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Assessment of Marine Ecosystem Services Indicators: Experiences and Lessons Learned from 14 European Case Studies

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EDITOR'S NOTE:

This paper represents 1 of 5 review articles generated from 2 research projects funded by the European Union's Seventh Framework Program, ARCH and LAGOONS. The projects aim to develop and apply participative methodologies in collaboration with key stakeholders, to manage the multiple problems affecting European lagoons and estuaries. The articles in this series provide strategies for the sustainable management of these vulnerable ecosystems, which are increasingly threatened by climate change, urbanization, and industrialization.

ABSTRACT

This article shares the experiences, observations, and discussions that occurred during the completing of an ecosystem services (ES) indicator framework to be used at European Union (EU) and Member States' level. The experience base was drawn from 3 European research projects and 14 associated case study sites that include 13 transitional-water bodies (specifically 8 coastal lagoons, 4 riverine estuaries, and 1 fjord) and 1 coastal-water ecosystem. The ES pertinent to each case study site were identified along with indicators of these ES and data sources that could be used for mapping. During the process, several questions and uncertainties arose, followed by discussion, leading to these main lessons learned: 1) ES identification: Some ES that do not seem important at the European scale emerge as relevant at regional or local scales; 2) ES indicators: When direct indicators are not available, proxies for indicators (indirect indicators) might be used, including combined data on monitoring requirements imposed by EU legislation and international agreements; 3) ES mapping: Boundaries and appropriate data spatial resolution must be established because ES can be mapped at different temporal and spatial scales. We also acknowledge that mapping and assessment of ES supports the dialogue between human well-being and ecological status. From an evidence-based marine planning-process point of view, mapping and assessment of marine ES are of paramount importance to sustainable use of marine natural capital and to halt the loss of marine biodiversity. *Integr Environ Assess Manag* 2016;12:726–734. © 2016 SETAC

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INTRODUCTION

The Millennium Ecosystem Assessment (MEA) was initiated in 2001, with the objective of assessing the consequences of ecosystem change for human well-being. In line with the priorities arising from the MEA and with the European Union (EU) objectives set forth in 2010 by the EU Biodiversity Strategy to 2020, the EU assessment of ecosystem services (ES) was set to provide a critical evaluation of the best available information for guiding decisions on complex public issues (Heink et al. 2016; Maes et al. 2016). Spatially explicit biophysical maps were recognized as useful for the identification and assessment of ES and biodiversity zones, and for the quantification of synergies and trade-offs among these. With these needs and approaches in mind, the European Commission (EC) Working Group on Mapping and Assessment of Ecosystems and their Services (WG MAES) proposed an indicator framework to be used at European and Member States' levels (Maes et al. 2014).

Three EU projects (LAGOONS, http://lagoons.web.ua.pt; ARCH, http://www.arch-fp7.eu; and TPEA, http://www.tpeamaritime.eu) participated in a Marine Ecosystem Pilot Exercise (the MAES Marine Pilot) to test the indicator framework. The projects gathered knowledge available for mapping ES for 2 types of marine ecosystems: 1) inlets and transitional waters and 2) coastal waters. The present article provides an overview of the MAES Marine Pilot and highlights lessons learned that will be useful for subsequent mapping and assessment foreseen in the EU Biodiversity Strategy for 2020 (Action 5, http://ec.europa.eu/), as well as the sustainable use of marine ecosystems natural capital. Insights from the exercise will help guide maritime spatial planning and coastal management (Jay et al. 2014; Zaucha 2014; Lillebø et al. 2015).

METHODS

The pilot studies carried out by the WG MAES followed the Common International Classification of Ecosystem Services (CICES; Haines-Young and Potschin 2013) (Supplemental Data Table S1), adopting the CICES V4.3 spreadsheet (available from the EU CIRCABC web page: https://circabc.europa.eu/w/browse/065ad102-48e224-46d6-bfcb-7bab4bad5704), hereafter called the "MAES matrix." CICES also proposes a provisional accompanying classification table of abiotic outputs from natural systems (Supplemental Data Table S2), which was not completed during this MAES Marine Pilot but was useful for discussion, for example, in order to clearly distinguish ES that are mediated by biological processes (e.g., salt works as habitat for waders) from abiotic outputs of natural systems (e.g., marine salt harvest from salt works). The exercise involved representatives from the 3 EU projects with background in natural and social sciences, including economics (approximately 2/3 and 1/3, respectively), who reviewed and discussed the matrices for their project case study sites. Some of the case study sites were discussed among participants across the EU projects involved because these participants possessed knowledge for more than 1 case study site. Ecosystem services for each of the 14 case study sites, in the 3 EU projects, were identified by finding the indicators and the data sources for mapping (Figure 1, Supplemental Data Table S3). The participants' experience of the exercise was obtained by asking questions regarding 1) identifying the ES, 2) finding the ES indicators, and 3) mapping the ES. While mapping was not part of the MAES Marine Pilot exercise, we considered it important to include because it is a goal of the EU Biodiversity Strategy for 2020 (http://ec.europa.eu/). Economic valuation was not addressed during the MAES Marine Pilot; at the Member States' level, valuation of ES is foreseen for the year 2020.

In order to evaluate the task of completing the MAES matrix, participants assessed the MAES Marine Pilot process by answering the following: 1) What were your main questions? 2) Do you have any comments? 3) Do you have any recommendations? The answers now presented and discussed were organized following the 3 questions.

Study sites

The 3 European research projects included 14 case study sites:

- 13 inlets and transitional waters ecosystems:
- 8 coastal lagoons
- Amvrakikos, Greece
- Lesina, Italy
- Mar Menor, Spain
- Óbidos and Ria de Aveiro, Portugal
- Razelm Sinoe, Romania
- Tyligulskyi Liman, Ukraine
- Vistula, shared by Poland and Russia
- 4 riverine estuaries
- Broads, United Kingdom
- Elbe, Germany
- Nordre älv, Sweden
- Rhine, Netherlands
- the Byfjorden fjord, Norway
- the Algarve coastal waters, Portugal

Their geographic locations are presented in Figure 1, and a short description is included in Supplemental Data Table S3.

The case study sites exhibit different characteristics and developmental factors, followed by the respective economies. Some sites are located in urbanized watersheds (e.g., Rhine, Elbe, Byfjorden, and Mar Menor) while others are rural in nature (e.g., Óbidos, Razelm-Sinoe, Lesina, and Tylygulsky Liman). Some are located within the more prosperous EU territories, while others are located in peripheral regions lagging behind in terms of prosperity. Vistula Lagoon has the particularity of being a transboundary system shared by an EU country (Poland) and Russia (both sides of the lagoon are considered in the exercise). For a more detailed description of the study sites, see Zaucha and Breedveld (2013), Jay et al. (2014), and Lillebø et al. (2015).

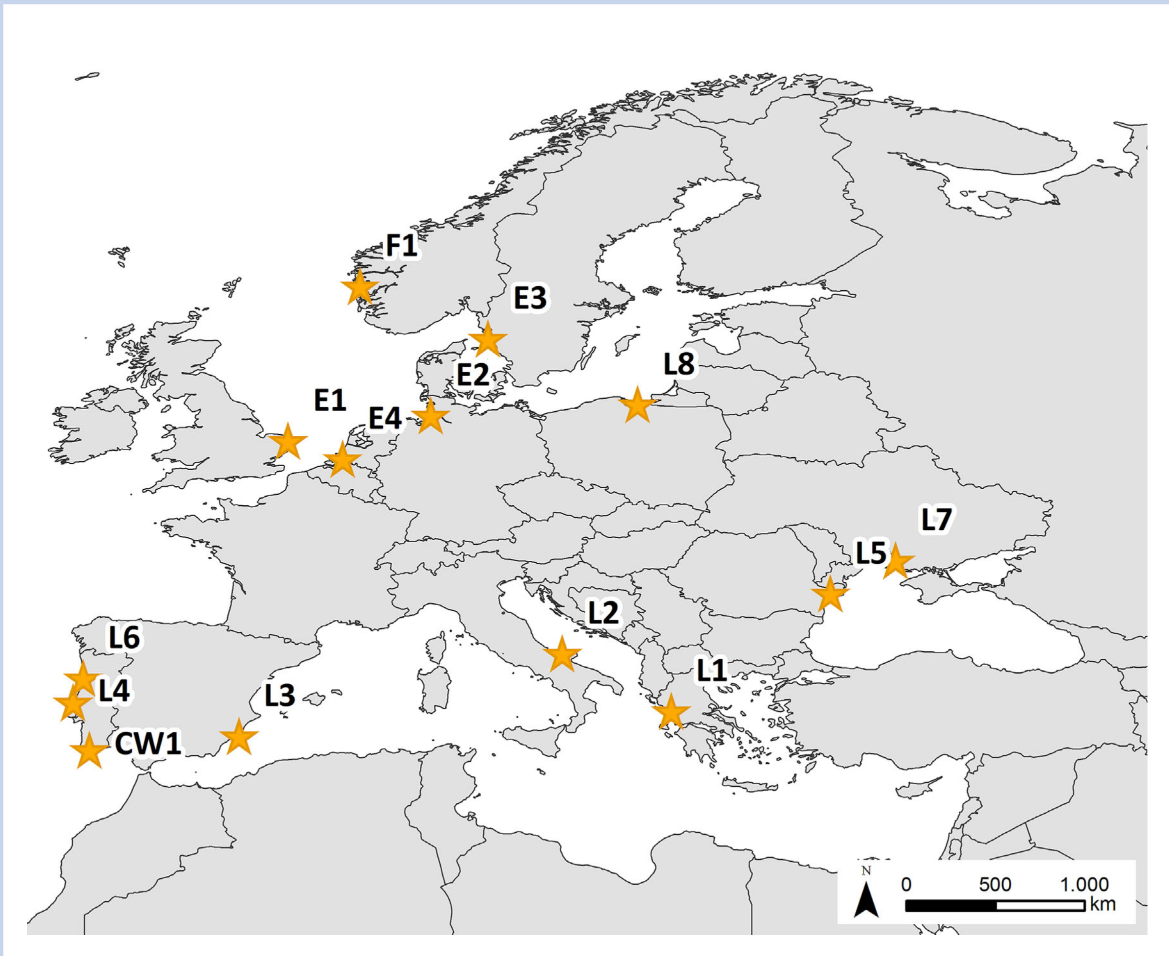

Figure 1. Location of the case study sites in the three EU projects together. Legend: L1 - Amvrakikos Lagoon complex (Greece); L2 - Lesina Lagoon (Italy); L3 - Mar Menor (Spain); L4 - Óbidos Lagoon (Portugal); L5 - Razelm Sinoe (Romania); L6 - Ria de Aveiro (Portugal); L7 - Tyligulskyi Liman (Ukraine); L8 - Vistula Lagoon (Poland/Russia); E1 - Broads (UK); E2 - Elbe (Germany); E3 - Nordre älv (Sweden); E4 - Rhine (Netherlands); F1 - Byfjorden (Norway); CW1 - Algarve (Portugal).

RESULTS

The spreadsheets resulting from the MAES Marine Pilot along with data on indicators for each case study and the source of the information are available at https://circabc.europa.eu/w/browse/065ad102-e224-46d6-bfcb-7bab4bad5704.

Ecosystem services identified at marine ecosystems

Ecosystem services for each case study site are presented in Table 1. Most of the variability in ES among sites relates to provisioning services, which include the nutritional, material, and energetic outputs from living systems. The only common ES among sites was the existence of wild animals and their human exploitation (e.g., fish and/or shellfish). This ES was followed by the provisioning of fibers and other materials from plants, algae, and animals for direct use or processing (e.g., common reeds for different uses and/or algae). For most of the case study sites, the provisioning class of materials from plants, algae, and animals for agricultural use have been historically important, whereas in Algarve coastal waters contain maerl beds with future potential use for the agrochemical industry (fertilizer in agriculture and aquaculture). Ecosystem services associated with regulation and maintenance services, which consist of the ways in which living organisms can mediate or moderate the environment and thus inherently affect human activities and well-being, are provided at all case study sites. The only exception might be the presence of invasive nonindigenous species (in some cases, no data were available). Marine cultural services, which include nonmaterial and/or nonconsumptive ecosystem outputs that affect human physical and mental states, are also represented at all the considered case studies. Such cultural services include experiential interactions (bird watching), physical interactions (diving, sailing, and angling), intellectual and representative interactions (research, educational, entertainment, heritage, inspiration for painters and writers). In contrast to the more common ES across sites, the ES energy from plant biomass is present at only 1 case study site, the Razelm-Sinoe Lagoon.

Identifying ecosystem services

One of the most challenging efforts for the pilot study was the differentiation between the biological mediated processes that underpin ES (Supplemental Data Table S1) and the abiotic outputs from natural systems (Supplemental Data Table S2). Relevant examples of abiotic outputs sometimes regarded as services were offshore energy, extraction of sand and other minerals, including marine salt, and wind sports. There was also some misunderstanding between human activities and ES, namely shipping, that is, using seawaters for transport of goods and passengers, or tourist activities, which were regarded as ES.

When comparing the classes considered at the general or European scale (Supplemental Data Table S1) with the ones

Table 1. Summary of ES identified by the participants in each of the marine subecosystems, following the CICES hierarchical structure for the classification of ES[ab]

	Coastal lagoons								Estuaries				Fjord	Coastal waters
Class	Amvrakikos complex, Greece	Lesina, Italy	Mar Menor, Spain	Óbidos, Portugal	Razelm-Sinoe, Romania (now a freshwater lagoon)	Ria de Aveiro, Portugal	Tyligulskyi Liman, Ukraine	Vistula, shared by Poland and Russia	Broads, United Kingdom	Elbe, Germany	Nordre älv, Sweden	Rhine, Netherlands	Byfjorden, Norway	Algarve, Portugal
Provisioning														
Wild plants and their outputs		*				✓								✓
Wild animals and their outputs	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Plants and algae from in situ aquaculture						✓								
Animals from in situ aquaculture	✓				✓	✓		✓						✓
Fibers and other materials from plants, algae, and animals for direct use or processing	✓		✓	✓	✓	✓	✓	✓			*			✓
Materials from plants, algae, and animals for agricultural use				*	✓	*				*	*	*		**
Energy from plant biomass–based resources					✓									
Genetic materials from all biota			✓											✓
Surface water for nondrinking purposes			✓		✓	✓			✓	✓		✓		✓
Ground water for nondrinking purposes		✓	✓			✓	✓							
Regulation and maintenance														
Bioremediation and filtration, sequestration, or storage by microorganisms, algae, plants, animals	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

(*Continued*)

Table 1. (*Continued*)

	Coastal lagoons								Estuaries				Fjord	Coastal waters
Class	**Amvrakikos complex, Greece**	**Lesina, Italy**	**Mar Menor, Spain**	**Óbidos, Portugal**	**Razelm-Sinoe, Romania (now a freshwater lagoon)**	**Ria de Aveiro, Portugal**	**Tyligulskyi Liman, Ukraine**	**Vistula, shared by Poland and Russia**	**Broads, United Kingdom**	**Elbe, Germany**	**Nordre älv, Sweden**	**Rhine, Netherlands**	**Byfjorden, Norway**	**Algarve, Portugal**
Filtration, sequestration, storage, or accumulation by ecosystems	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Dilution by atmosphere, freshwater and marine ecosystems	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Mass stabilization and control of erosion rates	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Buffering and attenuation of mass flows	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Flood protection	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Maintaining nursery populations and habitats	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Pest control (presence of alien species)			✓	✓		✓		✓		✓	✓	✓		✓
Decomposition and fixing processes	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Chemical condition of salt waters	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Global climate regulation by reduction of greenhouse gas concentrations	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Cultural														
Experiential use of plants, animals, and land- or seascapes in different environmental settings	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Physical use of land- or seascapes in different environmental settings	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Scientific	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Educational	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Heritage, cultural	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Entertainment	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Aesthetic	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Existence	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Bequest	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

[a]ICES = Common International Classification for Ecosystem Services (Haines-Young and Potschin 2013); ES = Ecosystem services (Maes et al. 2014).
[b]Gray cells = not applicable or no data available; * = relevant in the past; ** = potential use in the near future.

identified at the case studies' regional or local scale (Table 1), it became evident that some ES not identified as particularly important at the European scale were considered important at the regional or local level. These included, for example, 1) cultural services such as the regional identity and the sense of place and 2) provisional service of water, namely in Ria de Aveiro and Mar Menor, where surface and ground brackish water can be used in summer for crop irrigation and for fire fighting, while in Elbe estuary it can be used in summer for irrigation and in winter for frost protection.

During the MAES Marine Pilot, several uncertainties were identified, including how to

- consider coastal and transitional waters that are used for aquaculture in inland marine aquaculture facilities;
- classify a service that at the regional or local scale can fall into 2 sections (e.g., provisioning service, landings of wild animals captured by fishing vs cultural service, landings of wild animals captured by sports fishing or angling);
- refer to ES that were important in the recent past but are no longer important;
- refer to ES that apply to a singular water body, or part of it, but not to the entire marine subsystem;
- or refer to ES that have temporal variability in the same spatial area.

For example, in the Algarve coast, the ES that underpins the tourist activity during the summer overlaps the fishing activity during the winter within the same area; the Razelm-Sinoe Lagoon marine subecosystem was transformed into a freshwater coastal lagoon (Bretcan et al. 2008). Another uncertainty relates to sacred or religious cultural services with respect to ES. For example, there are some cultural activities (Fiesta de la Virgen del Carmen in Mar Menor and the procession of Nossa Senhora dos Navegantes in Ria de Aveiro, both processions of the divine faith of the fishermen communities) that might be interpreted as sacred and/or religious cultural services. However, according to the CICES (V4.3) classification, they are not recognized as such. A relevant example of such an ES would be the water of Jordan River for Christians because for them the water is recognized as sacred. In Vistula Lagoon, transboundary issues were also highlighted, specifically the difficulty in completing the MAES matrix in an unified manner due to the fact that Polish and Russian parts of the lagoon are differently managed, have different legislation systems, and have different economical and political interests (Różyński et al. 2015).

Identifying ecosystem services indicators

Feedback from the participants indicated that some found it challenging to understand the differences among capacity, flow, and benefit, that is, the ecosystems cascade model (Supplemental Data Figure S1). The difference between capacity and flow was especially challenging to understand, and this made it difficult to select and agree upon the appropriate indicators. There were also challenges in defining the differences between indicators for supply and demand. Despite these challenges, it was necessary to test the selected indicators, to check whether or not data were available for these indicators, and to assess the adequacy and harmonization among the study sites. Another challenge was to understand some of the WG MAES proposed indicators of ES, specifically "pest control" as a class of the regulating and maintenance services. It is defined as the reduction in risk and/or area protected, but the indicator is the number of alien invasive species. In some cases ES indicators were not easily available, especially concerning the regulating and maintenance services. This issue sometimes resulted in qualitative rather than quantitative information. In other cases for which the identification of the relevant indicators was possible, application would require the establishment of new data collection activities (e.g., cultural services) or the broadening of existing monitoring programs to coincide with ES mapping activities (e.g., invasive species, emergent contaminants at the regional or local scale). Moreover, the data relevant for the case study might only be available at the subnational scale (e.g., regional or local institutional studies, scientific papers, local associations' databases) and might not always cover the entire territory, or might not be specifically associated with the ecosystem or service under assessment. The subjectivity of "other cultural outputs" was also pointed out, and it was also suggested that for the indicators of "existence" and "bequest" services, at this regional or local scale, a survey directed to the population should be conducted. Finally, it was difficult to find a balance between the accuracy of an indicator and the feasibility of acquiring the needed information. For example, the indicator "harvested" wild *Salicornia* sp. (halophyte) (ton ha^{-1}) is very accurate; however it is not easy to access this type of data; on the other hand, data for "fish and shellfish landings" are available but do not reflect the landings of wild animals captured by sports fishing or angling, which might represent a parallel activity to the local economy.

Mapping ecosystem services

Even though the MAES Marine Pilot did not specifically include a mapping step, participants were invited to reflect on mapping of ES. While mapping ES is of critical importance, it can be quite challenging. In particular, data and information have to be collected in an appropriate spatial resolution, and the exercise revealed that most of the desired data lack the spatial component and the existing spatial data do not contain enough resolution. Thus, while some of the ES can be mapped (e.g., nursery areas for fish, distribution of macrophytes), this is not the case for other ES for which data do not apply to any particular area but instead apply to the entire area. As a result, we foresee that the representation of ES indicators may be very diverse and complex, with ES mapped at different scales (national, regional, and local), and some for discrete variables (categories) and others for continuous variables. This aspect of mapping for future gathering of ES-related information has to be considered in the revision or planning of the monitoring programs.

While mapping can also be a powerful tool for guiding management decisions, maps need to be supported by other contextual information. For example, protecting a particular area and the services it provides usually requires actions in adjacent areas. Furthermore, mapping involves the establishment of nested boundaries with some smaller areas specific to an ES or geography falling within larger boundaries. For example, marine inlets and transitional waters are land–water ecotones, and the appropriate water body boundary may be unclear. In the case of coastal lagoons, sand spits or dune systems are included because they ensure the integrity of the system; however, it may be unclear how far inland the boundary should reach. Careful consideration and understanding is needed when analyzing, for example, land-based recreation activities driven by the marine ecosystem (e.g., bird watching, angling, walking). These activities can take place at the land boundary but also in islands located in the considered marine subecosystem.

DISCUSSION

The survey of participants in the MAES Marine Pilot, following the 3 steps (Table 2) reveal that some of the main questions, comments, and recommendations are comparable and/or add to other authors' experiences regarding the selection of indicators for ES. The challenges regarding temporal and spatial scales are transversal to the identification of ES, the selection of indicators, and mapping. The complexity will be illustrated further in a paper on mapping ES provided by Ria de Aveiro, a complex coastal region in Portugal (Sousa et al. 2016).

The WG MAES initiative, and the MAES Marine Pilot in particular, foresees the sustainable use of marine ecosystems natural capital (Maes et al. 2014, 2016). The definition of natural capital, as adopted in CICES (V4.3) includes the abiotic outputs from ecosystems and the ecosystems capital, whereas ES are restricted to the outputs of ecosystems dependent on living processes (Supplemental Data Figure S2). This definition is controversial among the scientific community (e.g., Heink et al. 2016), who sometimes regard abiotic outputs as services. This disparity was also observed during the MAES Marine Pilot, and although we focused on the ES MAES matrix, we recognize that the provisional accompanying classification table of abiotic outputs from natural systems can be very useful for supporting ecosystems management and governance. The exploitation of abiotic outputs (e.g., offshore wind energy) can represent a "driver of change" for the provided ES or support an important social–economic activity at the regional or local scale (e.g., marine salt extraction). This method could also be complemented by adding information (layers) on how much of the land closest to the sea is covered with houses and roads, and for the ocean by adding information about harbors, piers, and outlets, etc., because this provides information on the degree of disturbance. Insights can be gained from participants' experience with the process.

Some of the case studies involved multidisciplinary teams, including natural and social scientists, who found the matrix quite complex, meaning that successful implementation might require an interdisciplinary team, which might not be available. Participants felt that a better understanding of the ecosystems' cascade flow model is needed. The EC Joint Research Centre has produced supportive MAES cards (available at https://circabc.europa.eu/faces/jsp/extension/wai/navigation/container.jsp) containing indicators in a supply and demand perspective. The review on marine ES by Liquete et al. (2013) also includes a table summarizing the indicators in a capacity, flow, or benefit perspective. Yet, as remarked by Heink et al. (2016), the proposed indicators do not directly address a linkage to economic assessments, requiring in this sense the indicators to be validated.

We concluded that the ES MAES matrix for marine services is indicative of the main services but that some services that are not evident at the European scale might be important at regional or local scales. This evidence is particularly important for regional water management and cultural identity of local populations.

Table 2. Summary of the results from the main steps of the MAES Marine Pilot by participants answering the following: 1) What were your main questions? 2) Do you have any comments? 3) Do you have any recommendations?

	1) Main questions	2) Main comments	3) Main recommendations
Identifying ES	- How to consider coastal and transitional waters that are used for non-drinking purposes? - How to consider a service that at regional or local scale can be classified in 2 sections at the same time? - How to consider temporal and spatial scales?	- Uncertainty related to the concept behind some of the proposed class of services - Difficulty in completing the MAES matrix in an unified manner in a transboundary context - The exclusion of abiotic outputs from the ES category is not unanimous	- Transboundary issues should be highlighted when downscaling the mapping and assessment of ES to a national or a regional or local level. - The provisional accompanying classification table of abiotic outputs from natural systems can be very useful for the marine ecosystems assessment in support of ecosystems management and governance.
Identifying ES Indicators	- How to choose an indicator for a purely cultural service? - How to combine indicators to account for spatial variability and seasonality?	- Difficulty in selecting indicators to differentiate among capacity, flow, and benefit - Difficulty in defining the indicators for supply and demand for all ES - Difficulty in finding a balance between the accuracy of an indicator and its feasibility	- Clearly distinguish indicators in a supply–demand and capacity–flow–benefit perspective, their units, mapping scales, and even the procedures that give rise to them. - Foster the integration of indicators or their proxies across different components of EU legislation and international agreements.
Mapping ES	- How to establish the water–land boundaries for ES assessment in marine inlets and transitional waters? - How to map at different scales, (national, regional, and local), using discrete variables (categories) and continuous variables?	- Most data lacks the spatial component, and the existing spatial data do not contain enough resolution. - Mapping can be a powerful tool for managers and policy makers.	- The representation of indicators at different scales may become very diverse and complex and has to be considered in the revision or planning of the monitoring programs. - Mapping needs to be coupled with additional knowledge on the functioning of marine ecosystems.

ES = ecosystem services; EU = European Union; MAES = Mapping and Assessment of Ecosystems and their Services.

We found that clear definitions (e.g., boundaries of land–water ecotones) and descriptions of each of the ES in these marine subecosystems would be useful to harmonize interpretations. Transboundary issues should also be highlighted when downscaling the mapping and assessment of ES to a national level or to a regional or local level. Jay et al. (2014) illustrates a good example on how transboundary maritime spatial planning (MSP) can be accomplished in the marine environment (e.g., Algarve coast), following 2 starting points: 1) a bottom-up approach starting from habitat and biodiversity mapping (data from Rensub and MeshAtlantic projects, e.g., Monteiro et al. 2013) and from this point the provided ES were identified as well as the main drivers of change; and 2) a top-down approach starting from the identification of the human activities and from this point identifying the ES that underpin these activities (e.g., Jay et al. 2014).

While the MAES matrix contains very important inventory information, alone it does not reflect ecosystem functioning (e.g., trophic levels and interactions, environmental pressures) or critical management-related points and bottlenecks (e.g., spatial and/or temporal data gaps). Given these limitations, the WG MAES (Maes et al. 2014) proposed a tiered approach for mapping and assessment of ES:

1) ES mapping using available indicators;
2) ES mapping linking different indicators; and
3) model-based approaches to map ES, which can also be used to assess uncertainty in quantification and valuation, for example, InVEST (Guerry et al. 2012), ARIES (Villa et al. 2014), and the ecosystem management tool, Ecopath with Ecosim and Ecospace (EwE; Pauly et al. 2000).

Regarding the quest and need for indicators, we support the use of proxies in the case that the indicator in the MAES matrix is not yet available. This is particularly relevant for regulating and maintenance services (Sousa et al. 2016). For mapping water, one could take into account the EU Water Framework Directive (WFD, 2000/60/EC) considering the final status (including the biological indicators), or by mapping the chemical indicators and the priority substances separately. Some indicators from the EU Marine Strategy Framework Directive (2008/56/EC) not included in WFD (e.g., marine litter) might also be considered as part of this proxy. This was the principle used by WG MAES when considering the number of invasive species as an indicator for "pest control." In fact, proxies for ES indicators could also include available data on monitoring requirements imposed by other EU legislation and international agreements (e.g., Environmental Quality Standards Directive (2008/105/EC), Habitats Directive (92/43/EEC), Birds Directive (2009/147/EC), Common Fisheries Policy (COM (2011) 418 final) and Regional Sea Conventions covering European seas (OSPAR - North-East Atlantic sea, HELCOM - Baltic sea, Barcelona - Mediterranean sea, UNEP MAP - United Nations Environment Programme Mediterranean Action Plan, Black Sea Commission).

The assessment of ES indicators has been addressed in different perspectives, namely how to link ES indicators with human pressures and mitigation measures (Egoh et al. 2012), the possibilities for integration of monitoring across EU legislation and international agreements (Nikolaos et al. 2012), and how ES can be used in the ecosystem risk assessment and decision-making processes (Munns et al. 2016). This pilot study represents one of the first systematic EU-wide attempts allowing comparison among different marine ecosystems.

We conclude that, the "indicator way" is appropriate if the ES concept is to be used to a larger extent and in a multidisciplinary approach. From the marine planning process point of view, this is one of the key prerequisites of evidence-based planning. We acknowledge that the identification of the relevant indicators will require data collection to coincide with ES mapping. Practical recommendations are needed on how to use ES to guide decisions that will lead to sustainable use of marine natural capital and halt the loss of marine biodiversity.

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SUPPLEMENTAL DATA

Supplemental data may be found in the online version of this article. The provided data contain the MAES matrix and the respective indicators after Maes et al. (2014); CICES (Version 4.3) provisional accompanying classification table of abiotic outputs from natural systems; a short description of the considered marine subecosystems; a figure illustrating the ES cascade model (redrawn after Haines-Young and Potschin 2013); and a schematic representation of natural capital components (after Haines-Young and Potschin 2011).

Table S1. Representation of the Mapping and Assessment of Ecosystems and their Services (MAES) matrix and indicators after Maes et al. (2014)

Table S2. Common International Classification for Ecosystem Services (CICES, Version 4.3) provisional accompanying classification table of abiotic outputs from natural systems

Table S3. Short description of the considered marine subecosystems, that is, of the 14 case studies

Figure S1. The ecosystem services cascade flow model (redrawn after Haines-Young and Potschin 2013).

Figure S2. Schematic representation of natural capital components (after Haines-Young and Potschin 2011).

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