Operationalisation of ecosystem services in support of ecosystem-based marine spatial planning: insights into needs and recommendations

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Highlights:

- Mapping and assessment of ecosystem services can support marine spatial planning
- We assess the needs for ecosystem services application in marine spatial planning
- Literature search and outcomes derived from 14 case studies are combined
- We identify main needs dealing with theoretical, methodological and policy aspects
- Recommendations for overcoming identified limitations are provided

Abstract

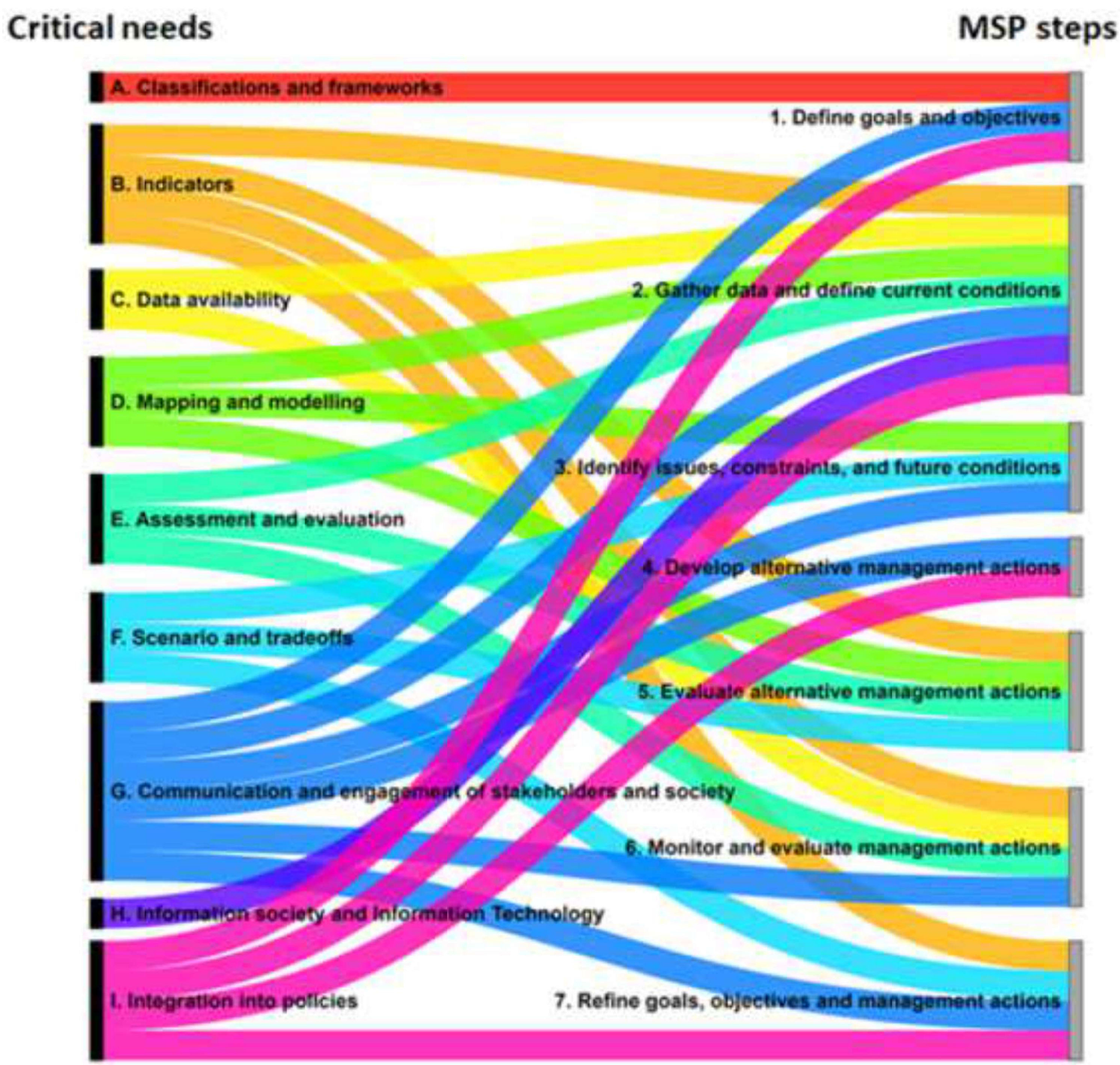
Marine or maritime spatial planning (MSP) works across borders and sectors to ensure human activities at sea take place in an efficient and sustainable way. The ecosystem service (ES) concept links ecosystem functioning to human wellbeing and has emerged as a potential framework supporting MSP, as it can be used to link different sectorial and environmental policies. However, due to the complexity of the marine realm, mapping and assessment of ES is still in its infancy and there remains a need to develop and agree upon the appropriate progress in ES development to support MSP.

This contribution highlights research needs and recommendations to advance the operationalization of the ES concept into MSP. We apply a mixed method approach combining literature research and expert knowledge derived from 14 case studies, to address current status and prospects of ES application in MSP. We present nine main needs dealing with (i) improvement and adaptation of existing ES frameworks and classifications to the marine realm and (ii) definition of an indicator pool; (iii) methodological and technical developments to support data availability and accessibility; (iv) advances in mapping and modelling methods; (v) improvements in assessment and valuation approaches; (vi) further use of scenario and trade-off analysis; (vii) taking advantage of supporting Information Technologies (IT); (viii) improvements in communication and engagement with stakeholders; and (ix) further work for the integration of ES knowledge into policies and for supporting management and MSP. The manuscript concludes with a set of recommendations to foster the operationalization of the ES concept into MSP.

Keywords

Maritime Activities, Blue Growth, Maritime Spatial Planning, Management, Natural Capital

Graphical Abstract



1. Introduction

The World's oceans and seas provide ecosystem services that contribute significantly to fulfilling human needs and well-being [1, 2]. Healthy marine ecosystems provide substantial benefits in terms of food production, recreation and tourism, climate change mitigation and adaptation, shoreline dynamics control and disaster prevention. Globally, the demand for coastal and marine ecosystem services is high and continues to grow, resulting in the diversification and intensification of maritime activities, which puts more pressure on marine ecosystems and increases competition for space at sea. If not managed properly, human activities can lead to a deterioration of environmental status and loss of biodiversity, which can have severe effects on ecosystem services supply; and consequently, hinder the sustainable development of marine and coastal activities [3-5].

The integration of ecosystem services into marine spatial planning (MSP) is a promising approach [6-9] with multiple advantages: supporting the sustainable development goals [10], promoting the development of new maritime activities in accordance with the Blue Growth strategy [11-13], and supporting the creation of conservation zones, such as Marine Protected Areas (MPA) [14]. By making nature's value more explicit, the ecosystem services approach can promote better informed discussions about ecosystem services trade-offs between different MSP scenarios and prioritizes sustainable management options [15]. Additionally, the ecosystem services approach fits well within a broader management paradigm known as ecosystem-based management (EBM), which recognizes the multiple interactions within ecosystems where, humans are included as an integrative part [16]. Thus, the adoption of ecosystem-based marine spatial planning (EBMSP) can inform about the spatial distribution of existing and emerging sea uses, use-conflicts reduction, ecosystem health and protection and sustainable use of ecosystem services [17, 18]. Thus, mapping and assessment of ecosystem services can become a framework which links different sectorial and environmental policies [19-23].

The need for operational approaches that integrate ecosystem services into management and decision making has been raised frequently [6, 8, 24-29]. For example, in the European Union (EU), the Marine Strategy Framework Directive (MSFD; Directive 2008/56/EC), seeks the achievement of the Good Environmental Status and the sustainable use of ecosystem services, emphasizing the importance of healthy ecosystems as a prerequisite for ecosystem services to be provided. Similarly, the Maritime Spatial Planning Directive (MSPD; Directive 2014/89/EU), recognizes that healthy marine ecosystems and their multiple services, if integrated in planning decisions, can deliver substantial benefits. Moreover, the Biodiversity Strategy to 2030 recognises that the global Gross Domestic Product (GDP) depends on nature and the services it provides, and asks member states to improve knowledge by assessing and mapping the state of ecosystems and their services [30].

Despite previous research efforts, there is still a considerable lack of basic knowledge and best practices on how to operationalize coastal and marine ecosystem services into decision-making [31]. The adoption of such an approach requires knowledge about how, where and when ecosystem functions deliver ecosystem services and how those functions interact when providing ecosystem services [4]. There is a need to understand how humans benefit from ecosystem services, through their direct or indirect use, how humans influence ecosystem functions, and how this influences ecosystem services supply, and in turn, the effect on human well-being [32-35].

Recent research advancements in the field of marine ecosystem services focused on addressing specific theoretical, procedural, and methodological challenges. For instance, the development of marine ecosystem services oriented classifications [11, 36], data availability checks [37], assessment and valuation methods [38, 39] or ecosystem services assimilation through participatory stakeholder engagement [40, 41]. Most studies target very specific aspects of ecosystem services research, whereas only more multifaceted investigation would provide the critical knowledge needs to support the wider scope of EBMSP processes.

This research aims to define a set of scientific and operational recommendations to advance the integration of the ecosystem services into EBMSP. For that purpose, (i) most frequently reported limitations for mapping and assessment of ecosystem services and its operationalisation into MSP were identified by performing a bibliographic review; (ii) 14 case studies were investigated to further analyse the limitations in real applications and analyse the strengths and weaknesses of the approaches implemented for overcoming such limitations; (iii) links between the critical needs for operationalisation of ecosystem services and the marine spatial planning implementation phases were defined; and finally,

(iv) based on the outcomes obtained, a number or recommendations were derived to contribute to the integration of ecosystem services assessment into EBMSP.

2. Methods

The research approach followed can be summarized into: (1) a literature review to identify the limitations and critical needs for ecosystem services operationalization into EBMSP; 2) a collation of the lessons learnt, elicited via structured questionnaire, from 14 case studies applying the ecosystem service approach to inform and support MSP; 3) interpretation and categorization of the responses into most-reported critical needs, in addition to the strengths and weaknesses of the approaches implemented; and 4) development of a framework and derivation of recommendations for operationalising ecosystem services into EBMSP (Figure 1). Similar mixed method approaches have been previously implemented in ecosystem service research [42], as it allows the combination of different investigation methods into a single framework and contributes to better understanding of findings compared to using individual approaches [43, 44].

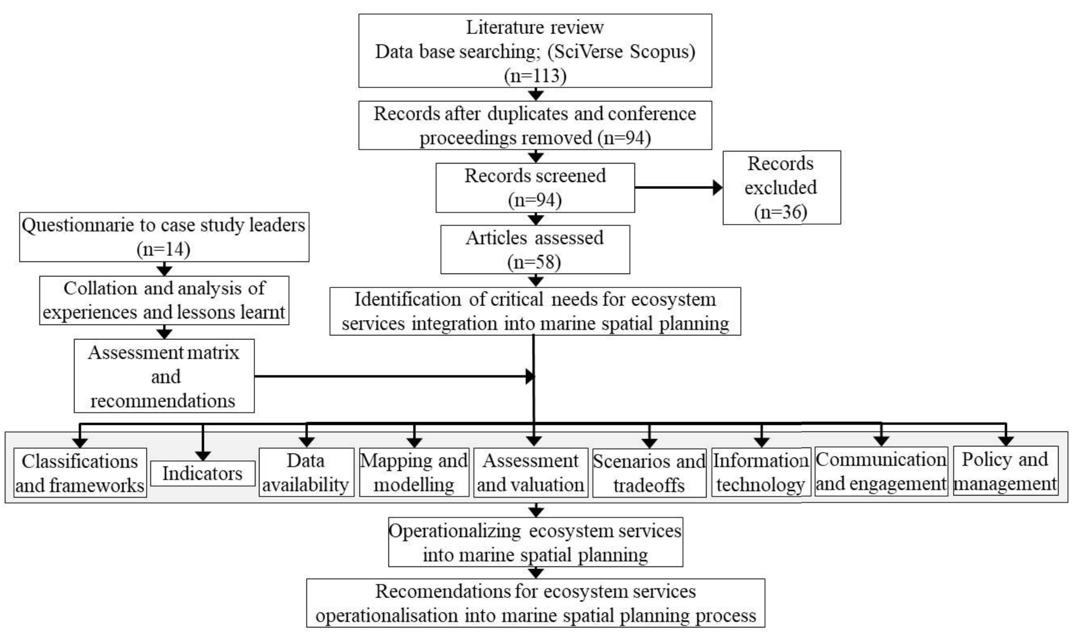


Figure 1. Workflow for the identification and analysis of critical needs for the operationalisation of the ecosystem services approach into marine spatial planning.

2.1. Literature review

The bibliographic search was performed consulting the SciVerse Scopus (www.scopus.com). The consultation was performed on 30/08/2019. The query applied a discursive approach with the aim to incorporate explicit and implicit references of the ecosystem services concept and marine/maritime spatial planning. The search looked for the following terms within the title, abstract and keywords of the manuscript: "ecosystem services" AND "marine spatial planning" (ES&MSP; resulting into 85 publications); "ecosystem services" AND "maritime spatial planning" (ES&MTSP; resulting into 14 publications). In total 113 articles were retrieved. Duplicates and conference proceedings were removed, leaving 94 manuscripts. The first publication dealing with ES and MSP is from 2008 (see Figure SM 1, for the temporal evolution of number of papers published). After a first detailed screening, 58 publications were selected as providing relevant information for the scope of the present research (see Table SM 1 for the list of the selected manuscripts and Table SM 2 for the articles excluded in the final selection (n= 36)).

Selected publications were analysed and reported shortcomings to operationalizing the ecosystem services concept into EBMSP were extracted and classified, resulting in nine commonly cited critical needs (see Table 1 for the definitions adopted). The critical needs were grouped into theoretical (i.e., classification and frameworks; development of indicators); technical and methodological (i.e., data availability; mapping and modelling; assessment and valuation; scenario and trade-offs) and societal and policy (i.e., information society and information technology (IT); communication and engagement of stakeholders and society; integration into policies).

Table 1. Critical needs and their definition adopted in this research. Note: T: theoretical; TM: technical and methodological; and SP: societal and policy.

Critical need (and type)	Definition used in this research
Classifications and frameworks (T)	Schemes and definition of ecosystem services according to international or national designation. They are developed to support standardisation and facilitating comparison (e.g., CICES [27]). They should also facilitate the use of available data to spatially map and explore the pathways between ecosystem services, processes, and the ecological function responsible for ecosystem services provision.

Indicators (T)	Proxy measures derived from empirical data or modelled estimates of ecosystem status, functions and ecosystem services [45].
Data availability (TM)	The products and services that ensure that data are reliable, updated and continuously available.
Mapping and modelling (TM)	*Ecosystem services map*. Spatially explicit representation of ecosystem services production capacity within a given territory. Ecosystem services maps can be used for different purposes such as: problem identification, synergy trade-off analysis, visualization support and as a communication instrument [46]. *Ecosystem services model*. A graphical or mathematical representation of concepts or processes that is used to estimate links and quantify the delivery and flow of ecosystem benefits from marine systems under different ecological or socioeconomic scenarios [47].
Assessment and valuation (TM)	Assembling, summarizing, organizing, interpreting, and reconciling pieces of existing knowledge to measure the ecosystem services´ economic, ecological, and social values (monetary or non-monetary); that can be used as an estimate of the contribution to human well-being [48].
Scenario and trade-offs (TM)	*Scenario*. Storyline that describes possible futures. They explore aspects of, and choices about, the future that are uncertain. Scenarios can include qualitative descriptions of changes (i.e., a narrative) and quantitative representations [49] of potential economic, environmental, social or technical developments and their expected consequences on society and environment [50]. *Trade-offs*. When the provision of one service is reduced as a consequence of increased use of another [45].
Information society and Information Technology (SP)	Post-industrial society which benefits from the application of information technologies (IT) to support production and distribution of all kinds of information.
Communication and engagement of stakeholders and society (SP)	Participatory approaches that foster articulation and elicitation of values allowing the integration of different value dimensions to inform decision-making processes.
Integration into policies (SP)	Process of assimilation of the ecosystem services concept into national and supra-national policymaking.

2.2. Case studies

A call for contributions dealing with experiences in "*Operationalizing Ecosystem Services in Support of Ecosystem-based Maritime Spatial Planning*" for a workshop at the European Ecosystem Services Partnership Conference of 2018 (San Sebastian, Spain) was launched [51]. Case studies were selected according to a set of criteria that included the objective of the study, area in which the research was conducted (i.e., coastal, offshore), the scale of the analysis (i.e., local, regional, international), the ecosystem services analysed, methods implemented, and the relevant outcomes and lessons learnt during the implementation of ecosystem services in EBMSP. After the workshop, case study leaders were invited to contribute to the present research by sharing and discussing their experiences in integrating ecosystem services approaches into EBMSP.

In total, 14 case studies were considered, which were distributed in 13 countries across Europe´s four regional seas (Figure 2 and Table 2). Seven case studies were regional, four transnational and three were local. In seven case studies the research considered the integrated assessment of coastal and open sea ecosystems and three were purely open sea and one was a review study, therefore not location specific. To note is that CS5 includes three sub-areas (Greifswald Bay - Germany, Szczecin Lagoon - Poland, Curonian Lagoon - Lithuania), CS9 included four regional seas (i.e., Black Sea, Baltic Sea, Mediterranean Sea and North east Atlantic), CS6 refers to the Italian Adriatic Sea, and CS7 considers the entire Adriatic-Ionian Region (CS7). CS5 and CS9 used the same methodologies for their respective sub-areas, while for CS6 and CS7 distinct ecosystem services assessment methods were applied.

With the aim of collecting information on experiences and lessons learnt when operationalizing ecosystem services into EBMSP, a questionnaire was distributed among researchers and experts responsible for the case studies (in June 2019). The questionnaire was composed of the following questions:

- *In which context was the approach implemented? (i.e., purely research, consultancy, under request to inform managers?)*
- *Have the results obtained in this research been used to assist/inform any MSP process? Which one? In which country/region? How?*
- *Which are the main weaknesses of the approach implemented in terms of its applicability in EBMSP?*
- *Which are the main strengths of the approach implemented in terms of its applicability in EBMSP?*

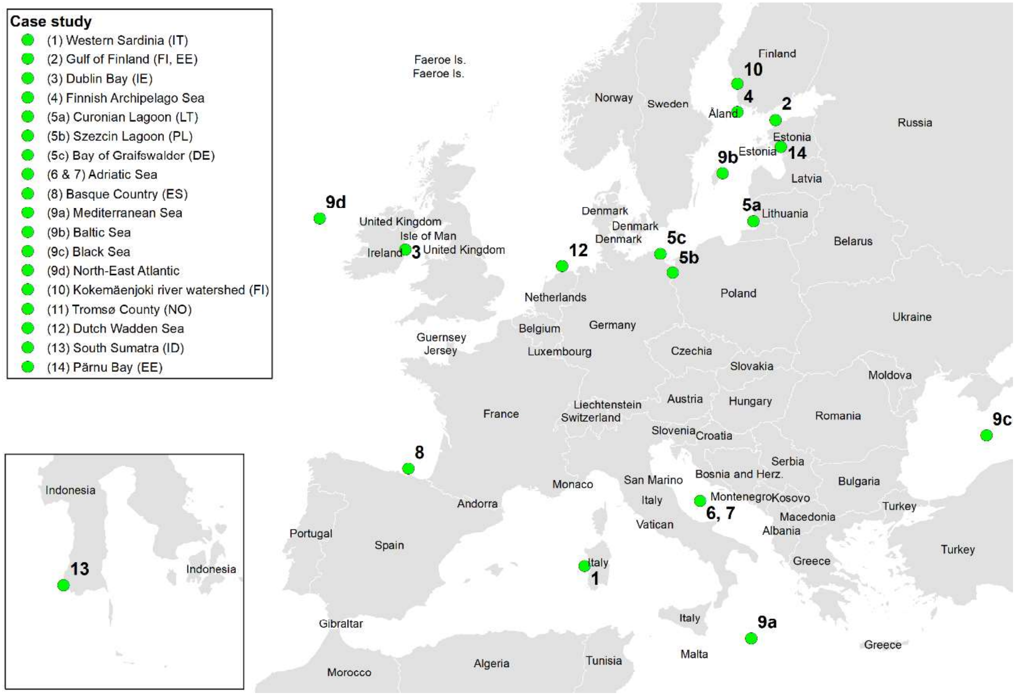


Figure 2. Geographical distribution of case studies (CS). Note: CS5 includes sites a, b, c; CS9 includes site a, b, c and d; the Adriatic Sea has two distinct case studies (i.e., CS6 and CS7).

Table 2. Case study overview (see Table SM 3 for detailed description of each case study). MSP: marine spatial planning.

Case study title	Geographic location
1 Operationalizing ecosystem services in support of conservation measures of marine-coastal protected areas in Sardinia Region (Italy).	West Coast of Sardinia Island (IT).
2. Mapping cumulative risk to marine ecosystem services provided by benthic habitats in the Gulf of Finland.	Gulf of Finland (FI, EE).
3. Valuing coastal cultural ecosystem services to inform MSP.	Dublin Bay (IE).
4. Optimizing the management of multiple ecosystem services - case study from the Finnish Archipelago Sea.	Finnish Archipelago (FI).
5 a,b,c. Assessing and mapping changes in ecosystem services provision: examples from Baltic transitional waters bodies.	Graifswald Bay (GE), Szczecin Lagoon (PL), Curonian Lagoon (LT).
6 The socio-ecological dimension of multi-use sea spaces.	Italian Adriatic Sea (IT).
7 Marine ecosystem services trade-off assessment: a methodological approach to inform MSP.	Adriatic-Ionian Region (AIR).
8 Analysing the dependencies of marine activities and natural capital: a spatially explicit Bayesian Belief Network approach under the MSP framework.	Basque country (ES).

Case study title	Geographic location
9 a-d Linking marine ecosystems with the services they supply: which are the relevant services providing units?	European Regional Seas – North East Atlantic, Baltic Sea, Black Sea, Mediterranean Sea (all countries).
10 Stakeholders' place-based knowledge supporting ecosystem-based MSP in Kokemäenjoki riverine landscape.	Kokemäenjoki river watershed (FI).
11 Mapping ecosystem services for coastal zone planning.	Troms County (NO).
12 A Bayesian Network Analysis of Trade-Offs between ecosystem services in the Dutch Wadden Sea.	Dutch Wadden Sea (NL).
13 Valuation of ecosystem services for a sustainable aquaculture development.	Southeast Asia - South Sumatra (ID).
14 Knowledge to decision in dynamic seas: novel species are jeopardizing the integrity of vital ecosystems and their functioning.	Gulf of Riga (EE).

2.3. Information integration and analysis

Based on the responses received from case studies, general characteristics and objectives together with information on the ecosystem services and implemented approaches were collated. The reported experiences of limitations and needs for the operationalisation of ecosystem services within MSP were classified according to the nine needs most frequently identified during the literature review. The strengths and weaknesses of the implemented approaches to overcome the limitations were also interpreted and classified.

3. Results and discussion

3.1. Operationalisation of ecosystem services into marine spatial planning

The main focus of the research in the reviewed case studies was the development, implementation and testing of ecosystem services assessment and valuation methods for supporting MSP, and the use of such information for communication and engagement with stakeholders during MSP implementation processes. In fact, most of the case studies were research-related projects linked to academia (12 out of 14) and only two were purely consultancy projects (CS1 and CS9) (Table SM 3). Moreover, three case studies reported that the outcomes of the research were already used to inform or support MSP plans, whilst five case studies that the outcomes were planned to be used in MSP plans (Table SM 3).

The ecosystem services assessed and the methodology implemented in each case study, is shown in Table 3; whereas an overview of the topics assessed are provided in Figure 3. The strengths and weaknesses reported by case studies during the development and implementation of approaches for operationalisation of ecosystem services into MSP are provided in Table SM 4. In the subsequent sections, we describe and discuss the outcomes derived from the case studies.

Table 3. Overview of the ecosystem services assessed and methodology implemented in each case study. Each case study reported the main limitation and associated needs for operationalisation of ecosystem services into marine spatial planning, according to the classification derived from the literature review: A: Classifications and frameworks; B: Indicators; C: Data availability; D: Mapping and modelling; E: Assessment and evaluation; F: Scenario and trade-offs; G: Communication & engagement of stakeholders & society; H: Information society & information technologies; and I: Integration into policies. Note: AM: Assessment method; CE: communication and engagement with stakeholders; I: indicators, SB: scenario-based analysis; T/S: Trade-off/synergy; GIS: Geographic Information System; MSP: marine spatial planning.

Case study	Ecosystem services assessed	Ecosystem service type	Applied methology	Reported needs								
				A	B	C	D	E	F	G	H	I
1	Cultural	Cultural	(AM) Market price. (I) Monetary value.				■	■				
2	All	Provisioning Maintenance and regulating Cultural	(AM) Habitat model; cumulative effect assessment. (I) Species distribution index; filtration index; environmental risk index. (CE) Environmental risk tolerability.				■					
3	Cultural	Cultural	(AM) Participatory mapping geo-tagged analysis. (I) Number of respondents. (CE) Public survey based on a questionnaire.	■				■				
4	Habitat maintenance Recreational	Provisioning Maintenance and regulating Cultural	(AM) Bayesian Belief Network; stakeholder analysis. (I) Biomass; number of individuals; nutrient load. (SB) Climate scenarios and impact on local stakeholders. (CE) Stakeholder questionnaires for ecosystem effects to recreation.			■			■			
5	All	Provisioning Maintenance and regulating Cultural	(AM) Participatory scenario; expert-based elicitation. (I) Marine Ecosystem Services Assessment Tool (MESAT index). (SB) Management scenarios in MSP.							■		
6	Food from fish Habitat maintenance Recreational	Provisioning Maintenance and regulating Cultural	(AM) Multi-criteria ecosystem services assessment; habitat modelling. (I) Suitability index for multi-use development. (T/S) Synergy of ecosystem services in a multi-use context.				■					

	Cultural heritage		(SB) Multi-use scenario applied to oil and gas infrastructure decommissioning. (CE) Stakeholder engagement on multi-use concept and benefits.				■					
7	Food from fish Habitat maintenance Primary production	Provisioning Maintenance and regulating	(AM) Bayesian Belief Network. (I) Monetary value. (T/S) Trade-offs between fishery and nature conservation. (SB) Scenario on fishery banned in nature conservation areas.	■					■			
8	Food from fish Habitat maintenance	Provisioning Maintenance and regulating	(AM) Habitat modelling; ecosystem services assessment. (I) Spatial index of dependencies of human activities on natural capital and ecosystem services. (T/S) Trade-offs among fishery and supporting ecosystem services.				■		■			
9	All	Provisioning Maintenance and regulating Cultural	(AM) Link marine ecosystems with the services they supply.			■	■					
10	Cultural	Cultural	(AM) Participatory GIS. (I) Number of respondents. (CE) Crowed sourced respondents.							■		
11	All	Provisioning Maintenance and regulating Cultural	(AM) Participatory GIS. (I) Presence/absence of human activities.		■		■	■				
12	Food from fish Nutrient regulation Habitat maintenance	Provisioning Maintenance and regulating	(AM) Bayesian Belief Network; participatory definition of scenarios. (I) Index of pressures. (T/S) Trade-offs between agricultural runoff and coastal ecosystem services.				■		■	■		

			(CE) Experts based probability scoring.									
13	Food from fish Ecosystem services in magroves	Provisioning Maintenance and regulating Cultural	(AM) Cost-Benefit Analysis; market value; replacement cost; benefit-transfer; carbon credits; contingent valuation; Bayesian Belief-Networks; post-normal science. (I) Monetary and non-monetary values. (T/S) Trade-offs between aquaculture and environmental benefits. (CE) Contingent valuation methods.									
14	Food from fish Water filtration Habitat maintenance	Provisioning Maintenance and regulating	(AM) Habitat model; Cumulative Effect Assessment tool.									

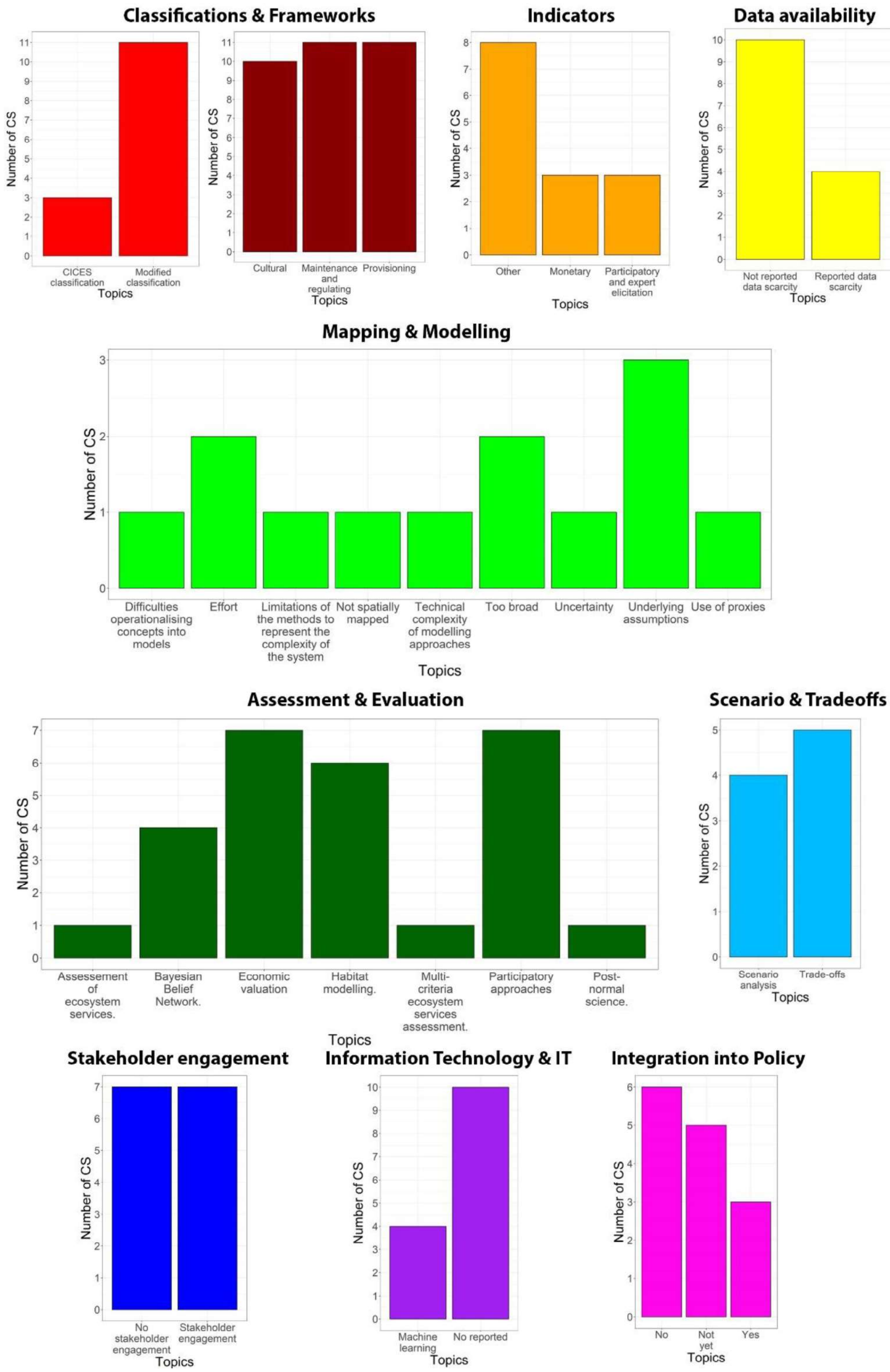


Figure 3. Overview of the main topics analysed in the case studies with respect to the critical needs to operationalize ecosystem services into marine spatial planning. Note MSP: marine (or maritime) spatial planning; CICES: Common International Classification of Ecosystem Services; IT: information technology.

3.1.1. Ecosystem services classifications and frameworks

Categorizing and describing ecosystem services is the basis of any attempt to measure, map or valorisation (Czúcz et al., 2018). Moreover, ecosystem service classes are intended to guarantee unequivocal understanding and avoid double accounting. In the present study, only three out of 14 case studies reported the use of the CICES [27] classification, while 11 case studies used modified or adapted ecosystem services classifications. The limited use of existing ecosystem frameworks reinforces the need for the adaptation of existing classifications for marine ecosystems, to better suit policy and management [36], and in particular for the purpose of MSP [31]. In that sense, two of the case studies (i.e., CS2 and CS14), aimed at the development of a single analysis framework and the standardisation of methodologies.

In terms of the number of ecosystem services approached, in 13 of the case studies two or more ecosystem services were assessed. Provisioning services (e.g., aquaculture, seafood from wild animals) and maintenance and regulating services (e.g., habitat maintenance, nutrient regulation) were assessed in 11 of the case studies; whereas cultural services (recreation, cultural heritage) were assessed in 10 of the case studies (Table 3 and Figure 3).

3.1.2. Indicators

Indicators are considered as the starting point for ecosystem service assessments within MSP [31, 52]. Indicators directly related to MSP could be those linked to provisioning services (i.e., fisheries and aquaculture) and cultural services (i.e., recreational activities). Nevertheless, the relevance of indicators related to maintenance and regulating services, which are supporting other services, should be highlighted, and indicators linked to environmental status (e.g., MSFD indicators) [53]. Most indicators used in each case study were specific to the main aims or focus of the research (e.g., specific ecosystem services or maritime activities), highlighting the lack of consistency and harmonization of indicators (Table 3). Monetary value indicators were used in three of the case studies, whilst indicators related to public participation and stakeholders engagement were used in three case studies. The rest of the indicators were diverse, related to regulating and maintenance service proxies such as, *inter alia*, environmental risk, filtration, indicators related to the cumulative effect of human activities, habitat maintenance.

3.1.3. Data availability

The main challenges related to the mapping of coastal and marine ecosystem services are the lack of geo-referenced data with sufficient resolution [54], quantitative data [55], and bio-physical data on ecosystem functioning over space and time. Data availability was frequently reported by case studies as one of the main barriers when operationalizing ecosystem services into MSP processes (four out of 14) (Table SM4). The approaches implemented in the case studies, especially when modelling techniques were used for ecosystem services assessment and mapping, are very data driven and thus, dependent on environmental and socioeconomic data availability. Moreover, the reliability of the models' outcomes depends on the amount and accuracy of data. Limitations on data availability are not unique to marine systems, but are a constraint on the application and limit the progress being made in the operationalisation of ecosystem services (Townsend *et al.*, 2018).

3.1.4. Mapping and modelling

Modelling was the most used approach for mapping and assessment of ecosystem services. It was applied in nine of the case studies (Table 3) and the strengths and potential of modelling approaches for producing geo-referenced information was highlighted (Table SM 4) (Figure 3). The approaches implemented tried to gain an understanding of the linkages between marine ecosystems and human activities (e.g. CS7 and CS8) [9, 56]. When data are available, models are based on empirical evidence; thus, modelling approaches can give analytical support and inform about alternative management options [6]. Multi-ecosystem service models are particularly useful to policy-makers if they can help illustrate potential trade-offs between economic development and ecosystem services provision (e.g. CS9) (Nelson and Daily, 2010). Nevertheless, the most common limitations reported by case studies were commonly related to background assumptions and proxies needed to run models. This includes difficulties operationalising concepts into models and the limitations of the models to represent the complexity of the system. It also includes a lack of knowledge on how to convert different structural elements (e.g., biophysical components) into the functioning of ecosystems to derive values of ecosystem services. Case studies also reported the effort needed during model development due to technical complexity of modelling approaches (Table SM4).

3.1.5. Assessment and valuation

The diversity of approaches implemented in the case studies needs to be highlighted (Table 3 and Figure 3). The most common approach used was the participatory mapping (in seven of the case studies), which is useful when there is a lack of scientific data available and when investigating socio-cultural value given by society [40, 57], and economic valuation (e.g. market price, benefit-transfer, carbon credits, contingent valuation, cost-benefit analysis). The second most used approach was habitat modelling (including cumulative effect assessment) (in six of the case studies). Habitat modelling and mapping is a commonly used approach to link the distribution of habitats to the ecosystem services they provide [58, 59]. Bayesian Belief Networks (in four of the case studies) was also reported as a commonly used approach. The strength of the Bayesian approach is that it allows inclusion of data from different sources and can be carried out even if some data are missing (Table SM 4).

One of the most important strengths of the information on ecosystem services assessment and spatial distribution reported by case studies (Table SM 4), was its relevance for management purposes, as it can be used by managers to take environmental, social and economic factors into consideration (Börger *et al.*, 2014). However, the assessment and valuation of ecosystem services is also dependant on previously highlighted limitations such as methodological challenges and data availability.

3.1.6. Scenarios and trade-offs

Scenario analysis supports the assessment of the potential economic, environmental, social consequences and trade-offs of management measures. In nine of the case studies a scenario or trade-off analysis was performed. Scenarios were defined for climate change and impact on local stakeholders (CS4), and the definition of management scenarios in MSP (CS5 and CS7). Scenario and trade-off analysis can assist the assessment of activities that benefit from the same resources and allow exploration of different planning and marine activities distribution configurations (e.g., CS7 and CS13) (Coccoli *et al.*, 2018). Thus, it is of high relevance for EBMSP and decision making.

Five of the case studies mentioned made use of trade-offs for comparison of environmental benefits and potential human activities (e.g., aquaculture facilities or fishery); assessment of agricultural run-offs and coastal ecosystem services; and sustainable fishery management. Thus, the analysis to inform EBMSP adopts different types of ecosystem services interactions (non-interacting services, direct trade-off, etc.) to find the optimal ocean space which is appropriate for human activities to reduce conflicts and achieve ecological, economic and social objectives [60].

3.1.7. Communication and engagement of stakeholders and society

A key opportunity of ecosystem services research is to facilitate communication with decision makers in a way that can be easily understood and used to make informed decisions (Wright *et al.*, 2017). In seven of the 14 case studies analysed, different types of communication and society engagement actions were adopted. The main engagement instruments were meetings and questionnaires to address, for instance, the effects of ecosystem components on recreational experience and livelihood or to address the feasibility of ocean multi-use [43] (Table 3). Case studies acknowledged that society should have an active role at different stages of the ecosystem services assessment process. In data scarce situations in particular, stakeholder involvement significantly contributes to: (i) data collection (e.g. social media, information on the use patterns, valuation and perceptions); (ii) conceptual model construction (establishing relationships between ecosystem and users); (iii) model validation; (iv) mapping and assessment results validation (critical concepts for the implementation of ecosystem services into EBMSP) (Table 3). One strength of stakeholder engagement and consultation processes reported by case studies, was that it gives the opportunity to understand non-monetary values of ecosystem services, which are difficult if not impossible, to measure using monetary valuation methods (e.g. aesthetic value, value of existence) (Table SM 4). It enables a comprehensive evaluation of policy impacts, which is dependent on the incorporation of the diversity of stakeholders' perceptions, knowledge and preferences [61, 62]. Moreover, without detailed knowledge of the human dimensions of the marine environment, decision-makers are likely to face continued resistance to forms of management that spatially restrict the use of the marine environment (St. Martin and Hall-Arber, 2008).

3.1.8. Information society and information technology

Advances in information technologies are revolutionizing marine monitoring programs and data processing capabilities, opening up novel opportunities for EBMSP (St. Martin and Hall-Arber, 2008). New technological advances such as artificial intelligence and machine learning have increased application in ecosystem service assessment (Villa et al., 2014) including four studies reviewed in this paper (Table 3) to predict ecosystem services flows in a given geographic area. Machine learning algorithms may enable the use of increasingly available 'big data' and assist applying ecosystem services models across scales, analysing and predicting the flows of these services to disaggregated beneficiaries (Willcock et al., 2018). An emerging application of big data in ecosystem services assessment is the use of social media data (e.g. Twitter, Flickr, Panoramio) to address cultural values, such as people's preference for recreational areas (Cornu et al., 2014) and landscape beauty (Wood et al., 2013).

3.1.9. Integration into policies and management

Although the relevance of ecosystem services for the optimal performance and sustainable growth of maritime sectors is recognised, and a substantial part of the scientific literature provides theoretical insights into marine ecosystem services integration into MSP processes [63], the practical integration of ecosystem services into EBMSP processes is still incipient. In fact, only three case studies informed an official MSP process, but five cases reported that the outcomes of the research were expected to be used in MSP in the near future (Table SM 3).

3.2. Ecosystem services and marine spatial planning framework

Ecosystem services offer an interesting framework for integrating economic, environmental, and social concerns into EBMSP [64], but successful implementation is limited by the critical needs described in the previous section. The links between the nine critical needs identified during the bibliographic review and further investigated in the case studies analysed (A-I left column) when operationalizing the ecosystem services approach with generic MSP implementation steps (1-7 adopted from Ehler and Douvere [65] are shown in Figure 4.

Data, information and knowledge gathering for the definition of current conditions (step 2 in MSP implementation process, with seven links to ecosystem services critical needs), together with communication and engagement of stakeholders and society (with six links to MSP implementation steps), are key linkages between ecosystem services and MSP. In an early stage of an MSP implementation process, a clear definition, classification, understanding and assessment of the ecosystem services present within the planning area is critical when defining the objectives of the whole plan; and when establishing the strategic and specific environmental, social and economic objectives. Moreover, communication and engagement actions also contribute to the identification of users and stakeholder groups according to the benefits they obtain from ecosystem services; as well as their dependency on them, which is necessary for the definition of the MSP objectives. The most relevant (and vulnerable) stakeholders can be involved in the process though participatory approaches, increasing the legitimacy and social impact of the MSP.

A clear definition of ecosystem services is a key element that affects the whole MSP implementation process such as avoiding double accounting when assessing the current condition (step 2); as well as when assessing and evaluating alternative management actions (step 5). Linked to each ecosystem service type, the use of environmental, economic and social indicators is an essential requirement for ecosystem services assessment and the MSP implementation process [31, 52] (step 2 in MSP). When defining the current condition, the process of mapping and assessment of ecosystem services can be used to better understand the spatial distribution of the current ecosystem services supply, flow and demand, by linking intensity of human activities and economic benefits obtained [56, 66-68]. The definition of current condition also considers the assessment of environmental status (e.g. as defined by MSFD), as it is linked to ecosystem services provision capacity [53]; and thus, it determines the distribution of maritime activities. The assessment of environmental condition could also determine the adoption of specific conservation and restoration measures, which could also influence the distribution of maritime activities.

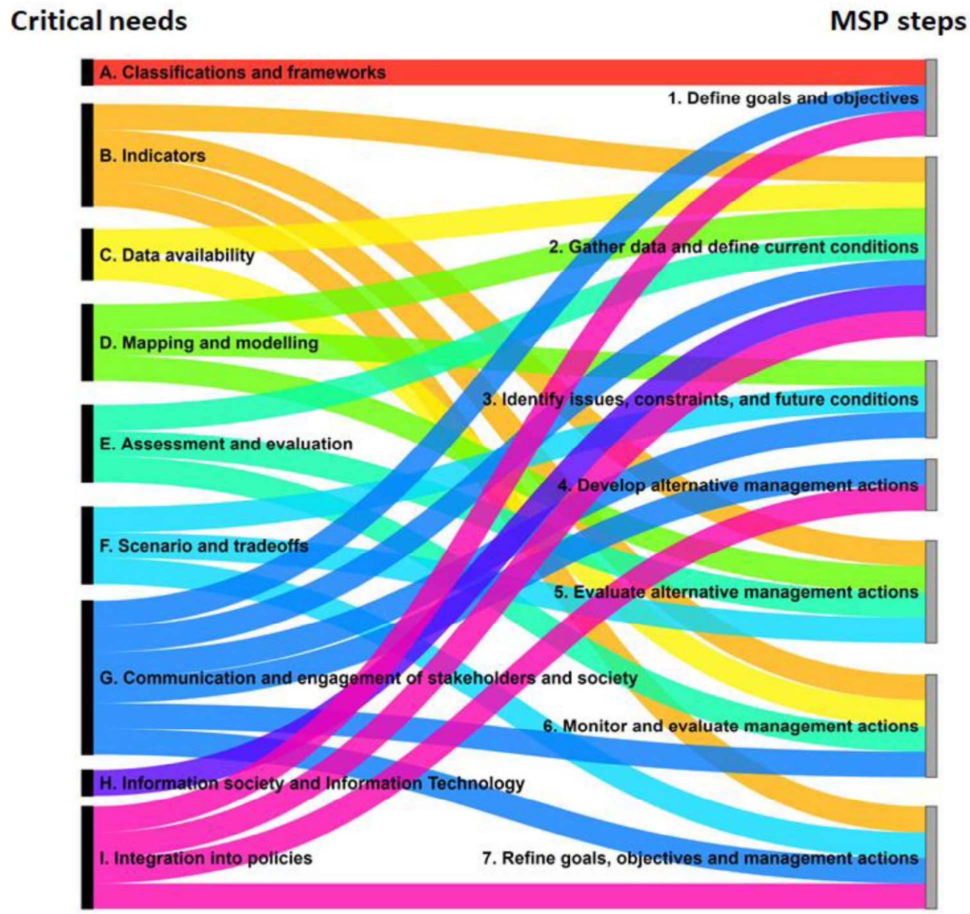


Figure 4. Links between the critical needs for operationalisation of ecosystem services (left) and the marine spatial planning implementation steps (right). Note: MSP - marine (maritime) spatial planning.

When identifying issues, constraints, and future conditions (step 3 in MSP), ecosystem services modelling, mapping and assessment approaches can inform and support the development and evaluation of management actions [60]. Scenario definition and analysis is of high relevance to identify potential conflicts and competition for space, especially between existing traditional sea uses, and new ones (e.g. development of offshore renewable energy production farms). Moreover, resulting outcomes from future scenarios helps the identification and assessment of trade-offs between different strategic management alternatives (step 4 in MSP). Currently, future conditions related to climate change effects are of high relevance [69]; especially when trying to anticipate potential shifts of suitable areas for aquaculture production [70] and species of commercial interest [71, 72].

Monitoring and evaluating the adopted management actions (step 5 in MSP), should assess the achievement of environmental, social and economic objectives, for which the ecosystem services assessment could provide highly relevant insights [73] (step 6 in MSP). The information on the assessment or potential changes in the delivery of ecosystem services and environmental status, should be used to support the re-definition of goals, objectives, and management actions (step 7 in MSP) and to communicate to stakeholders the results of the adopted management plan.

4. Conclusions and recommendations

In the last decade, the number of publications referring to ecosystem services and its potential to inform MSP has increased significantly. But most of the published research refers to theoretical frameworks and methodologies, with few of them describing practical examples of consideration of ecosystem services in EBMSP. The complexity of the approach is evident when considering the number of limitations on mapping and assessment of ecosystem services and its operationalisation into MSP. According to our scientific review the limitations could be grouped into nine types, which in turn define the needs for operationalising ecosystem services into EBMSP. Moreover, 14 case studies have been reviewed to further investigate the limitations of implementing ecosystem services mapping, assessment, and valuation to support MSP and to derive recommendations according to experiences, strengths and weaknesses of the approaches implemented, to overcome such limitations.

According to the outcomes, the framing of the ecosystem services approach into EBMSP requires further development and adaptation of common ecosystem services classification systems to fully consider biogeographic features of the marine biome and all the ecosystem services supplied. This is stressed by the number of publications and case studies in which adapted classifications are used or proposed. The framework and associated indicators should be agreed between scientists, managers and maritime sectors representatives to reach a common understanding of the links and flows, between ecosystems, maritime uses and beneficiaries. At present, the indicators used are very case specific. The adoption of a common classification would increase transparency, which would contribute to the reliability and the operationalization of ecosystem service concepts and its real use in policy making and management. Moreover, common classification systems and concepts, would assist the production of comparable assessments between countries and promote regional assessments and contribute to EBMSP. Similarly, regional working groups involving core members of different scientific disciplines and institutions, should be created to develop, discuss and agree on methods and approaches to produce reliable and objective outcomes and recommendations that may be used to inform policy and management. Particular focus should be given to the integration of non-monetary and monetary valuation methods to provide socio-economic indicators for the demand of ecosystem services that can better explain the benefits to society. This is highlighted by the number of case studies that implemented participatory approaches for gathering relevant information for modelling, mapping and assessment of ecosystem services.

The definition of ecosystem services indicators should be linked to environmental status and tailored to an EBMSP relevant spatial scale. Broszeit, Beaumont [53] identified 247 biodiversity indicators proposed for the MSFD, as potentially useful ecosystem services indicators. This could be an essential starting point to analyse the benefits of improved environmental status, as well as the costs associated with degradation. Indicators should ideally link ecosystem services supplied by marine ecosystems to socio-economic activities. This is an essential aspect to better understand the potential social, economic and environmental trade-offs among different sectors depending on marine resources and the environmental status.

Geospatial information is one of the main requirements of integrating an ecosystem services approach into EBMSP, and according to the outcomes derived from case studies is one of the main strengths of the approaches implemented. In addition, the graphical representation of the distribution of ecosystem services also facilitates communication and discussion with stakeholders. This communication could be improved by developing visualization tools which should be made available to society. New web-platforms or mobile applications can create opportunities to reach to bigger audience numbers and get information from them. This recommendation is also linked to the fact that planning teams should be interdisciplinary, with sectorial involvement and ensuring public participation oriented to the actual ecosystem services beneficiaries on local and regional scales. Stakeholder knowledge and preferences should be elicited to understand the socio-ecological and cultural values of marine resources.

Data availability is one of the main limitations when assessing and modelling ecosystem services according to the literature and the case studies reviewed. New approaches should benefit from recent technological developments in data-driven-modelling (DDM), such as Artificial Intelligence to process ‘big data’ that can assist in analysing ecosystem services across scales, predict flows and disclose disaggregated ecosystem services beneficiaries. Nevertheless, data scarcity should not prevent ecosystem services assessments from being carried out and expert judgement approaches should be further promoted. As new data are available; they should be used to update the assessment and to improve models results to reduce uncertainties. A significant number of case studies reviewed reported that it is essential to reduce uncertainty and to increase the reliability of assessment and valuation of ecosystem services to be used in real management plans development. Institutions should ensure mechanisms that give access to regional but also national and often fine scaled ecosystem service data by using existing MSP related geospatial data platforms. The interoperability among data storage and processing systems should be guaranteed to further facilitate this process. Moreover, updated data availability and quality should be ensured to keep models and Decision Support Tools operational.

The capacity of modelling approaches to produce scenarios is a frequently reported strength. Scenario-based models should be implemented to explore EBMSP impacts and/or benefits to ecosystem services provision, and vice versa. Scenario analysis can be used to include society preferences of what future would they prefer and can improve transparency in EBMSP decision-making processes. Further, the use of trade-off analysis techniques should be consolidated to better understand and communicate intra-sectorial environmental and socio-economic conflicts of planning decisions. Also, the integration of the ecosystem services concepts within global change phenomena such as climate change, can provide further advancement in the integration and provide novel insights into climate change adaptation strategies.

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Figure01

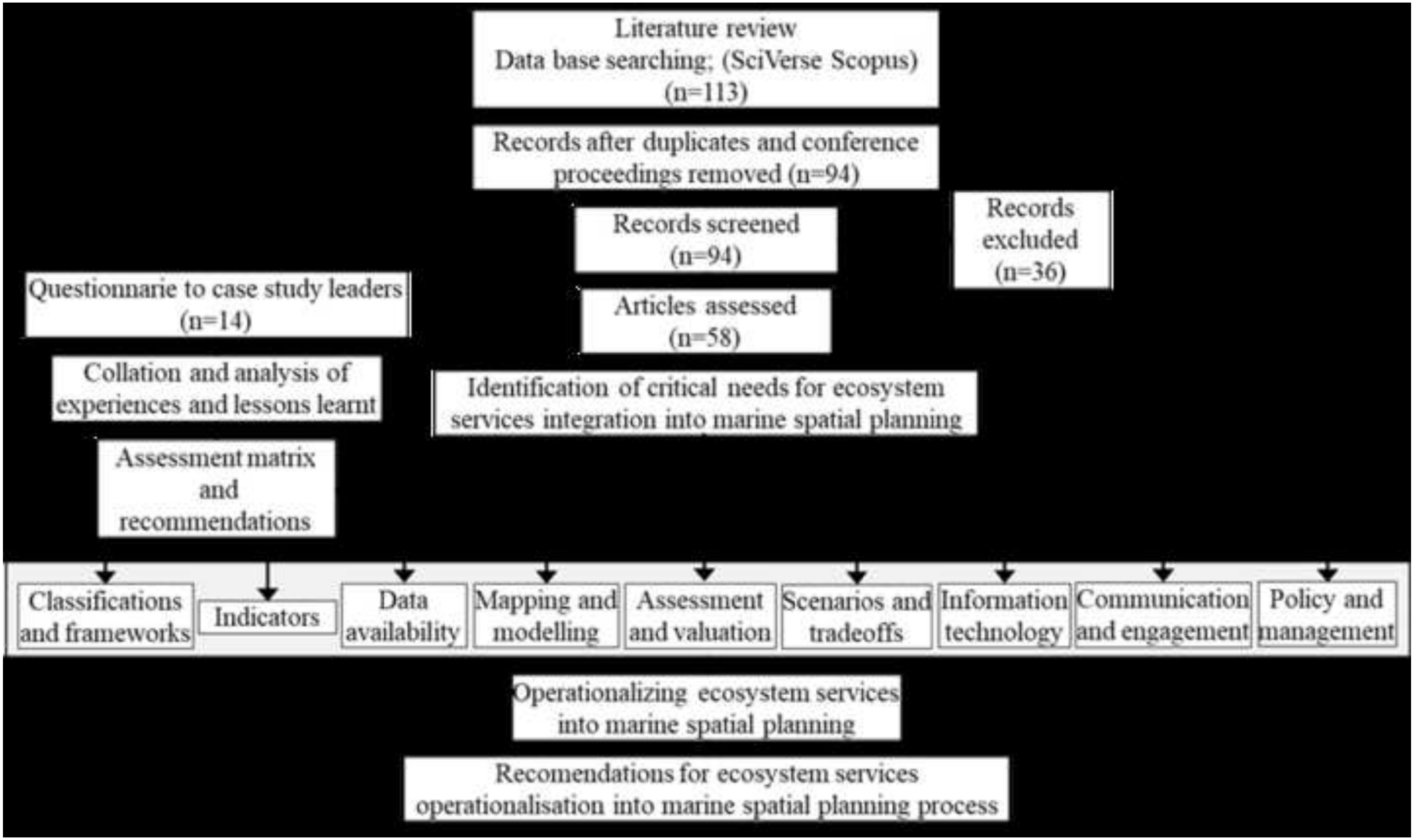
Literature review
Data base searching; (SciVerse Scopus)
(n=113)
Records after duplicates and conference proceedings removed (n=94)
Records screened
(n=94)
Records excluded
(n=36)
Articles assessed
(n=58)
Identification of critical needs for ecosystem services integration into marine spatial planning
Questionnarie to case study leaders
(n=14)
Collation and analysis of experiences and lessons learnt
Assessment matrix and recommendations
Classifications and frameworks
Indicators
Data availability
Mapping and modelling
Assessment and valuation
Scenarios and tradeoffs
Information technology
Communication and engagement
Policy and management
Operationalizing ecosystem services into marine spatial planning
Recomendations for ecosystem services operationalisation into marine spatial planning process

Figure02.tif

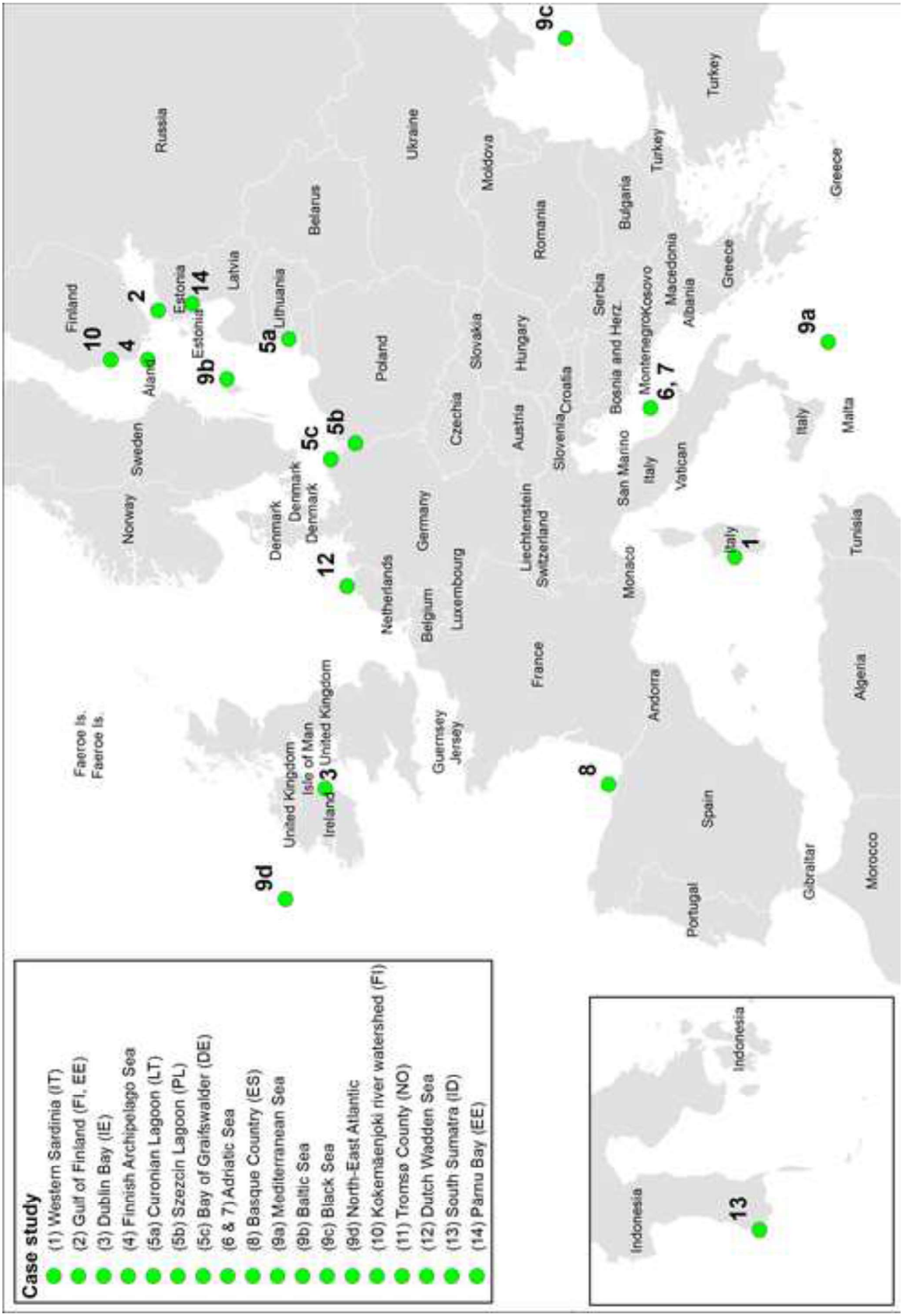

Figure03

Click here to access/download;Figure;Figure03.tif

Figure03.jpg

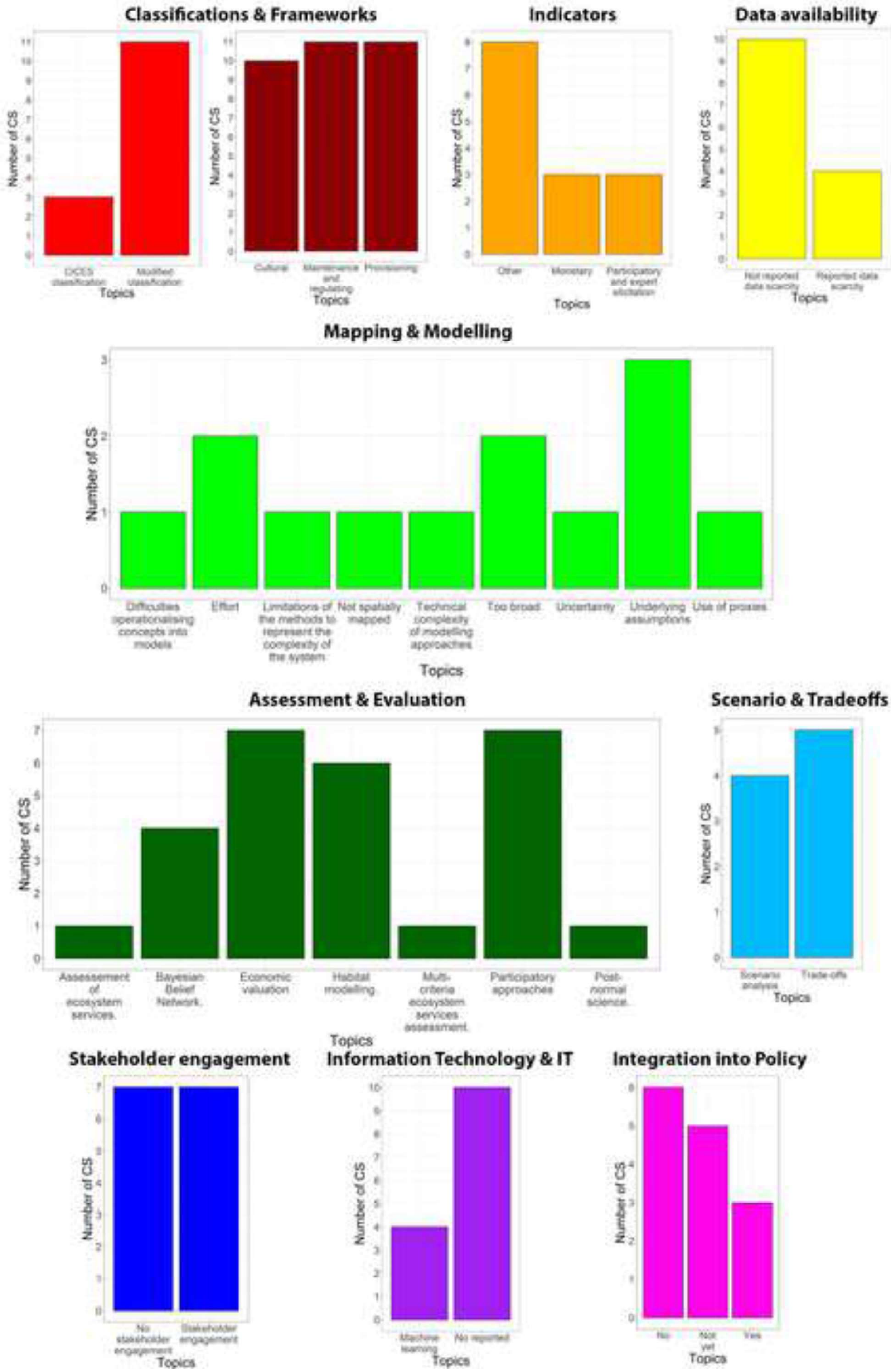

Table 1. Critical needs and their definition adopted in this research. Note: T: theoretical; TM: technical and methodological; and SP: societal and policy.

Critical need (and type)	Definition used in this research
Classifications and frameworks (T)	Schemes and definition of ecosystem services according to international or national designation. They are developed to support standardisation and facilitating comparison (e.g., CICES [27]). They should also facilitate the use of available data to spatially map and explore the pathways between ecosystem services, processes, and the ecological function responsible for ecosystem services provision.
Indicators (T)	Proxy measures derived from empirical data or modelled estimates of ecosystem status, functions and ecosystem services [45].
Data availability (TM)	The products and services that ensure that data are reliable, updated and continuously available.
Mapping and modelling (TM)	*Ecosystem services map*. Spatially explicit representation of ecosystem services production capacity within a given territory. Ecosystem services maps can be used for different purposes such as: problem identification, synergy trade-off analysis, visualization support and as a communication instrument [46]. *Ecosystem services model*. A graphical or mathematical representation of concepts or processes that is used to estimate links and quantify the delivery and flow of ecosystem benefits from marine systems under different ecological or socioeconomic scenarios [47].
Assessment and valuation (TM)	Assembling, summarizing, organizing, interpreting, and reconciling pieces of existing knowledge to measure the ecosystem services´ economic, ecological, and social values (monetary or non-monetary); that can be used as an estimate of the contribution to human well-being [48].
Scenario and trade-offs (TM)	*Scenario*. Storyline that describes possible futures. They explore aspects of, and choices about, the future that are uncertain. Scenarios can include qualitative descriptions of changes (i.e., a narrative) and quantitative representations [49] of potential economic, environmental, social or technical developments and their expected consequences on society and environment [50]. *Trade-offs*. When the provision of one service is reduced as a consequence of increased use of another [45].
Information society and Information Technology (SP)	Post-industrial society which benefits from the application of information technologies (IT) to support production and distribution of all kinds of information.
Communication and engagement of stakeholders and society (SP)	Participatory approaches that foster articulation and elicitation of values allowing the integration of different value dimensions to inform decision-making processes.
Integration into policies (SP)	Process of assimilation of the ecosystem services concept into national and supra-national policymaking.

Table 2. Case study overview (see Table SM 3 for detailed description of each case study). MSP: marine spatial planning.

Case study title	Geographic location
1 Operationalizing ecosystem services in support of conservation measures of marine-coastal protected areas in Sardinia Region (Italy).	West Coast of Sardinia Island (IT).
2. Mapping cumulative risk to marine ecosystem services provided by benthic habitats in the Gulf of Finland.	Gulf of Finland (FI, EE).
3. Valuing coastal cultural ecosystem services to inform MSP.	Dublin Bay (IE).
4. Optimizing the management of multiple ecosystem services - case study from the Finnish Archipelago Sea.	Finnish Archipelago (FI).
5 a,b,c. Assessing and mapping changes in ecosystem services provision: examples from Baltic transitional waters bodies.	Graifswald Bay (GE), Szczecin Lagoon (PL), Curonian Lagoon (LT).
6 The socio-ecological dimension of multi-use sea spaces.	Italian Adriatic Sea (IT).
7 Marine ecosystem services trade-off assessment: a methodological approach to inform MSP.	Adriatic-Ionian Region (AIR).
8 Analysing the dependencies of marine activities and natural capital: a spatially explicit Bayesian Belief Network approach under the MSP framework.	Basque country (ES).
9 a-d Linking marine ecosystems with the services they supply: which are the relevant services providing units?	European Regional Seas – North East Atlantic, Baltic Sea, Black Sea, Mediterranean Sea (all countries).
10 Stakeholders' place-based knowledge supporting ecosystem-based MSP in Kokemäenjoki riverine landscape.	Kokemäenjoki river watershed (FI).
11 Mapping ecosystem services for coastal zone planning.	Troms County (NO).
12 A Bayesian Network Analysis of Trade-Offs between ecosystem services in the Dutch Wadden Sea.	Dutch Wadden Sea (NL).
13 Valuation of ecosystem services for a sustainable aquaculture development.	Southeast Asia - South Sumatra (ID).
14 Knowledge to decision in dynamic seas: novel species are jeopardizing the integrity of vital ecosystems and their functioning.	Gulf of Riga (EE).

Table 3. Overview of the ecosystem services assessed and methodology implemented in each case study. Each case study reported the main limitation and associated needs for operationalisation of ecosystem services into marine spatial planning, according to the classification derived from the literature review: A: Classifications and frameworks; B: Indicators; C: Data availability; D: Mapping and modelling; E: Assessment and evaluation; F: Scenario and trade-offs; G: Communication & engagement of stakeholders & society; H: Information society & information technologies; and I: Integration into policies. Note: AM: Assessment method; CE: communication and engagement with stakeholders; I: indicators, SB: scenario-based analysis; T/S: Trade-off/synergy; GIS: Geographic Information System; MSP: marine spatial planning.

Case study	Ecosystem services assessed	Ecosystem service type	Applied methology	Reported needs								
				A	B	C	D	E	F	G	H	I
1	Cultural	Cultural	(AM) Market price. (I) Monetary value.									
2	All	Provisioning Maintenance and regulating Cultural	(AM) Habitat model; cumulative effect assessment. (I) Species distribution index; filtration index; environmental risk index. (CE) Environmental risk tolerability.									
3	Cultural	Cultural	(AM) Participatory mapping geo-tagged analysis. (I) Number of respondents. (CE) Public survey based on a questionnaire.									
4	Habitat maintenance Recreational	Provisioning Maintenance and regulating Cultural	(AM) Bayesian Belief Network; stakeholder analysis. (I) Biomass; number of individuals; nutrient load. (SB) Climate scenarios and impact on local stakeholders. (CE) Stakeholder questionnaires for ecosystem effects to recreation.									
5	All	Provisioning Maintenance and regulating Cultural	(AM) Participatory scenario; expert-based elicitation. (I) Marine Ecosystem Services Assessment Tool (MESAT index). (SB) Management scenarios in MSP.									
6	Food from fish Habitat maintenance Recreational	Provisioning Maintenance and regulating Cultural	(AM) Multi-criteria ecosystem services assessment; habitat modelling. (I) Suitability index for multi-use development. (T/S) Synergy of ecosystem services in a multi-use context.									

	Cultural heritage		(SB) Multi-use scenario applied to oil and gas infrastructure decommissioning. (CE) Stakeholder engagement on multi-use concept and benefits.				■					
7	Food from fish Habitat maintenance Primary production	Provisioning Maintenance and regulating	(AM) Bayesian Belief Network. (I) Monetary value. (T/S) Trade-offs between fishery and nature conservation. (SB) Scenario on fishery banned in nature conservation areas.	■					■			
8	Food from fish Habitat maintenance	Provisioning Maintenance and regulating	(AM) Habitat modelling; ecosystem services assessment. (I) Spatial index of dependencies of human activities on natural capital and ecosystem services. (T/S) Trade-offs among fishery and supporting ecosystem services.				■		■			
9	All	Provisioning Maintenance and regulating Cultural	(AM) Link marine ecosystems with the services they supply.			■	■					
10	Cultural	Cultural	(AM) Participatory GIS. (I) Number of respondents. (CE) Crowed sourced respondents.							■		
11	All	Provisioning Maintenance and regulating Cultural	(AM) Participatory GIS. (I) Presence/absence of human activities.		■		■	■				
12	Food from fish Nutrient regulation Habitat maintenance	Provisioning Maintenance and regulating	(AM) Bayesian Belief Network; participatory definition of scenarios. (I) Index of pressures. (T/S) Trade-offs between agricultural runoff and coastal ecosystem services.				■		■	■		

			(CE) Experts based probability scoring.									
13	Food from fish Ecosystem services in magroves	Provisioning Maintenance and regulating Cultural	(AM) Cost-Benefit Analysis; market value; replacement cost; benefit-transfer; carbon credits; contingent valuation; Bayesian Belief-Networks; post-normal science. (I) Monetary and non-monetary values. (T/S) Trade-offs between aquaculture and environmental benefits. (CE) Contingent valuation methods.									
14	Food from fish Water filtration Habitat maintenance	Provisioning Maintenance and regulating	(AM) Habitat model; Cumulative Effect Assessment tool.									

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Supplementary Material. Table SM2