three issues were encountered when attempting to use these to inform accounts: (1) the data are often not available at a high enough resolution necessary to detect spatially-explicit change over time; (2) only one round of reporting had been conducted, preventing comparison between timeframes (not including the Habitats Directive), and/or (3) they were—in the case of Article 17—focused on one species (*Posidonia oceanica*) in one location (Mediterranean Sea). For instance, OSPAR's 'Threatened and/or Declining Habitats 2015' dataset offered useful data on the known distribution of *Zostera marina* and *Zostera noltii* in the OSPAR region, but did not have any available information on seagrass condition, or a time series for comparison (see Annex 1, Table A1, for a summary of the review of available data).

Beyond reported data, the majority of available geospatial datasets on known seagrass extent derive from fixed-term projects, often with short timelines. This constrains their use for a long-term regional understanding of change in the stock over time. For instance, while the high-resolution CORINE (Coordination of Information on the Environment) Land Cover dataset provides consistent spatially-explicit updates on the locations of different terrestrial classes of land cover within Europe

(e.g. class 4.2.1 'Salt marshes', under 4.2 'Coastal wetlands'), which aligns largely with EUNIS (see MAES, 2016), there is no marine equivalent known to the authors that includes seagrasses. Over the past 12 years, UNEP-WCMC, Fred Short (SeagrassNet) and partners have led the collation of existing data on the known extent of seagrasses globally, which have been compiled and shared as a dataset via UNEP-WCMC's bespoke spatial data platform, the Ocean Data Viewer. Version 4 of the dataset includes 29,322 polygons of seagrass extent in European waters, alongside 9,898 data points marking areas of seagrass occurrence (UNEP-WCMC and Short, 2016). This collates data obtained from multiple European sources, including the Mediterranean Sensitive Habitats (MEDISEH) project (Belluscio et al., 2013) and accompanying peer-reviewed paper (Telesca et al., 2015), and the OSPAR Commission's 'Threatened and/or Declining Habitats 2015' dataset mentioned previously (OSPAR Commission 2015). Although Telesca et al. (2015) attempted to identify trajectories of change for *Posidonia oceanica* in the Mediterranean based on historical data, these were generally restricted to the western Mediterranean and only suitable to estimate percentage regression of seagrasses at a country level.

In conjunction with the above, the IUCN Red List spatial dataset on the ranges of different seagrass species were used to cross-check knowledge of regional representation of seagrasses within European waters (IUCN, 2017). Finally, existing reviews of seagrass extent and trajectories were referred to, where available (e.g. Telesca et al., 2015, Boström et al., 2014), focusing primarily at the scale of regional seas. While site-level studies with updated estimates do exist and could supplement gaps in knowledge, corresponding data are not consistently nor readily available across Europe and are drawn from different time frames, making them frequently unsuitable for developing a comprehensive regional- or national-scale account.

Table 2. Examples of available spatial data on seagrass extent by regional sea, and species known to occur in that region.

Regional Sea	Species	Data source(s) and quality
Baltic Sea	*Zostera noltii; Z. marina*	Green and Short (2003), in UNEP-WCMC and Short (2016) [*superseded*]; Baltic Marine Environment Protection Commission (1993) [*superseded*]; HELCOM HOLAS II Dataset (2017), available at a 5 x 5 km grid-cell resolution (HELCOM Commission, 2017) [*latest*]; Boström et al., 2014
Mediterranean Sea	*Cymodocea nodosa, Posidonia oceanica, Zostera marina, Z. noltii, Ruppia maritima; R. cirrhosa; Halophila stipulacea.*	EUSeaMap (EMODnet, 2016)*; P. oceanica* occurrence data collated through MEDISEH (Telesca et al., 2015) [*latest*]; Article 17 data (#1120), Habitats Directive, available at a 10 x 10 km grid-cell; modelled *P. oceanica* distribution data as part of the FP7 MEDINA project (Zucchetta et al., 2016).
North-east Atlantic Ocean	*Zostera noltii; Z. marina*	OSPAR Habitats in the North-east Atlantic Ocean – Polygons 2015 (OSPAR Commission, 2015; *to be updated in February 2018*), in UNEP-WCMC and Short 2016 [*latest*].
Black Sea		UNEP-WCMC and Short (2016).

While comprehensive, geospatial data reported under Article 17 of the Habitats Directive is too coarse a resolution (10 km^2 grid cells) to support spatially accurate estimates of extent in seagrass

extent accounts, as demonstrated by the contrasting estimates in **Table 3.** Furthermore, they are only applicable to one regional sea (Mediterranean Sea) and one species (*Posidonia oceanica*). If higher quality, raw occurrence data (at a higher resolution) were submitted under EU instruments across multiple rounds of reporting, this information could be used to construct a more comprehensive seagrass extent account. For instance, initiatives such as EMODnet's broad-scale seabed habitats map for Europe (EUSeaMap) and OSPAR's *List of Threatened and/or Declining Species and Habitats* offer higher-resolution coverage for seagrasses in the Mediterranean and Northeast Atlantic, respectively; in EUSeaMap, seagrass data derive from surveys obtained from countries in the Mediterranean and Telesca et al. (2015) (EMODnet, 2016). Seagrass data held by the HELCOM Commission are also comprehensive, covering the *Zostera marina* distribution much of the Baltic Sea; however, this coverage is likely overestimated given the resolution of the data (i.e. 5 km^2 grid cells) and the use of models to fill gaps in known occurrence (HELCOM, 2017b).

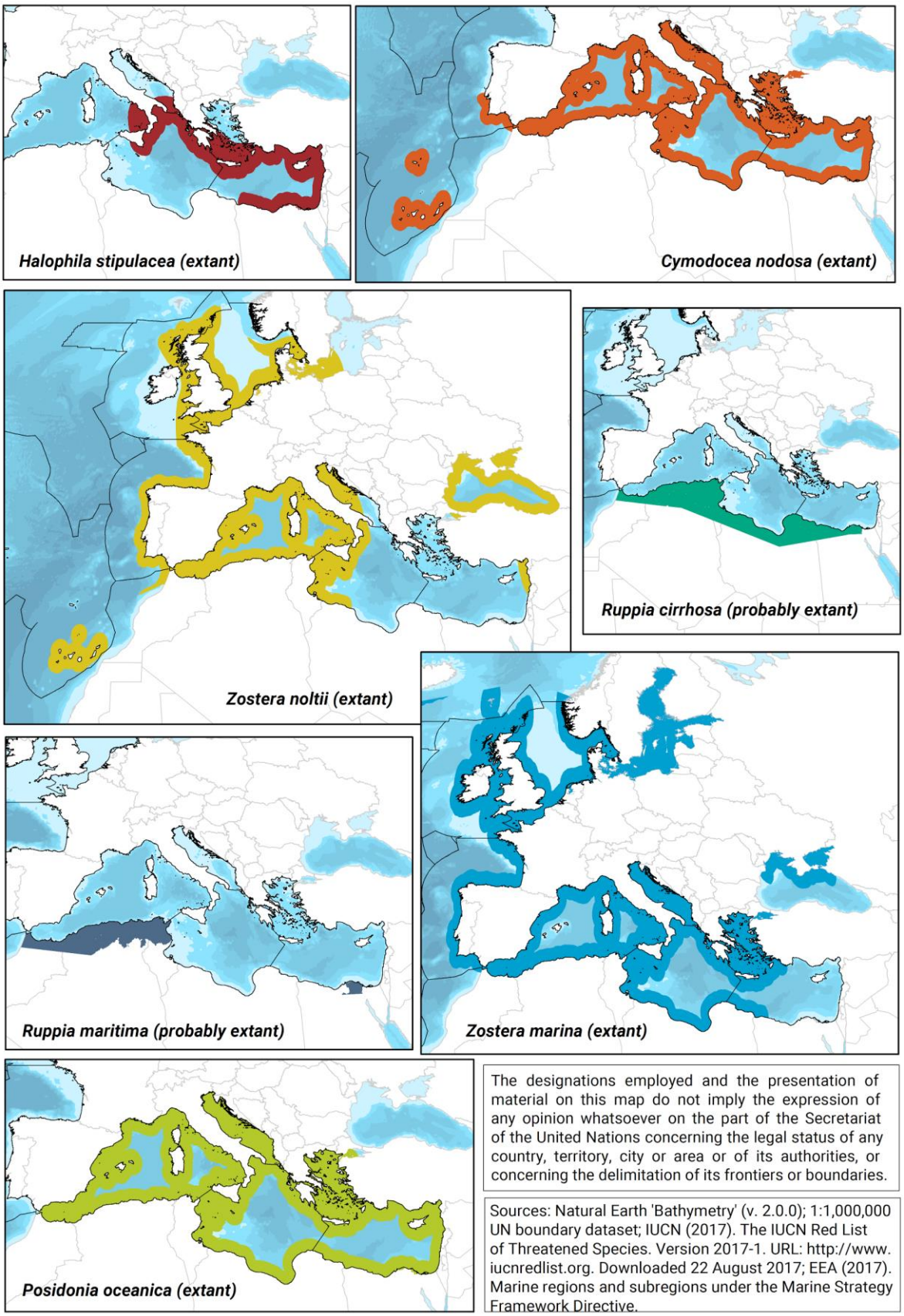

Figure 2. IUCN ranges of assessed extant (existing) and probably extant seagrass species in European waters, showing where the species may be found (IUCN, 2017).

Table 3. Example of discrepancies in spatial coverage (in square kilometres) across data sources for seagrasses in European waters, illustrating the importance of high-quality data for accurate accounts. Further details available in Annex 1.

Region	Source	Species	Surface area (km^2)	Explanation
Mediterranean Sea	Article 17, Habitats Directive	*Posidonia* beds (1120)	85,510	Resolution (generalised to 10 x 10 km^2) arguably too coarse to estimate seagrass extent and temporal change, with each grid cell potentially representing only a small amount of seagrass presence (leading to an overestimate in spatial coverage).
	Global Distribution of Seagrasses	*Posidonia oceanica, Cymodocea nodosa, Zostera marina, Z. noltii*	25,849* (+ 1,645 data points of occurrence where coverage information is lacking)	Species-level information not always available. *Surface area figure is from polygons only.
	EMODnet broad-scale seabed habitats map for Europe (EUSeaMap)	*Posidonia oceanica (including dead mattes), C. nodosa*	21,304	Includes EUNIS habitat types A5.531, A5.535, and A5.5353, based exclusively on occurrence data from the Mediterranean Sea. New update to be released soon.
	MediSeH (Telesca et al., 2015)	*Posidonia* beds	12,247	Most comprehensive assessment of the status and trends of *P. oceanica,* though there was no information on the presence or absence of *Posidonia* for almost half of the Mediterranean coastline (especially the southeastern Mediterranean).
Baltic Sea and Northeast Atlantic	HELCOM HOLAS II	*Zostera marina*	20,912	Mixture of observed and modelled data. Likely overestimates coverage given the scale of the data (generalised to 5 x 5 km^2 grid cells).
	Boström et al., 2014	*Zostera marina*	1,480 – 2,100	Synthesis of data published between 1890 and 2010, providing an estimate of *Zostera marina* extent within the Nordic region.
OSPAR Region	OSPAR Threatened and/or Declining Habitats 2015	Zostera beds (*Zostera marina, Zostera noltii*)	300.25	No information available on status or trends.

While available data do not currently support a refined, continuous and spatial comparison of changes in seagrass extent over time at a regional scale, advances in remote sensing technologies—combined with standardised metrics for *in situ* surveys—are likely to lead to greater consistency in measurements and monitoring. However, with such advances, it is often difficult to determine whether observed changes are the result of true changes in seagrass extent or due to greater access to data, often obtained at higher resolutions over time. Species-level information can be obtained from the Global Biodiversity Information Facility (GBIF) and the Ocean Biogeographic Information System (OBIS), which can be used to validate species occurrences within an ecosystem. However, these data are not consistently collated across scales and timeframes, do not explicitly reflect known change in ecosystem extent and the availability of associated services, and do not reflect other pressures that would influence distributions.

A current collaboration between the Ocean Biogeographic Information System (OBIS), Marine Biodiversity Observation Network (MBON) (including UNEP-WCMC, as a partner) and the Global Ocean Observing System (GOOS) is seeking to identify ways forward to overcome these challenges, including through in-country focal points and nodes to collate and validate data on marine and coastal habitat extent in a more systematic manner. Similar to Telesca et al.'s (2015) approach that mapped "no data" areas in the Mediterranean (discussed in below, in Section 3.2.2), this work aims to increase transparency with regards to the degree to which available data are representative of the overall extent of occurrence. Indeed, seagrass absence in a given area may be either due to no surveys having been conducted or reported on (i.e. false absence), or the area being unsuitable for seagrass to grow (i.e. real absence).

3.2.2 Case study: Seagrass ecosystem extent account for Posidonia oceanica

One approach to assessing the known extent and trajectory of *Posidonia oceanica* within the Mediterranean Sea was employed by Telesca et al. (2015), as part of the Mediterranean Sensitive Habitats (MediSeH) service contract funded by DG MARE (as part of the MAREA Framework). This work entailed an in-depth literature review of available data sources, frequently obtained from short-term research studies, which were used to form a picture of the current status of *P. oceanica,* and a more transparent understanding of existing gaps in knowledge (see **Table 5**). The authors found that the known extent of *P. oceanica* within the Mediterranean was 12,247 km^2, with an estimated loss of 1,240.91 km^2 over the past 50 years (an average regression of 10.1%) (Telesca et al., 2015).

Table 4. Change in total extent of *Posidonia oceanica* meadows (in square kilometres) in the Mediterranean Sea by country (adapted from Telesca et al., 2015, as part of the MediSeH project [SI2.600741] funded by DG MARE).

Country	Currently surveyed coastline (%)	Historical surveyed coastline (%)	*P. oceanica* total current area (km^2)	*P. oceanica* total historical area (km^2)	*P. oceanica regression* (%)	Time range of data
Spain	100%	70%	17,266.9	22,225.4	29%	1993-2011
France/ Monaco	100%	60%	940.3	967.83	9%	1980-2011
Italy	100%	42%	3,376.11	3,952.98	25%	1990-2005
Slovenia	100%	--	0.09	--	--	2004
Croatia	14%	--	314.37	--	--	2010
Montenegro	100%	--	--	--	--	2004
Albania	100%	--	48.03	57.10	16%	2007-2008
Malta	100%	--	58.6	--	--	2002
Greece	8%	--	449.39	--	--	2011
Turkey	29%	6%	2.87	--	--	2009
Cyprus	30%	--	90.4	--	--	2008
Syria, Lebanon	100%	Absent	Absent	--	--	2003

Country	Currently surveyed coastline (%)	Historical surveyed coastline (%)	*P. oceanica* total current area (km^2)	*P. oceanica* total historical area (km^2)	*P. oceanica regression* (%)	Time range of data
and Israel						
Egypt	63%	3%	--	--	--	2006
Libya	11%	--	12.35	--	--	2011
Tunisia	81%	13%	5,186.85	5,318.44	2%	1972-2010
Algeria	16%	--	40.72	--	--	2010
Morocco	100%	--	--	--	--	2006

The trends illustrated by Telesca et al. (2015) (**Table 4**), can be reworked into a partial seagrass extent account, as shown in **Table 6**. While forming a useful baseline, the primary difficulty with this approach is that the estimates are obtained from multiple studies using different methodologies, which are unlikely to be repeated on a consistent basis. This makes it difficult to repeat the approach in the future to obtain comparable results. As one of the most comprehensive studies to date on *P. oceanica* in the Mediterranean, this study demonstrates the challenges associated with tracking the extent of marine ecosystems at a national or regional scale on a consistent basis. Thus, long-term funding and standardised monitoring approaches (e.g. combination of *in situ* and remote sensing data collection techniques), directly linked to EU reporting requirements, are necessary to track change over time.

3.3 Seagrass ecosystem condition account

To explore potential methods for assessing seagrass condition, two components were reviewed: **indicators of seagrass health, or state** (direct), and **pressures and management measures affecting seagrass condition** (indirect).

3.3.1 State

A review of indicators used to monitor seagrasses yield 49 indicators used across 42 monitoring programmes in Europe, with a total of 51 metrics across six broad categories (Marbà et al., 2013). However, a lack of consistency across monitoring programmes makes it difficult to define indicators that are regionally applicable. Seagrass condition is dependent on below-ground biomass, which plays an important role in carbon storage, carbohydrate storage, and stabilisation of sediments (Christianen et al., 2013; Vonk et al., 2015). Seagrasses are also highly sensitive to environmental deterioration, including water turbidity, eutrophication, erosion and warming) (Marbà et al., 2013). Thus, the capacity of seagrasses to store carbohydrates can be affected by cumulative environmental stress, and therefore can be considered a complementary indicator of condition and resilience (Collier et al., 2016). As 'canaries in the coal mine,' seagrass metrics can also be combined with associated metrics to develop indicators of ecosystem condition. For instance, "*distribution of herbivorous waterfowl in relation to eelgrass biomass distribution*" has been proposed as an indicator relevant to several 'good environmental status' criteria (Berg et al., 2016; Heiskanen et al., 2016).

Within the Essential Ocean Variables (EOV) framework[8] (Duffy, 2017; Constable et al., 2016), direct parameters considered to represent seagrass condition include shoot density and cover, canopy height, and photosynthetic efficiency, while supporting variables include water clarity and turbidity, temperature, salinity, and epiphytic algae and fouling load. Indirect variables that could be used to assess the condition of seagrasses include the abundance of algae, which detrimentally affects seagrass habitats, and the abundance of associated species (e.g. epifaunal abundance and the abundance and species composition of fishes and invertebrates (Duffy, 2017). Examples of potential measures of seagrass condition are indicated in **Table 5**.

Table 5. Measures of ecosystem (seagrass) condition within an Ecosystem Accounting Area (adapted from Table 4.3 in the SEEA-EEA framework; UN et al., 2014).

Ecosystem	Ecosystem extent	Characteristics of ecosystem condition			
	Area	Vegetation (volume)	Biodiversity	Light	Water quality
Seagrass	In km^2, or estimates of above-ground biomass	Shoot density (no. of shoots/m^2) and cover (km^2)	Abundance of associated species (e.g. waterfowl)	Photosynthetic rates (µmol O_2 g^{-1} FW h^{-1}	Nutrient enrichment

[8] More information available at: www.goosocean.org/eov.

Table 6. *Posidonia oceanica* extent account for the Mediterranean Sea (1972 – 2011), in square kilometres (adapted from Telesca et al., 2015). Figures in the bottom line are drawn directly from Telesca et al. (2015), representing the current calculated extent of *Posidonia oceanica* meadows (2002 – 2011).

	Spain	France/ Monaco	Italy	Slovenia	Croatia	Monten-egro	Albania	Malta	Greece	Turkey	Cyprus	Egypt	Libya	Tunisia	Algeria	Moro-cco
Original Extent (km^2) (1972 – 2011)	22,225.4	967.83	3,952.98	--	--	--	57.10	--	--	--	--	--	--	5,318.44	--	--
Est. reductions in stock (km^2)	4,998.5	27.53	57.87	--	--	--	9.07	--	--	--	--	--	--	131.59	--	--
Est. % Original Extent	71%	91%	75%	--	--	--	84%	--	--	--	--	--	--	--	--	--
2002 – 2011 (Closing stock, km^2)	**17,226.9**	**940.3**	**3,376.11**	**0.09**	**314.37**	**--**	**48.03**	**58.6**	**449.39**	**2.87**	**90.4**	**--**	**12.35**	**5,186.85**	40.72	--

3.3.2 Case study: Seagrass ecosystem condition account based on the Water Framework Directive's Ecological Quality Ratios (EQRs)

Under the Water Framework Directive (WFD; 2000/60/EC), angiosperms—or seagrasses, in the marine realm—are considered a *Biological Quality Element (BQE)* to be used in defining the ecological status of a transitional or coastal water body. In this regard, stated attributes for monitoring the status of seagrasses include taxonomic composition (presence of disturbance-sensitive species), abundance (seagrass shoot density) and cover (spatial extent) (Foden, 2007).

In an effort to align with the WFD, many multi-metric indices based on *Z. noltii, C. nodosa, and P. oceanica* (e.g. POMI, BiPo, AquA, AQI, CYMOX, EQBI, ZoNI and PoSte) have been developed to assess the ecological quality of coastal and estuarine systems in Europe (Personnic et al., 2014; Mascaró et al., 2012; Romero et al., 2007; Royo et al., 2011; García-Marín et al., 2013; Oliva et al., 2012; Caçador et al., 2013; García et al., 2009). However, many of these indices require significant data inputs, making it challenging to apply them at a regional scale without comprehensive *in situ* surveys, and to integrate them with other assessments.

On the other hand, the Seagrass Quality Index (SQI) is a WFD-compliant tool that has a lower metric requirement, focusing on three common parameters of seagrasses: the number of taxa, bed extent and shoot density (Neto et al., 2013). These parameters are commonly used in studies concerning seagrasses across Europe (Marbà et al., 2013) and align with those proposed under the Essential Ocean Variables framework (Duffy, 2017), but would need to be aggregated to a scale that is appropriate for accounting. Moreover, they align with the three attributes used under the WFD to assess water body condition through seagrass condition, as a proxy. Thus, one approach to constructing a seagrass condition account through the use of WFD-derived data for seagrasses is outlined in **Table 7**, based on the calculation of Ecological Quality Ratio (EQR) metric values aggregated to the water body level (WFD UK TAG, 2014). The associated equations and proposed thresholds for these metrics, based on EQR metric ranges, are outlined in **Table 8.** The overall seagrass condition—as a proxy for the 'Ecological Status' of the water body, in accordance with the WFD—would be the mean value of the three EQRs, i.e. (1.0 + 0.957 + 0.482) / 3 = 0.81 (good status) (WFD UK TAG, 2014).

Table 7. Theoretical example of an approach to constructing a seagrass condition account, using the Ecological Quality Ratio metrics (EQR) in the Water Framework Directive (2000/60/EC) (adapted from WFD UK TAG, 2014).

	Taxonomic composition (number of taxa)	Spatial extent of seagrass beds (km^2)	Annual mean shoot density (%)
Historic	1	58.2	39
Change in metric	0	-2.15	-41.72
Closing stock [and EQR]	**1 [1.0]**	**56.95 [0.957]**	**22.73 [0.482]**

Table 8. Selection of proposed metrics for use in seagrass condition accounts, aligning with the Ecological Quality Ratio (EQR) metrics set out in the Water Framework Directive (2000/60/EC) and the proposed suite of Essential Ocean Variables, and that are commonly found across seagrass studies in Europe (adapted from WFD UK TAG, 2014).

EQR metric	Equation	Proposed thresholds (% loss), and corresponding EQR range [ ].				
		High	Good	Moderate	Poor	Bad
Taxonomic composition	% loss = (Observed no. of taxa / Reference no. of taxa) * 100	0 to 25 [0.8 to 1.0]	>25 to 33 [0.6 to <0.8]	>33 to 66 [0.4 to <0.6]	>66 to 75 [0.2 to <0.4]	>75 to 100 [0 to <0.2]
Spatial extent of seagrass beds	Total increase/decrease = ((recent area – past area)/past area * 100	0 to 10 [0.8 to 1.0]	>10 to 30 [0.6 to <0.8]	>30 to 50 [0.4 to <0.6]	>50 to 70 [0.2 to <0.4]	>70 to 100 [0 to <0.2]
Annual mean shoot density	Total increase/decrease = ((recent % cover – past % cover) / past % cover) * 100	0 to 10 [0.8 to 1.0]	>10 to 30 [0.6 to <0.8]	>30 to 50 [0.4 to <0.6]	>50 to 70 [0.2 to <0.4]	>70 to 100 [0 to <0.2]

3.3.3 Case study: Seagrass ecosystem condition accounts based on Red List assessments

Though not spatially explicit, IUCN Red List assessments may also inform condition accounts in the absence of spatial data, and where sufficient information is available through these assessments. For instance, while all of the European seagrass species reviewed were listed as Least Concern on the IUCN Red List of Threatened Species, many were noted as having declining populations (see Table 9). Thus, as climatic and human pressures increase, it is likely that these listings may change in the coming years. Thus, a Red List account for threatened species, as discussed in the SEEA-EEA (UN et al., 2014) and in UNEP-WCMC (2016), could be adapted for use when assessing changes in ecosystem condition. The premise of such an account would be to focus on these species as indicators of good condition, where negative changes in threat status implied a negative impact on condition. Changes across species could be communicated in aggregate by a Red List Index calculated for this set of indicator species.

Table 9. Example of an IUCN Red List Account for seagrass species within the Mediterranean Sea, drawing from regional assessments (between 2009 and 2013). *Ruppia cirrhosa, Ruppia maritima*, and *Halophila stipulacea* were also listed as being of Least Concern in their global and regional assessments (Ghogue, 2010; Lansdown, 2011; Short et al., 2010a, 2010b).

Species	Date	Red Listing						References
		Extinct or Extinct in the Wild (5)	Critically Endangered (4)	Endangered (3)	Vulnerable (2)	Near Threatened	Least Concern (0)	
Dwarf eelgrass (*Zostera noltii*)	2009						N/A	
	2013						✓ *	Pergent-Martini et al., 2015a
Eelgrass (*Zostera marina*)	2009						N/A	

Species	Date	Red Listing						References
		Extinct or Extinct in the Wild (5)	Critically Endangered (4)	Endangered (3)	Vulnerable (2)	Near Threatened (1)	Least Concern (0)	
	2013						✓ *	Buia and Pergent-Martini, 2015
Neptune grass (*Posidonia oceanica*)	2009						✓	Pergent et al., 2010
	2013						✓ *	Pergent-Martini et al., 2016
Slender seagrass (*Cymodocea nodosa*)	2009						N/A	
	2013						✓	Pergent-Martini et al., 2015b

The European Red List of Habitats, which draws from a modified version of the IUCN Red List of Ecosystems, currently assesses 257 EUNIS Level 4 habitats across four regional seas—the Baltic Sea, North-east Atlantic, Mediterranean Sea, and Black Sea—and may offer a more consistent and region-specific approach to assessing change in the condition of priority marine habitats within Europe (Gubbay et al., 2016). Notably, current assessments under the European Red List of Habitats differ from the species-level assessments conducted through the IUCN Red List. While these assessments do not provide spatially-explicit assessments of change, they do function as proxies for assessing the condition of marine habitats (above 200m depth) within the European Union, complementing the data collected on Annex I habitat types through Article 17 of the Habitats Directive and representing known trends in quantity and quality of habitats and associated pressures, threats, and conservation measures (Gubbay et al., 2016) (see **Table 10**). Likewise, the HELCOM Red List assesses the state of the common eelgrass within the Baltic Sea, with an estimated decline of more than 25% of its original extent (HELCOM, 2017b). This assessment could be used alongside the European Red List of Habitats assessments to gain a better understanding of the changing condition of seagrass habitats within Europe. However, it is important to note that the relative stability of conservation assessments—particularly at the global scale, but also at the regional scale—may make them intransient to change, and therefore insensitive to measures of condition.

Table 10. Example seagrass condition account derived from the European Red List of Habitats within the European Union (EU28; n = 247) (Gubbay et al., 2016) and the HELCOM Red List (HELCOM, 2017b). In the case of the European Red List of Habitats, the estimated areas are taken from the corresponding factsheets, where known. Although there is no time series of assessments at present, these assessments (including estimates of area and classifications) are likely to be updated in the future.

Regional Sea	Corresponding Habitat Codes (EUNIS	Est. area (km^2)	Classifications

	or HELCOM)		Collapsed (5)	Critically Endangered (4)	Endangered (3)	Vulnerable (2)	Near Threatened (1)	Least Concern (0)	Data Deficient
Black Sea	A5.53 Seagrass and rhizomatous algal meadows in Pontic freshwater infralit muddy sands	Unknown						✓	
	A5.5w Seagrass meadows in Pontic lower infralittoral sands	Unknown				✓			
	A5.5z Seagrass meadows in Pontic mod exposed up infralit clean sands	Unknown							✓
Mediterranean Sea	A5.53 Seagrass beds (other than *Posidonia*) on Mediterranean infralittoral sand	274,000						✓	
	A5.535 *Posidonia* beds in the Mediterranean infralittoral zone	12,247				✓			
North-east Atlantic	A2.61 Seagrass beds on Atlantic littoral sediments	Unknown					✓		
	A5.53[1] Seagrass beds on Atlantic infralittoral sand (Macaronesian)	Unknown				✓			
	A5.53 Seagrass beds on Atlantic infralittoral sand (non-Macaronesian)	Unknown		✓					
Baltic Sea	Substrate dominated by common eelgrass (*Zostera marina*) (AA.H1B7, AA.I1B7, AA.J1B7, AA.M1B7)	Unknown (has declined by >25%)					✓		

Other assessments, such as the HELCOM Project for the development of a second holistic assessment of the Baltic Sea (HOLAS II), provide useful (non-spatial) indicators of ecosystem health and associated threshold values for the region (HELCOM, 2017a). However, many of the indicators used are national, making it difficult to compare between coastal areas of different countries, while other indicators relevant to natural capital accounts are still in development (e.g. a core indicator on 'Condition of benthic habitats', reflecting the area, extent and quality of specific benthic habitats, which is to become available in 2018) (HELCOM, 2017a).

3.3.4 Pressures

Where suitable datasets are not available to inform the above indicators on seagrass condition, indirect metrics associated with pressures and measures implemented to overcome these pressures (e.g. protected areas) could potentially be used as proxies. According to the 3rd *MAES* report, there are five key pressures that affect ecosystems: habitat change; climate change; overexploitation (including unsustainable land or water use or management); invasive alien species;

and pollution and nutrient enrichment) (MAES, 2016)[9]. Most of these pressures have been shown to play roles in the decline in the condition and extent of seagrasses (see **Table 11**).

Table 11. Examples of major pressures on seagrasses (adapted from Table 5.8, MAES, 2016).

Habitat changes	Climate change	Overexploitation	Invasive alien species	Pollution and nutrient enrichment
Coastal development Habitat conversion and landscape fragmentation Bottom fishing activities	Changes in mean sea surface temperature (°C) and salinity Ocean acidification	*Not applicable.*	Expansion of alien species (e.g. invasive seagrasses).	Changes in light availability/turbidity Nutrient enrichment Eutrophication and chemical pollution

Once indicators have been selected, determining the 'reference condition' or baseline from which to assess an ecosystem's condition can be challenging, particularly when determining capacity for service provision: an ecosystem's relative condition is dependent on the timeframe selected, and knowledge regarding an ecosystem's thresholds with regards to pressures (i.e. 'tipping points'). 'Capacity' here can be defined as "*The ability of an ecosystem to generate a service under current ecosystem condition and uses, at the highest yield or use level that does not negatively affect the future supply of the same or other ecosystem services from that ecosystem*" (Hein et al., 2016). However, it is possible to use the same point in time as a baseline for different ecosystem assets, and to thereby assess their condition relative to that time, as suggested in the SEEA-EEA (UN et al., 2014).

For instance, excessive nutrient discharge from human activities is one of the primary causes of the decline in seagrass meadows due to changes in nutrient concentrations and light availability, which affect primary production (Leoni et al., 2008). The availability of MSFD monitoring parameters for indicators of eutrophication, with relevance to seagrasses, include:

- *1.5.1 Habitat area* (relevant to the Habitats Directive and Birds Directive)
- *1.5.2 Habitat volume, where relevant* (relevant to the Habitats Directive and Birds Directive)
- *5.1.1 Nutrients concentration in the water column* (aligns with WFD and the OSPAR, HELCOM, and Mediterranean regional seas conventions)
- *5.3.1 Abundance of perennial seaweeds and seagrasses (e.g. fucoids, eelgrass and Neptune grass) adversely impacted by decrease in water transparency* (aligns with WFD and the OSPAR and HELCOM regional seas conventions) (Zampoukas et al., 2012).

Observed environmental parameters such as sea surface temperature, sea surface salinity, chlorophyll-a concentrations, nutrient loads (phosphorus and nitrate) and turbidity—available as time series through Copernicus—could be explored as indirect indicators of potential change in seagrass condition through habitat suitability, with recognition of the uncertainties associated with this approach. For instance, some endemic species have been found to be more sensitive to higher sea surface temperatures than others, suggesting that endemic species may decline in extent in response to pressures such as increased sea surface temperature, with invasive species potentially

[9] A more comprehensive list of threats and pressures is available under Article 17 of the Habitats Directive, and is the same as that used for reporting under Article 12 of the Birds Directive (available at: https://bd.eionet.europa.eu/activities/Reporting/Article_17/reference_portal).

benefitting from this decline (Marín-Guirao et al., 2016; Georgiou et al., 2016). However, this approach does not capture other pressures that would affect seagrass condition, such as anchoring, coastal urban development, fishing activities and aquaculture (Telesca et al., 2015), all of which would need to be considered alongside environmental suitability. Moreover, habitat suitability modelling is strongly dependent on the quality of the data used to inform the models, and therefore would not be able to replace ground-truthed data on the known spatial extent of seagrasses.

In addition to helping to identify the relative likelihood of occurrence, models of habitat suitability could facilitate projections of how changes in environmental conditions could affect the relative abundance and distributions of seagrasses (e.g. Zuchetta et al., 2016) and associated services, thereby assisting with scenario-based assessment of suitable management measures. Although available at a coarse scale, such projections could be integrated with seagrass condition accounts in combined presentations to give an indication of potential outcomes (though not reflecting cumulative impacts, as discussed above). For instance, Valle et al. (2014) projected the future distribution of *Z. noltii* under anthropogenic ocean warming and sea level rise, using version 2.0 of the Global Distribution of Seagrasses dataset (UNEP-WCMC and Short, 2005) and data obtained from GBIF to inform a habitat suitability model. Their results suggested that *Z. noltii* could undergo a poleward shift, losing much of its southern distribution while occupying greater area in the northern regions (Valle et al., 2014). This projection has direct relevance to planning for changes in the availability of associated ecosystem services, but does not provide a full understanding of cumulative pressures facing seagrasses and is limited by the quality of the data used to inform the model, as noted above.

Other relevant data sources and information are likely to be identified in the coming year, with the expected release of the *Pressures and impacts in Europe's seas* report in 2018.

3.3.5 Case study: Seagrass condition account based on change in protected area coverage

An integrated seagrass condition account could also take into account measures taken to offset or reduce pressures, such as the implementation of protected areas with conservation management objectives (see **Table 12** as an example). As the extent of protected areas is compiled and updated on a regular basis (i.e. monthly) through Protected Planet's World Database on Protected Areas (UNEP-WCMC and IUCN, 2017), which aligns with JRC's Digital Observatory for Protected Areas (DOPA), this approach could be readily used to track improvements in the management of locations with known seagrass extent over time. In particular, if this approach were combined with the higher resolution, raw data (where available) on habitat extent released by countries through the Habitats Directive and/or the Marine Strategy Framework Directive (in accordance with Article 19.3 of MSFD), this account could be updated with every reporting cycle.

Table 12. Exploratory analysis of overlap of seagrass beds with protected areas in the Marine Strategy Framework Directive's [MSFD's] subregions (UNEP-WCMC and IUCN, 2017; UNEP-WCMC and Short, 2016), as one illustrative example of a potential proxy of condition.

	Proportion of seagrass beds intersecting* protected areas by MSFD location (km^2; [number of points])

MSFD Location	Est. seagrass extent (km^2)	Number of points of seagrass occurrence	2011	2013	2015	**2017 (Closing)**
Celtic Seas	54	1,607	50 [1,397]	50 [1,435]	50 [1,468]	**51 [1,487]**
Macaronesia	2,070	59	2,070 [26]	2,070 [26]	2,070 [35]	**2,070 [35]**
Adriatic Sea	536	209	486 [72]	486 [126]	486 [126]	**486 [126]**
Aegean-Levantine Sea	398	250	341 [81]	341 [81]	341 [81]	**341 [81]**
Bay of Biscay and the Iberian Coast	79	323	77 [314]	77 [314]	77 [316]	**77 [316]**
Greater North Sea	1,529	5,178	1,406 [2,718]	1,407 [2,718]	1,407 [2,718]	**1,407 [2,786]**
Ionian Sea and the Central Mediterranean Sea	13,041	328	11,778 [104]	12,881 [104]	12,881 [104]	**12,883 [104]**
Western Mediterranean Sea	11,874	858	11,560 [425]	11,560 [425]	11,590 [460]	**11,590 [460]**
All of the above MSFD locations	**29,581**	**8,812**	**27,840 [5,137]**	**28,872 [5,229]**	**28,902 [5,308]**	**28,905 [5,395]**

***Note:** These quick, illustrative calculations represent intersection between seagrass beds and protected areas; thus, the total extent of the seagrass bed may not completely occur within the protected area.

It is important to note that the initial analysis presented in Table 12 represents the intersection between the known occurrence and extent of seagrasses in Europe with protected areas, but does not necessarily reflect protection. For instance, seagrasses may not be explicitly protected by the management measures of a protected area within which they occur. However, protected areas recorded in the World Database on Protected Areas are submitted by countries on the basis that each area has biodiversity conservation as a primary management objective, therefore suggesting some level of protection afforded to features deemed to be of biodiversity importance within that location.

Moreover, this approach does not necessarily confirm the current condition of a seagrass habitat, which may be intact, in recovery, or no longer exist, depending on the time frame that the original data were collected. Thus, ground-truthing would be necessary to establish a current baseline.

3.3.6 Example: Seagrass condition account in the North-east Atlantic based on proxies (pressures and management measures)

Linked to the approaches taken above, another potential approach would be to develop an indicator of seagrass condition based on available spatial time series data on pressures, such as those

collated through OSPAR (e.g. bottom fishing intensity, marine contaminants[10]), and management measures (e.g. advances in protected area coverage or fishing closures). These could be combined with additional information on sea surface temperature and salinity, which are available as time series through the EU Copernicus Marine Environment Monitoring Service, and human population (available through the Global Rural-Urban Mapping Project, or GRUMP[11]) or coastal development. This information could be combined with OSPAR's List of threatened and/or declining habitats' and corresponding background documents (see Table 10.3 of OSPAR's Quality Status Report 2010; OSPAR, 2010). These documents also propose different thresholds for assessing seagrass condition, largely based on the metrics proposed above (i.e. taxonomic composition, seagrass bed extent, shoot density) (OSPAR Commission, 2009)[12]. Beyond the Baltic Sea, data from WISE-Marine on water quality, including nitrogen, phosphorus and contaminants, as reported under the Water Framework Directive, could be used to assess pressures on seagrasses (to become available in 2018).

3.4 Exploring seagrass ecosystem service accounts

3.4.1 Seagrass ecosystem production and service supply-use accounts

The final steps in the development of integrated biophysical seagrass accounts is the measurement of the flows of ecosystem services supply and use in physical terms, which can then inform the valuation of associated benefits. Biophysical accounts of ecosystem service supply and use can be generated via various approaches, including models (e.g. InVEST, WaterWorld, CostingNature), indicators and proxies used to estimate service outputs (see Burgess et al., 2016, for discussion). For instance, models have been used to develop spatially-explicit maps of ecosystem services, such as tourism associated with coral reefs (Spalding et al., 2017) and biomass associated with mangrove forests (Hutchison et al., 2013), which represent the steps required before the development of monetary accounts. Quantitative estimation of potential—before determining actual—ecosystem service supply frequently requires additional data and information beyond that of ecosystem extent and condition, such as fisheries landings and tourism activity (e.g. number of dives in the location, and associated revenue), that can be linked spatially to the ecosystem, and thereby used to produce biophysical units per area of ecosystem extent before considered in monetary terms.

As an example, recruitment enhancement by seagrass habitat was first estimated in Port Phillip Bay, Australia, by determining the quantity of commercially-harvested, seagrass-dependent fish (in kilograms) per hectare of seagrass (based on total known extent), which in turn was attributed a value per hectare based on market prices for seafood (Eigenraam et al., 2016). A theoretical example of how ecosystem services could be linked to ecosystem extent and condition is represented in **Table 13**, based on 'Ecosystem Production Accounts' (see Hein, 2014).

[10] Available here: https://odims.ospar.org/layers/?limit=100&offset=0
[11] Available here: http://sedac.ciesin.columbia.edu/data/collection/grump-v1.
[12] Available here: https://qsr2010.ospar.org/media/assessments/Species/P00426_Zostera_beds.pdf

Table 13. Hypothetical table of indicators of ecosystem services associated with seagrasses, as examples (adapted from Eigenraam et al., 2016) (Y1 = baseline year, or year one; Y2 = current year, or year 2; SD = standard deviation).

	Indicators of ecosystem services (annual flows)							
	Shoreline protection		Nutrient cycling		Carbon sequestration		Fisheries resources	
	Y1 mean (SD)	Y2 mean (SD)	Y1 mean (SD)	Y2 mean (SD)	Y1 mean (SD)	Y2 mean (SD)	Y1 mean (SD)	Y2 mean (SD)
Ecosystem								
Seagrass								

Ecosystem service 'Supply-Use Accounts', as defined in the SEEA-EEA, then make explicit links between the flows of the final ecosystem services and their use, linking to the 'Ecosystem Production Account.' This represents the physical flows of the ecosystem services in biophysical units.

Through expert consultation, Nordlund et al. (2017) identified the many different ecosystem services that derive from seagrasses, reflecting on the variation across genera and geographical regions, including the Mediterranean and the temperate North Atlantic. Of these, a selection represent final services that result in direct benefits to humans, and are therefore of direct relevance to Supply-Use Accounts (examples captured in **Table 14**). Whilst there is increasingly recognition of the potential to record supporting or intermediate services as exchanges within and between ecosystem assets, and the importance of doing so (see Potschin and Haines-Young, 2011), this goes beyond the initial challenge of linking ecosystem extent and condition with the associated, final ecosystem services and their benefits to humans. This aligns with the Common International Classification of Ecosystem Services (CICES) framework's definition of 'ecosystem services' as "contributions that ecosystems make to human well-being." As suggested in the SEEA-EEA TR (2017), it may be possible to account for relevant intermediate services to be recorded within ecosystem extent and condition accounts, which could be extended to consider the presentation of indicators relevant to ecosystem functionality and implications for final service provision.

Uncertainties regarding the structure of **Table 14** include how best to represent scenarios where final services are used in different ways by multiple users or beneficiaries (e.g. some accruing only monetary benefit). For instance, it was assumed that food derived from seagrass-associated species was ultimately used by households, though additional benefits are accrued by the fishers who catch the species. In this case, the households are the final user of the provisioning service, while the economic valuation of the service would need to be considered separately. Conversely, coastal protection from damage is primarily considered in terms of the costs of damage that have been avoided through the presence of seagrass (e.g. Campagne et al. 2015), which may differ by user/beneficiary: for instance, an enterprise may have infrastructure assets that are considerably more expensive to repair than a household's, for instance.

Table 14. Illustrative examples of the supply and use of final services of seagrasses, with potential indicators used for biophysical assessments (adapted from Nordlund et al., 2017 and Martín-López et al., 2014; corresponds with CICES version 5.0).

EC			USE OF ECOSYSTEM SERVICES		
		Seagrass-associated ecosystem services	Enterprises	Households	Governments

	Provisioning	Wild plants as food for humans (1.1.1.3) (kg seagrass harvested/km^2/year)		4 t seagrass/km^2 /year	
		Food from seagrass-associated species (1.1.1.4) (t fish/km^2/year)		1,245 t fish/km^2/year	
	Regulating & Maintenance	Carbon sequestration (2.2.6.1) (t CO_2/km^2/year)			1,300 t CO_2/km^2 /year
		Coastal protection (2.2.1.1, 2.2.1.2) (damage cost avoided/km^2)	$80 USD/km^2	$15 USD/km^2	$57 USD/km^2
		Water purification (e.g. Litres of clean water/km^2/year)	3,000 L/km^2/year	500 L/km^2/year	240 L/km^2/year
	Cultural	Education (3.1.2.2) (e.g. number of educational initiatives)		5 educational initiatives (for schools)/km^2	3 educational initiatives (for adults)/km^2
		Recreation / tourism (3.1.1.1, 3.1.1.2, 3.1.2.4) (e.g. number of visitors/km^2/year)	1,000 visitors/km^2 /year		500 visitors/km^2 /year
		Research (3.1.2.1) (e.g. number of scientific publications/km^2/year)	5 publications/ km^2/year		10 publications/ km^2/year

3.4.2 Seagrass service valuation

As shown in **Table 14**, seagrass beds provide a wide range of ecosystem services and associated socioeconomic benefits. Different methods can be applied to measure the economic value of these services and benefits, with many different approaches having been used to value seagrasses in European seas (see **Table 15**). Most of these valuation studies focus on four ecosystem services provided by seagrasses: carbon storage and sequestration; shoreline protection; fish nursery and habitat; and nutrient cycling. These align with many of the criteria in the prioritization framework set out in the SEEA-EEA, with sensitivity to environmental change, economic importance, and the capacity to influence environmental and/or economic policy and decision-making (UN et al., 2014).

For instance, carbon sequestration contributes to climate regulation and is mainly valued using market prices from CO_2 emissions trading schemes (Fletcher et al., 2012; Jackson et al., 2012; Garrard and Beaumont, 2014; Röhr et al., 2016). An alternative method is to use damage costs avoided, which provides a value estimate based on the costs that would be incurred if the impacts of climate change were not mitigated through the carbon sequestration service provided by the seagrass (Campagne et al., 2015; Cole and Moksnes, 2016). 'Damage cost avoided' is also used to value the contribution of seagrasses to the protection of shorelines from erosion (Campagne et al., 2015).

The contribution of seagrasses to fisheries resources, mainly through the provision of nursing grounds and habitats, is valued using different market prices (Mangos et al., 2010, Tuya et al., 2014), including landings values and recreational fishing expenditures (Jackson et al., 2015), production functions (Campagne et al., 2015), or lost value caused by seagrass decline (Cole and Moksnes, 2016).

Lastly, nutrient cycling services provided by seagrasses are mainly valued using the benefit (or value) transfer method, i.e. applying value estimates from comparable studies (Brenner et al., 2010; Campagne et al., 2015; Martino and Amos, 2015). An alternative is the replacement cost method, which provides value estimates based on the cost that would incur if the nutrient cycling service provided by the seagrass had to be replaced, for example, by a water treatment facility (Cole and Moksnes, 2016). It is noted that these valuations are generally based on market prices or costs and are commensurate with the exchange value approach required for integration with national accounts. The potential exception relates to benefit transfer, where care would be needed to ensure exchange, rather than welfare, values are employed. Moreover, these values are compiled from different locations using different methods, and are therefore not necessarily comparable and cannot be summed to obtain a total value.

The above-mentioned studies value the ecosystem services of seagrasses by calculating the economic value of the associated benefits. An alternative approach is presented by Vassallo et al. (2013), who base their valuation on measurements of the ecological functions behind the ecosystem services. In their study on the value of *Posidonia oceanica* in Italy, they first calculate the natural resources used to provide different ecosystem services and then translate these into monetary estimates using the Environmental Emergy Money Ratio (Vassallo et al., 2013).

Differences in estimated values are likely to occur by location, species and approach used. Reasons for this include, for instance:

- Different levels of risk and costs associated with coastal infrastructure, depending on development status (in the case of 'coastal protection' as an ecosystem service);
- Different carbon storage potential by species (e.g. Lavery et al., 2013, Fourqurean et al., 2012);

For example, a review of peer-reviewed estimates of marginal damage costs caused by a metric tonne of CO_2 emissions revealed a mean estimate of $43 per tonne of carbon with a standard deviation of $83 per tonne of carbon (Tol, 2005, as reported in Jackson et al., 2012).

Table 15. Examples of ecosystem service valuations for seagrass-related services within European seas.

Regional Sea or country	Species	Ecosystem services/benefits valued	Biophysical unit metrics	Estimated values	Valuation methods	Ref.
Mediterranean	*P. oceanica*	Aggregated value for 14 ecosystem services	*N/A*	€284-514 ha^{-1} $year^{-1}$	Aggregated value	[1]
		Bioindicator (dead leaves used as material)	*Not recorded*	€1.5 ha^{-1} $year^{1}$	Market prices	
		Protection from coastal erosion (decrease of wave power and current)	*Not recorded*	€188 ha^{-1} $year^{-1}$	Damage cost avoided	
		Wastewater treatment	(cost in lieu of)	€60 ha^{-1} $year^{-1}$	Benefit transfer	
		Carbon sequestration	t CO_2 ha^{-1} $year^{-1}$	€7.7 ha^{-1} $year^{-1}$	Damage cost avoided	
		Fishery contribution	*Not recorded*	€27 ha^{-1} $year^{-1}$ *	Production function	
		Knowledge contribution (research subject)	*Not recorded*	€0.33 ha^{-1} $year^{-1}$	Market prices	
Mediterranean	*P. oceanica*	Fishery resources	t fish km^{-2} (A/D)	€2,379 km^{-2} (C/D)	–	[2]
Mediterranean	Not specified	Commercial fishery resources	*Not recorded*	€58.3-91.4 million $year^{-1}$	Landing values (based on seagrass residency index)	[3]
		Recreational fishery resources	*Not recorded*	€112.6 million $year^{-1}$	Expenditure	
Italy (Isola di Bergeggi)	*P. oceanica*	Aggregated value for nursery role (fish biomass), primary production (plant biomass), oxygen release (water oxygenation), sediment retention (shore protection)	seJ m^{-2} $year^{-1}$	€172 m^{-2} $year^{-1}$	Environmental Emergy Money Ratio	[4]
Italy (Tarquinia Lido)	*P. oceanica*	Nutrient cycling (services lost from degradation of 0.9km^2 seagrass meadow)	*Not recorded*	€1.8 million $year^{-1}$	Benefit transfer	[5]
Spain (Catalonia)	*P. oceanica*	Nutrient cycling**	*Not recorded*	US$24,448 ha^{-1} $year^{-1}$	Value transfer	[6]

Regional Sea or country	Species	Ecosystem services/benefits valued	Biophysical unit metrics	Estimated values	Valuation methods	Ref.
Gran Canaria	*C. nodosa*	Fisheries resources – habitat (fish biomass)	275.35 kg fish ha^{-1} $year^{-1}$	€866 ha^{-1} $year^{-1}$	Market prices	[7]
		Fisheries resources – nursery ground (production of juveniles)	15.68 kg fish ha^{-1} $year^{-1}$	€95.75 ha^{-1} $year^{-1}$	Market prices	
United Kingdom (Torbay)	*Z. marina*	Carbon sequestration (traded value)	0.52 t C ha^{-1} $year^{-1}$	£3.64 - 9.36 ha^{-1} $year^{-1}$***	Market prices	[8]
		Carbon sequestration (non-traded value)	0.52 t C ha^{-1} $year^{-1}$	£14.56 - 44.20 ha^{-1} $year^{-1}$***	Abatement costs	
United Kingdom	*Z. marina*	Carbon burial	1.91 t C ha^{-1} $year^{-1}$	£59.58 ha^{-1} $year^{-1}$	Carbon shadow price	[9]
				£106.96 ha^{-1} $year^{-1}$	Abatement costs	
United Kingdom	*Z. marina* *Z. noltii*	Carbon sequestration	t CO_2 ha^{-1} $year^{-1}$	£105.05 ha^{-1} $year^{-1}$	Market prices	[10]
Sweden	*Z. marina*	Food (commercial fishing – Atlantic cod)	26.6 kg fish ha^{-1}	1287 SEK ha^{-1} $year^{-1}$	Lost value to commercial fishing industry	[11]
		Food (commercial fishing – Goldsinny and corkwing wrasse)	690 individuals ha^{-1}	1911 SEK ha^{-1} $year^{-1}$	Lost value to aquaculture industry supplier	
		Climate mitigation (carbon storage)	1.49 C ha^{-1}	2322 SEK ha^{-1} $year^{-1}$	Damage cost avoided	
		Nitrogen sequestration	58.0 kg N ha^{-1} $year^{-1}$	5593 SEK ha^{-1} $year^{-1}$	Replacement cost	
		Aggregated value	*N/A*	11,114 SEK ha^{-1} $year^{-1}$	Aggregated value	
Finland	*Z. marina*	Carbon sequestration (total organic carbon)	6.98 t C ha^{-1}	€281 ha^{-1}****	Market prices	[12]
Denmark	*Z. marina*	Carbon sequestration (total organic carbon)	44.9 t C ha^{-1}	€1809 ha^{-1}****	Market prices	[12]

* 2010 auction selling prices from the Auction of Sète (see Campagne et al., 2015 [1]); ** Brenner et al. (2010) provide little information on the data/approach used to reach this value; *** Based on an estimate for Spanish seagrass beds (Cebrián et al. 1997); **** Equates to £36 per t C ha^{-1} (using the exchange rate on 19th October 2017).

Regional Sea or country	Species	Ecosystem services/benefits valued	Biophysical unit metrics	Estimated values	Valuation methods	Ref.
References: [1] Campagne et al. 2015; [2] Mangos et al., 2010; [3] Jackson et al., 2015; [4] Vassallo et al., 2013; [5] Martino and Amos, 2015; [6] Brenner et al., 2010; [7] Tuya et al., 2014; [8] Fletcher et al., 2012; [9] Jackson et al., 2012; [10] Garrard and Beaumont, 2014; [11] Cole and Moksnes, 2016; [12] Röhr et al., 2016.						

4. Key messages

This experimental review demonstrates the strong potential for developing integrated seagrass accounts, while highlighting the challenges that make it difficult to obtain a full and spatially-explicit understanding of the location and condition of seagrasses within Europe. Reporting requirements under the WFD, MSFD, the Habitats Directive, OSPAR and HELCOM all propose metrics and indicators compatible with tracking the extent and condition of seagrasses. However, to construct accounts, we require access to the underlying, spatially-explicit data that can be compared over time, and that are of sufficiently high resolution and quality.

Here, we reviewed short- and long-term approaches that could be used to develop seagrass accounts, based on information and spatially-explicit data available at present and likely to become available over the next few years. These approaches and recommendations are summarised in Table 16.

Table 16. Summary of reviewed approaches by account, and associated recommendations.

Account	Approach	Recommendations
Seagrass extent	Systematic reviews	Systematic reviews of available spatial data on seagrass extent by sea basin could be used to approximate change in extent over time (e.g. Telesca et al., 2015; EMODnet, 2016), but are dependent on data quality and coverage. Integrated, country-level accounts in data-rich locations may be worth exploring as a next step (e.g. France, Spain).
	CORINE Land Cover	With advances in remote sensing technologies, inclusion of seagrasses in the CORINE Land Cover dataset may help to facilitate long-term comparison of seagrass extent, complementing country's *in situ* monitoring initiatives.
	Long-term monitoring initiatives	With the establishment of long-term monitoring initiatives with standardised monitoring protocols, and the submission of underlying data used to complete country-level assessments (i.e. polygons outlining the spatial extent of seagrasses), these accounts could be strengthened over time.
	Models	While models can help to strengthen our understanding of the relative likelihood of occurrence, they largely capture the habitat suitability based on environmental characteristics in the absence of cumulative pressures. They cannot be used to replace *in situ* or remotely sensed occurrence data.
Seagrass condition (state/ health)	Remotely sensed or *in situ* metrics	Three metrics related to condition seem to be regularly recorded and are of direct relevance to the WFD's Ecological Quality Ratios (EQRs): shoot density (number of shoots/m^2), taxonomic composition (number of taxa), and spatial extent of seagrass beds (km^2). Standardised or regionally-defined thresholds (e.g., Table 8) would help with tracking the condition of seagrasses more systematically across regions, based on these three metrics. This would have the mutual benefit of providing information on water quality, since seagrasses are *Biological Quality Elements* under the WFD.
	Assessments of condition	Red List assessments may be too stable and high-level for use in accounts. The European Red List of Habitats and the HELCOM Red List may offer more regionally-applicable assessments, but would need to be updated regularly to inform accounts, and would be dependent on the quality and spatial coverage of the underlying data. They may therefore not be available at a sufficiently high enough resolution to inform long-term natural capital accounts and management measures, but could represent "quick wins" in the short term and

Account	Approach	Recommendations
		could possibly be adapted to suit accounting needs.
Proxies for seagrass condition	Pressures	With established baselines and an understanding of thresholds, pressures could be used as proxies for assessing changing seagrass condition in the absence of—or complementing—*in situ* or remotely sensed metrics. It may be feasible to review opportunities to construct a pressure index by drawing on available time series data on pressures for the Northeast Atlantic, available through OSPAR and the Copernicus Marine Environment Monitoring Service.
	Level of protection (overlay with protected areas)	With data on the spatial extent of seagrasses, an analysis of the intersection of seagrasses with protected areas could be conducted to review likely protection (see Table 12). However, this does not confirm that seagrasses are legally protected by the protected area, and does not establish the condition of the seagrass at the time of protection (i.e. degraded, in recovery, or healthy), and would therefore still depend on an established baseline for comparison.
	Models	As with seagrass extent, models do not represent a 'silver bullet' for assessing condition. Rather, they could be used to develop scenarios of likely change in habitat suitability based on different pressures, and associated impacts on service provision based on established thresholds. Again, models are only as strong as the data used to inform them (i.e. accuracy of seagrass extent and environmental data, and selected thresholds).
Seagrass ecosystem production	Proxies, models, and indicators (various)	The accuracy of ecosystem production accounts are largely dependent on the extent and condition accounts noted above, including condition thresholds for service provision. However, there are many examples of studies that have produced such accounts (see section 3.4.1), and different approaches to do so (see Burgess et al., 2016). Information on extent and condition frequently needs to be paired with additional data (e.g. fisheries landings, tourism activity, carbon storage) to determine ecosystem service supply.
Seagrass service supply-use + valuation	Integration of biophysical units with socio-economic data	Linking seagrass 'ecosystem production' accounts with 'service supply-use' accounts requires socio-economic data on *actual* service supply and use relative to the extent or quantity of seagrass. 'Use' can be quantified in various ways, whether in terms of monetary contributions or avoided cost (e.g. coastal protection), or a non-monetary benefit (i.e. in the case of many cultural services, for instance) (see Tables 14 and 15). Challenges included differences in estimated values by location, species, and approach used.

Each approach in Table 16 has strengths and challenges, making it difficult to capture a complete picture at any single point in time over a large area, and to replicate methods over different time frames. For condition accounts, the barriers noted in the 3rd *MAES* report—namely, "limited access to accurate, detailed and comparable information across countries"—still apply within the marine realm for seagrass accounts, as do the required next steps:

1. mapping and assessing the cumulative effect of multiple pressures;
2. detailed spatial mapping of condition indicators;
3. assessment of the impact of condition on biodiversity and ecosystem service delivery;
4. mapping supply and, especially, demand of ecosystem services (MAES, 2016).

Current approaches to determining seagrass extent across Europe are patchy, and rarely spatially explicit and consistent over time, but provide a basis from which to implement a more systematic approach. The most comprehensive assessments of seagrass coverage were collated for two sea

basins—the Mediterranean Sea and the Baltic Sea—from scientific publications across a range of time frames and methodologies, and used models to fill in gaps in knowledge (Telesca et al., 2015; Boström et al., 2014). EMODnet's broad-scale seabed habitats map for Europe (EUSeaMap; EMODnet, 2016), led by the Joint Nature Conservation Committee (JNCC), integrates raw data from Telesca et al. (2015) and countries, and is expected to be updated on a regular basis. Thus, estimates of seagrass extent in each of these studies are highly dependent on the availability, quality and resolution of spatial data, making it difficult to draw conclusions from assessment-level data (i.e. resulting estimates can vary significantly, as shown in **Table 3**). However, these approaches, combined with the raw data used to inform assessments under various Directives, could collectively provide a more systematic approach to tracking changes in the known extent of seagrasses within Europe over time. In the short-term, integrated, country-level seagrass accounts could be trialed in locations with sufficient amounts of spatially-explicit, time series data.

Increasingly, remote sensing approaches can be used to detect seagrass extent and canopy density (Lyons et al., 2013), suggesting opportunities to follow a similar approach to that used for capturing land cover through high-resolution remote sensing, such as that used to record saltmarsh extent through the CORINE Land Cover dataset. For instance, above-ground seagrass biomass has been found to be highly correlated to percent cover; thus, as demonstrated in Australia, it is feasible to convert percent cover data to above-ground biomass estimates, thereby facilitating quantitative comparison between datasets and assessment of spatial and temporal trends (Collier et al., 2016). It may therefore be worth exploring the possibility of adding seagrasses as one of the CORINE Land Cover classes, since advances in high-resolution satellite imagery may now facilitate use of the methodology for shallow-water habitats such as these.

The initial approaches documented here represent potential "quick wins" for ensuring monitoring consistency across countries, with an aim to map key spatial characteristics of seagrasses—such as spatial extent and condition—through metrics that align with WFD and MSFD reporting requirements (i.e. seagrass bed extent, taxonomic composition, and annual mean shoot density). With regards to pressures, further work is required to determine how best to incorporate limits and thresholds into accounts. Additional time would be required to fully examine the viability of each of the proposed approaches, and to advance an integrated seagrass account.

In data-poor locations, modelled outputs could be used to obtain estimates of the distributions of seagrasses, but would have limited application for long-term accounts. For instance, the distribution of *Posidonia oceanica* has been modelled for the entire North African coastline using a robust indicator of potential habitat suitability (Zucchetta et al., 2016), as part of the FP7 Marine Ecosystem Dynamics and Indicators for North Africa (MEDINA) project. While these models could be combined with pressures as a proxy for a likely change in extent and condition over time (scenario-based assessments), they are dependent on the quality of input data and would need to be ground-truthed.

This review represents the first step towards establishing more advanced and integrated seagrass accounts, with a selection of case studies that demonstrate how such accounts could be developed with sufficient information. In the coming year, spatial data relevant to these proposed accounts are expected to become available (e.g. next reporting period for MSFD), and could be used to advance the methodology. There are also international initiatives such as the Global Ocean Observing

System (GOOS), whose Essential Ocean Variables (EOVs) are intended as a discrete set of biodiversity variables that can be monitored using consistent methods globally (including 'seagrass cover'). GOOS has partnered with the Group on Earth Observations' (GEO's) Marine Biodiversity Observation Network (MBON)—which UNEP-WCMC belongs to—and the Ocean Biogeographic Information System (OBIS) to explore options for expanding marine monitoring of species and habitats through the implementation of the EOV framework. While still in the early days of development, this initiative suggests that efforts to monitor seagrasses are likely to gain additional guidance with regards to standardised approaches in the coming years.

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Annex 1: Datasets and classifications

Table A1. *List of potential datasets considered for seagrass extent, specifying reasons for why they were or were not used in the account. Datasets included within the Global Distribution of Seagrasses (UNEP-WCMC and Short, 2016) dataset are denoted with an asterisk, and the corresponding source ID(s) noted in red.*

Title	Description	Included?	Update frequency?	Reason
Conservation status of habitat types and species (Article 17, Habitats Directive 92/43/EEC)	1120 Posidonia beds	No	With each reporting period.	Though reported, spatial data are available at a 10 x 10km^2 grid cell, which may be too coarse for use in determining change in seagrass extent over time. Article 17 only addresses one species of seagrass (*Posidonia oceanica*), found in only one of Europe's seas (Mediterranean Sea).
*MEDISEH Report: Task 1.1 Seagrass beds distribution along the Mediterranean coasts. (Belluscio et al., 2013; Telesca et al., 2015) [Source ID 494]	Includes seagrass data along the Mediterranean coasts, as well as information on known changes in distribution and abundance. Collated during the Mediterranean Sensitive Habitats (MEDISEH) project.	Yes	*Not updated.*	Spatially-explicit data for *Posidonia oceanica* available, with estimates of change over time for the Mediterranean Sea. Integrated into the *Global Distribution of Seagrasses* dataset (UNEP-WCMC and Short, 2017).
*OSPAR Threatened and/or Declining Habitats 2015 [Source IDs 495-573] (OSPAR Commission, 2015)	Contains occurrence records for *Zostera marina* and *Zostera noltii* extent.	Yes	*Unknown.*	Integrated into the Global Distribution of Seagrasses dataset (UNEP-WCMC and Short, 2017). Although the dates the data were collected were noted throughout the dataset, no information was available on the status or trends of seagrasses in OSPAR regions.
Global Distribution of Seagrasses (UNEP-WCMC and Short, 2016)	Contains additional European data, particularly for the southern Mediterranean. Many of these occurrences were originally documented in the *World Atlas of Seagrasses* (Green and Short, 2003).	Yes	Irregular, but updated as new data become available.	Most comprehensive, spatially-explicit dataset available for Europe on seagrass extent. Timeframes differ across polygons: for Europe, 7,200 of 29,322 polygon records were originally collected between 2000 and 2014, 1,140 between 1980 and 2000, and 19,318 between 1961 and 2014.
SeagrassNet	Worldwide ecological monitoring programme for	No	Few times a year.	Available exclusively as polygons, but provides information on the seagrass condition metrics used in the Water

Title	Description	Included?	Update frequency?	Reason
	seagrasses, including sites in Europe.			Framework Directive. *Not readily available online.*
IUCN species ranges: seagrass (IUCN, 2017)		Yes	Updated regularly (within 10 years).	Used to identify the occurrence of a species by regional sea, but not to determine precise location. Represents ranges, rather than extent of occurrence.
Global Biodiversity Information Facility (GBIF)	Contains occurrence data for seagrasses (454,656 records globally). Specifically, contains 39,442 records for *Zostera* spp., 3,397 records for *Halophila* spp., and 2,793 for *Posidonia* spp.	No	Updated daily, but inconsistently across spatial extent.	Best suited to species data, rather than habitat extent. Can be used to ground-truth occurrences of seagrass species.
Ocean Biogeographic Information System (OBIS)	Contains occurrence data for seagrasses (20,523 records globally). Specifically, contains 10,696 records for *Zostera* spp., 485 records for *Posidonia* spp., and 1,407 records for *Halophila* spp.	No	Updated daily, but inconsistently across spatial extent.	Best suited to species data, rather than habitat extent. Can be used to ground-truth occurrences of seagrass species.
EMODnet Broad-scale seabed habitat maps (EUSeaMap)	European-wide coverage of habitats, recorded using EUNIS classifications (under 'HAB_TYPE'). Contains information on Posidonia beds (A5.535), dead mattes of *Posidonia oceanica* (A5.5353), and Cymodocea beds (A.531).	Yes	Update nearly completed.	While the full methodology includes broad-scale predictive modelling approach based on habitat suitability, the data for seagrass extent derive from surveys in the Mediterranean. Supplements gaps in spatial extent of the *Global Distribution of Seagrasses* dataset.
CORINE Land Cover		No	Updated regularly (every six to ten years).	Does not include seagrass coverage.
HELCOM HOLAS II Dataset: *Zostera marina* distribution (2017)				Distribution of eelgrass based on data submission by HELCOM contracting parties. Mainly pointwise occurrences of eelgrass were submitted, originally gathered in national mapping and

Title	Description	Included?	Update frequency?	Reason
				monitoring campaigns, or for scientific research. Polygon data from Puck Bay (Poland) was digitized based on Polish Marine Atlas and Orlowo cliff area was added based on expert knowledge. From Estonian waters, a predictive model was used (200m resolution), that was converted to presence/ absence using minimized difference threshold (MDT) criteria. All data (points, polygon and the raster presenting predicted presence of eelgrass in the Estonian waters) were generalized to 5km x 5km grid cells.
Cunha et al. (2013). Seagrasses in Portugal: A most endangered marine habitat	One-off study on the extent of seagrasses in Portugal (2007-2010), conducted through surveys. Provides information on trends. Could be used to supplement the *Global Distribution of Seagrasses.*	Yes	N/A	Would need to review the accompanying spatial data to assess level of spatial coverage. Information could be used to inform an account for Portugal.

Table A2. *European classification of seagrasses [references: 1, 2, 3].*

Framework	Code	Broad habitat type	Description	Species
Habitats Directive ANNEX I	1120	Posidonia beds	Beds of *Posidonia oceanica* (Linnaeus) Delile characteristic of the infralittoral zone of the Mediterranean (depth: ranging from a few dozen centimetres to 30 - 40 metres). On hard or soft substrate, these beds constitute one of the main climax communities. They can withstand relatively large variations in temperature and water movement, but are sensitive to desalination, generally requiring a salinity of between 36 and 39 per 1000.	*Posidonia oceanica*
EUNIS	A2.61	Seagrass beds on littoral sediments	Dominants are *Zostera spp.*	*Zostera noltii, Z. angustifolia, Z. marina,* and *Ruppia maritima* beds

Framework	Code	Broad habitat type	Description	Species
EUNIS	A5.545	*Zostera* beds in reduced salinity infralittoral sediments	*Not available.*	*Zostera* spp. (*Zostera marina, Zostera zoltii, Zostera angustifolia*)
EUNIS	A5.53; A5.535	Sublittoral seagrass beds	Beds of submerged marine angiosperms in the genera *Cymodocea, Halophila, Posidonia, Ruppia, Thalassia, Zostera*.	*Cymodocea* (*C. nodosa*), *Halophila* (*H. stipulacea*), *Posidonia* (*P. oceanica*), *Ruppia* (*R. maritima, R. cirrhosa*), *Thalassia, Zostera* (*Z. marina, Z. noltii*)
EUNIS	A5.531	*Cymodocea* beds	Formations of *Cymodocea nodosa* of the Atlantic shores of southern Iberia, northwestern Africa and the Macaronesian Islands.	*Cymodocea nodosa*
EUNIS	A5.535	*Posidonia* beds	This assemblage is characterised by the presence of the marine seagrass (phanerogam) *Posidonia oceanica.* This species is endemic to the Mediterranean and constitutes characteristic formations called Posidonia meadows, located between the surface and up to 50 metres depth.	*Posidonia oceanica*
EUNIS	A5.5353	Dead "mattes" of *Posidonia oceanica*	This facies is characterised by a dead mat of Posidonia oceanica without macro-epiflora.	*Posidonia oceanica*
EUNIS	C1.5212	Athalassic seagrass communities	*Zostera noltii* formations of the Caspian Sea.	*Zostera noltii*
HELCOM	AA.H1B7	*Zostera marina*	Baltic photic muddy sediment dominated by common eelgrass *(Zostera marina)*	*Zostera marina*
HELCOM	AA.I1B7	*Zostera marina*	Baltic photic coarse sediment dominated by common eelgrass *(Zostera marina)*	*Zostera marina*

Framework	Code	Broad habitat type	Description	Species
HELCOM	AA.J1B7	*Zostera marina*	Baltic photic sand dominated by common eelgrass *(Zostera marina)*	*Zostera marina*
HELCOM	AA.M1B7	*Zostera marina*	Baltic photic mixed substrate dominated by common eelgrass (*Zostera marina*)	*Zostera marina*

[1] European Commission, DG Environment. (2013). Interpretation Manual of European Union Habitats, version EUR 28. URL: http://ec.europa.eu/environment/nature/legislation/habitatsdirective/docs/Int_Manual_EU28.pdf.
[2] EUNIS habitat classification. URL: https://www.eea.europa.eu/themes/biodiversity/eunis/eunis-habitat-classification.
[3] HELCOM Red List Biotope Expert Team. (2013). Red List of Habitats: Baltic photic muddy sediment, coarse sediment, sand or mixed substrate dominated by common eelgrass (*Zostera marina*). Available here.