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Experimenting marine extent and condition accounts in France

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ABSTRACT

The development of an ecosystem accounting system to complete current wealth indicators is a core issue. Biophysical ecosystem accounts of the SEEA EA have been adopted as a statistical standard to bridge this gap. However, challenges remain as the specificities of marine ecosystems are poorly considered in the current standard, and link with policies is weak. This article aims at developing pilot biophysical ecosystem accounts in the European territory of France exclusive economic zone. We use available information from research and marine policy reporting databases to construct the extent and condition accounts. Remaining challenges include temporal and spatial issues of data availability, and several links between biophysical accounts and economic accounts.

1. Introduction

While the ocean contributes greatly to society [12] and human actions currently put the ocean under tremendous pressure [36], unified statistics on the interactions between the ocean and society is still lacking. Ocean accounting aims to describe these relationships, flows, and stocks, in a standardized manner that could be used by policy-makers [19]. Research has put forward proposals to structure accounting around economic aspects of marine natural capital [17], resource rent [21] and the blue economy [33], but the connection with the United Nations System of Environmental Economic Accounting - Ecosystem Accounting (SEEA EA) is missing. While ocean accounts broadly cover interactions between the ocean and the economy, including for example resource use or economic activities taking place on the ocean, marine ecosystem accounts specifically target the production of statistics around marine and coastal ecosystems, and their interactions with society.

The System of Environmental Economic Accounting started to produce norms in 2012 to steer the development of standardized ecosystem accounts [45]. The System of Environmental Economic Accounting - Ecosystem Accounting (SEEA EA) has been adopted as an international statistical standard by the United Nations Statistical Division in March 2021 [44]. This international acknowledgement should help to raise statisticians' and politicians' awareness of the value of integrated ecosystem accounts and to accelerate the development of environmental reporting systems [14,22]. The production of these ecosystem accounts should ultimately lead to the interoperability of large datasets, the integration of several environmental indicators into a coherent set of spatially explicit accounts, to create holistic information that can be used to inform management. While the biophysical ecosystem accounts put forward in the SEEA EA (ecosystem extent, condition, and ecosystem services in physical terms) are the object of the statistical standard, the monetary accounts of ecosystem services flow and ecosystem assets are "internationally recognized statistical principles and recommendations" (ibid.) The United Nations will "regularly evaluate and report on the usefulness and pertinence of [these] accounts" (ibid.). The foundational accounts to develop full sets of ecosystem accounts are the extent and condition accounts, which are the focus of this article.

In parallel, the degradation of ecosystems and the accelerating collapse of biodiversity are major issues that highlight the need for swift political and technical measures [24]. Environmental information is lacking to understand changes in ecosystems and inform management of marine ecosystems [5]. European Union (EU)'s Marine Strategy Framework Directive and Biodiversity Strategy 2020 (European Commission, 2011) as well as the Helsinki Commission (HELCOM) call upon an integrated economic-ecological assessment of the costs and benefits

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of improving the state of the marine ecosystem (HELCOM, 2018). The EU's Biodiversity Strategy also requires member states to map and assess the state and economic value of the ecosystems and their services and to promote the integration of these values into an accounting system by 2020. The use of ecosystem account to support these policy processes remains an open question. Natural capital accounting has for instance been identified as an important way forward to inform the development of environmental policies in the UK [23].

The literature on marine ecosystem accounts is emerging [6,9,27]. In the context of the SEEA, many articles are devoted specifically to the marine environment from the ecosystem services perspective [13,18,23,26,49,51], or marine protected areas [4]. Few have produced full sets of accounts, both biophysical and economic, except for the OSPAR region [1], which draws from Dutch experiment [42] and British experiment, the latter reporting on several conditions indicators, linked to the capacity to sustainably provide ecosystem services. Out of the ten accounting exercises analyzed in Cummins et al., [9], only three reported condition accounts and nine reported ecosystem services accounts. More recently, the Global Ocean Accounting Partnership is steering case studies in various parts of the world, consolidating the ocean accounting community, and has produce technical guidance documents on ocean accounts in order to structure guidelines, that were mostly lacking in the SEEA EA [20]. Many issues remain to develop marine ecosystem accounts, including feasibility, data availability, and notably on ecosystem condition [29]. This article therefore contributes to this literature by testing extent and condition accounts that are tailored to monitor policy-relevant dimensions of marine ecosystems.

France is a good candidate for a piloting of ocean accounts as it has the second largest Exclusive Economic Zone (EEZ) in the world, and a long history of work on environmental accounting [48,52]. In France, several experiments have been conducted on marine ecosystem accounts, the associated information system, and the use of environmental information for specific policies: satellite account for marine recreation [31]; input-output table on restoration of the Seine estuary [8]; synthesis on marine accounts in the Marine Strategy Framework Directive (MSFD) [32] reporting of the costs of environmental degradation for the implementation of the Marine Strategy Framework Directive [28]. A conceptual framework has been produced to link the strong sustainability approach to the SEEA EA [25]. Unfortunately, most of this work has been conducted in the European territory of France, and not in the French overseas territories, where the MSFD does not apply and further research is needed on mapping ecosystems.

The objectives of this article are thus two-fold: 1) to provide new pilot on the emerging literature on marine ecosystem accounting to further develop ocean extent and condition accounts, and 2) discuss how this can feed into policy-making given existing policies dedicated to marine ecosystems in Europe.

2. Methods

This section describes the materials and methods to produce marine ecosystem accounts, including the accounting framework used, and materials and methods to pilot the ecosystem extent and ecosystem condition accounts (Fig. 1). The accounts developed are based on the framework proposed in Kervinio et al. [25], aligned with the SEEA EA standard.

2.1. Ecosystem accounting structure

Ecosystem accounts are not just a set of tables: they are also an infrastructure for integrating diverse databases into a unified framework based on conventions and norms. Ecosystem accounting therefore defines what information is sought in the first place and imputes best available values for the desired information. Having this in mind, the SEEA EA can be described as an integrated and spatial monitoring of ecosystems structured according to a set of biophysical and monetary accounts. Ecosystem accounts aim to describe the spatial heterogeneity of ecosystems and their change over space and time. To do so, the construction of the accounting tables relies on spatially explicit information and aggregation rules.

Building on the SEEA EA, the system of ecosystem accounts presented here is structured around two biophysical accounts. The first is the ecosystem extent account, which maps the surface areas of different types of habitats and is the basis for the other accounts. The second is the ecosystem condition account, which represents the quality, health or state, of marine ecosystems. In this study, the ecosystem condition account uses indicators required to monitor the ecological status of marine waters defined in the context of the MSFD, as well as reference conditions of good ecological status to be reached.

The marine ecosystem accounts are experimented for the European territory of France EEZ. This EEZ is divided into ecosystem accounting areas corresponding to administrative units called marine subregions and defined in the MSFD.[1] At the French scale[2] these ecosystem accounting areas are defined as presented in the Fig. 2: 1) Greater North Sea (Manche-Mer du Nord), 2) Celtic Seas (Mer Celtique), 3) Bay of Biscay (Golfe de Gascogne), and 4) Western Mediterranean Sea (Méditerranée Occidentale). The EEZ is also divided into three zones starting from the shore: 1) coastal zone, 2) intermediate zone, 3) offshore zone which have reporting and ecological meanings, notably to measure eutrophication.

The basic spatial unit used here to map the accounts is a square grid with a resolution of 1 minute of degree in latitude by 1 minute of degree in longitude. This choice is a compromise between the resolution needed to produce accounts accurate enough for detecting change and informing territorial policies on the one hand, and the processing power needed to map datasets and calculate aggregated accounts. Higher resolution information is available for ecosystem extent and condition and should be used if the production of ecosystem accounts is institutionalized by governments, but this resolution is sufficient to produce maps and accounts at the scale of whole marine subregions.

2.2. Ecosystem extent account

The ecosystem extent account describes the extent of different ecosystem types that correspond to categories of habitats, their surface, and their evolution through time (additions to stock and reductions in stock). Extent within the accounting area can be linked to various properties of the ecosystem, such as range, type, function or features of the ecosystem. The IUCN Global Ecosystem Typology (Keith et al., 2020) is recommended to serve as a basis for reporting the ecosystem extents in the SEEA EA, to allow comparison between similar ecosystems across different accounts and geographical areas [44], but other classification systems can be used. Here, we use the European Nature Information System (EUNIS) classification, which is widely used at European scale, such as the MSFD implementation [11].

A multi-source benthic habitats chart covering the entire European territory of France EEZ was created during the Carpediem project [41]. About 150 datasets from 27 main data sources were compiled, harmonized and integrated into a single benthic habitats chart, using the EUNIS benthic habitats classification. This map is used as the main source of data for calculating the Ecosystem extent account since most of the other benthic habitats' maps produced for the last decades in France are focused on specific areas and specific ecosystem components.

EUNIS provides a hierarchical benthic habitats classification and typology, from bottom levels providing substrate type and ecological zones to top levels providing biological communities information. For

[1] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32008L0056

[2] https://www.milieumarinfrance.fr/Nos-rubriques/Cadre-reglementaire/Directive-Cadre-strategie-pour-le-milieu-marin

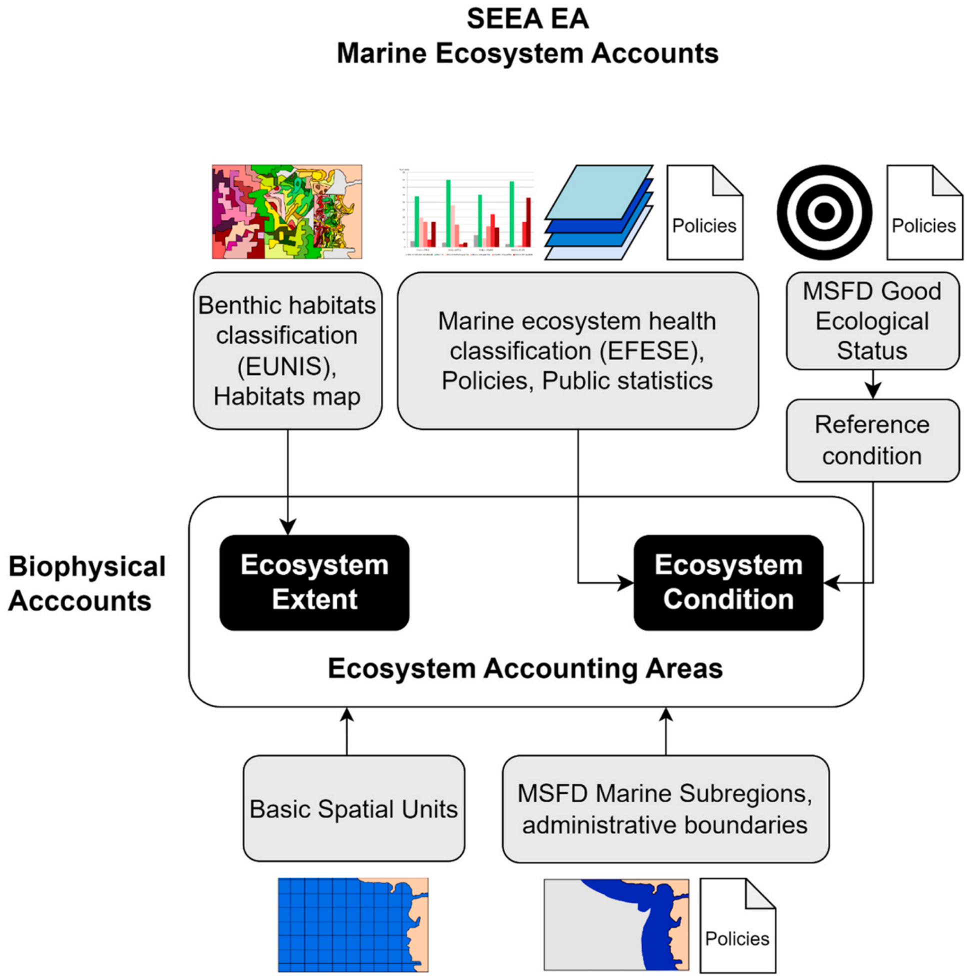


Fig. 1. Graphical abstract of the experimentation of marine ecosystem accounts in France. EUNIS: European Nature Information System; EFESE: French Evaluation of Ecosystems and Ecosystem Services; MSFD: Marine Strategy Framework Directive.

this study we use EUNIS levels 2 and 4 to get a balance between fine-scale habitats types useful for management and intermediate-level habitats types useful for national-scale reporting. In grid cells where more than one habitat is found, the grid cell is assigned only to the habitat that cover the highest surface area in that cell. Thus, only 86 out of the 120 habitats found in the European territory of France EEZ are included in the accounts.

2.3. Ecosystem condition account

The ecosystem condition account describes the quality of marine ecosystems. The condition account covers the dimensions required to monitor progress towards the good ecological status of marine waters and associated environmental targets as defined in the context of the MSFD and other dimensions of interest derived from complementary policy frameworks.

The SEEA EA is very flexible in the characteristics to be included in the ecosystem condition account [30], and even more so for the marine environment. This is the reason why it needs clarifications. In France, specific dimensions have been developed for the condition accounts, reflecting the recent works of the French Administration regarding the development of ecosystem accounts, the works of the French Ecological Accounting Chaire [7], and the conceptual frameworks developed in the French evaluation of ecosystems and ecosystem services [32]. These dimensions of conditions are: heritage, capacity, and functionality.

The heritage dimension encompasses the objective of conserving remarkable biodiversity, which is expressed in terms of the conservation status of habitat and species, but also, and more generally, in terms of no-net-loss on a set of dimensions. The second dimension is the capacity of healthy ecosystems to provide ecosystem goods and services. The objectives of maintaining the capacity of ecosystems to sustainably provide goods and services, which are expressed out of the objectives of other sectoral policies, and that draw the attention on other and complementary features of ecosystems and their functioning as compared to the previous points. There are some legal norms which are mentioned for many ecosystem services like the quality of water for bathing, the level of fisheries exploitation, etc. which are mentioned in the MSFD. They reflect political trade-offs on environmental targets. The third dimension is the functioning of ecosystems, which is a necessary condition to achieve the two previous sets of objectives. Although instrumental to them, it is necessary because of the complexity and the dynamic character of the systems considered; it can be expressed in terms of safe bounds or thresholds on a set of indicators within which the overall functioning of the system is guaranteed.

Indicators were selected to represent the three categories of conditions. One purpose of this experiment is to provide an experimental condition account as a proof of concept. We therefore also choose to focus on dimensions supported by some spatially explicit datasets. Publicly available projects and databases were scanned to identify possible sources of data, and how they relate to the MSFD descriptors (Table 1). In France, many institutions are responsible for the collection of datasets on the marine environment. All the datasets used here are publicly available. There are discrepancies in the data collection available to construct these indicators. Several indicators are using datasets

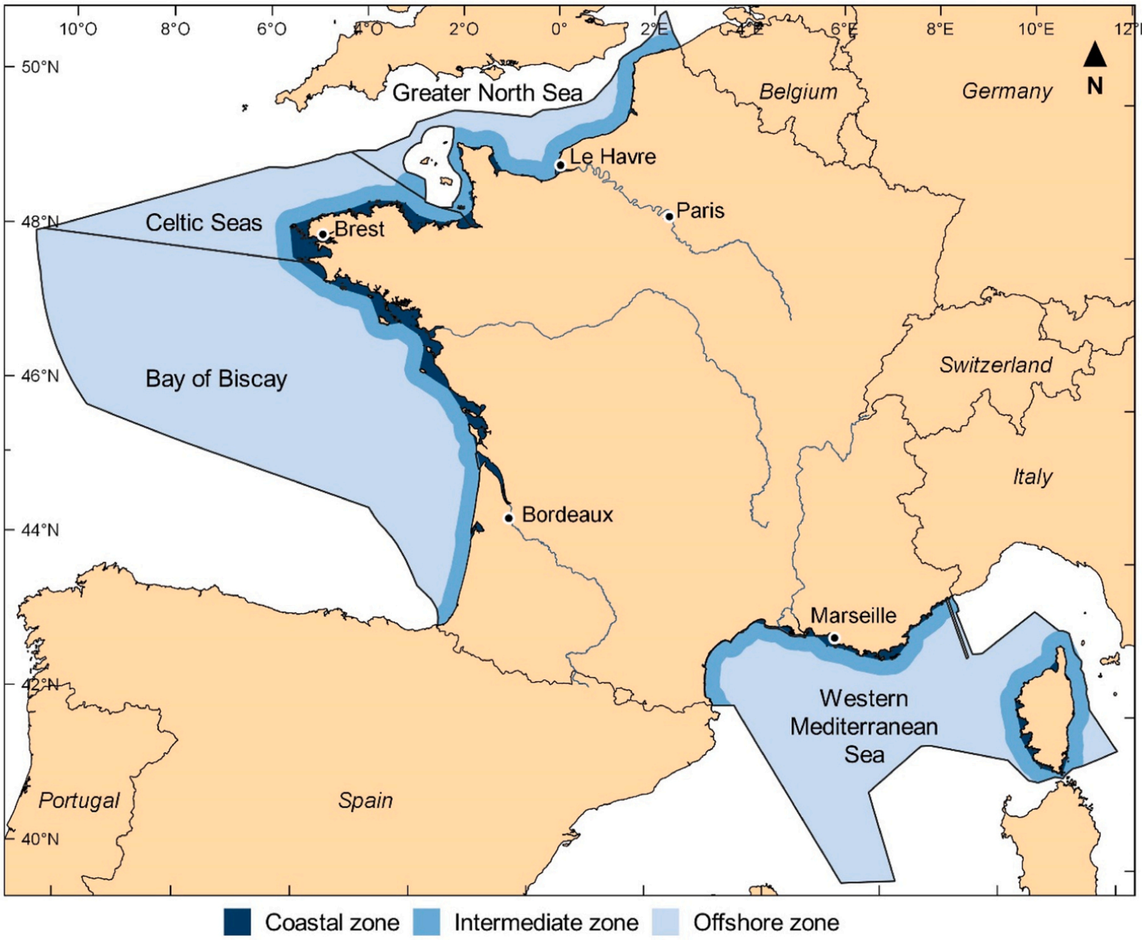


Fig. 2. Map of Marine ecosystem accounting area corresponding to the French water of the MSFD marine subregions and their three sub-zones from the coast to the offshore.

Table 1
Available datasets used to construct the extent and condition accounts.

Account	Indicator category	Indicators	MSFD tag[a]	Associated GES target	Years of data collection
Extent	Marine habitats	Habitats extent	D1C5	No	2010–2018 period (composite)
Condition (heritage dimension)	Birds (Annex E)	Number of species groups, abundance, density, IUCN classification	D1, D1C2, D1C4	No	2011–2012
Condition (heritage dimension)	Marine Mammals	Number of species groups, abundance, density, IUCN classification	D1, D1C2, D1C4	No	2011–2012
Condition (heritage dimension)	Marine mammal strandings	Number of strandings	D1C1	No	2014, 2015, 2016, 2017, 2018, 2019,2020
Condition (heritage dimension)	Protected areas	Protected areas extent	D1	Yes	2012 (SPAs), 2013 (NMP), 2016(SIC)
Condition (function dimension)	Floating waste	Density, weight	D10C1	No	2011–2012
Condition (function dimension)	Waste on the seabed	Density, weight	D10C1	No	2012, 2013, 2014, 2015, 2016
Condition (function dimension)	Risk of Cumulative Effects on Benthic Habitats	Physical risk on the marine benthic habitats	indirect	No	2005–2018
Condition (function dimension)	Eutrophication	Nitrate, phosphate, chlorophyll-a, turbidity, dioxygen	D5C1, D5C2, D5C4, D5C5	Yes	2010–2016
Condition (function dimension)	Non-indigenous species			No	2012–2017
Condition (capacity dimension)	Fish stock	Fishing mortality (F), biomass (SSB)	D3C1, D3C2	Yes	200 2006, 2012, 2018

[a] Under the format DXCY to refer to the Y^{th} criteria of the X^{th} descriptor of the MSFD.

aggregated over several years while others have time series available. The data reported to produce the experimental condition account comes from combined maps and/or datasets.

The indicators used here, while heavily based on MSFD reporting, are also associated with other environmental policies, including the Habitat directive, the Bird directive, OSPAR, and the Barcelona convention for indicators associated with the heritage dimension, the Common Fisheries Policy for indicators of capacity, and OSPAR and the Water Framework Directive for indicators related to functionality.

Regarding the heritage dimension, indicators include Protected habitats (surface areas) and abundance of marine species of interest (marine mammals, sharks and rays, seabirds, turtles, fish and cephalopods). For the capacity dimension, only one readily available spatialized indicator found is the maximum sustainable yield associated with the good ecological status of fish stocks. Five indicators describing physical chemical, and biological pressures on ecosystems could be used in the functionality dimension, including wastes, eutrophication, and physical pressures. The anthropogenic cumulative physical pressures on the marine environment is calculated based on 1) the extent of marine habitats, 2) the map of physical pressures that impact the marine environment, which include 21 human activities (e.g. dredging, concrete building of the coastline, trawling) 3) the degree of habitats sensitivity to the different physical pressures using matrices provided by the Natural History Museum [41].

Each dimension of ecosystem condition describes a present condition as well as a reference condition. Such reference levels could arise from existing environmental objectives, standards and limits [46]. The reference conditions are based on ecological diagnosis regarding cumulative risks for various components of marine ecosystems, as mentioned in the MSFD and called good ecological status. They are set for each dimension of the marine environment, called descriptors (see supplementary information), according to a methodology and criteria harmonized at the European level, then detailed in France in a specific decree.[3] Once this good ecological status is set, it can be compared with the scientific assessment of the ecological status of marine ecosystems to obtain information on their degradation.

Indeed, each descriptor of the MSFD has several specific evaluation criteria, allowing to say if it is considered as being in "good ecological status". These criteria must be able to be evaluated in a quantitative way. They are disaggregated spatially based on the accounting areas: by fish stock within each Marine Sub-Region for commercial species (fisheries), by water bodies for eutrophication. Whatever the reference unit, it is considered to be in good ecological status if all its criteria are (one-out all-out principle).

3. Results

3.1. Extent account

Using the spatially explicit information, synthetic account tables (Table 2) have been generated to report current extent for the 2010–2018 period, as only a composite map is available. Additions, reductions, and closing extent of each habitat types for each EAA and for each accounting period, are not possible due to the lack of datasets. The main habitats found in the French European EEZ are subtidal sediments (A5), and deep habitats (A6). Together, they account for more than 95 % of the extent of the French EEZ. This pattern holds across marine sub-regions, with some differences. Deep habitats are mostly found in offshore locations in the Atlantic and Mediterranean sub-regions. The marine extent spatial accounting for the EEZ, defined from the EUNIS Level 2 is detailed in Fig. 3.

3.2. Condition account

Ten indicator categories, each containing several spatially explicit indicators, could be used to feed the 3 dimensions of the ecosystem condition account, including four indicator categories for the heritage dimension, five indicator categories for the functionality dimension, and one indicator category for the capacity dimension (Table 1). Reference conditions were available for only three indicators. Several of these results are detailed below as they present particularities that influence the design of the condition account and that require specific treatment to fit in the SEEA EA framework.

In the functionality dimension, physical risk on the marine benthic habitats is mapped for all the areas that include anthropogenic cumulative pressures (Fig. 4). Then, the risks of cumulative effect make it possible to observe the high-risk areas according to habitats found in the extent account by the accumulation of pressures there. As an example, we show that while mearl is protected from physical harm, seagrass beds are at risk from this threat (Fig. 5).

Eutrophication, one of the most visible issues of marine functionality condition, is the indicator for which we have the more robust spatially-explicit information to produce maps and accounts. An aggregate indicator can be calculated for each marine sub-region (Fig. 6 Top) based on the spatially-explicit information (Fig. 6 Bottom). Explicit rules and conventions exist regarding how these results shall be aggregated to reflect overall good ecological status on this dimension.

For the capacity dimension of the condition account, only one indicator category could be mapped and constructed, related to fish stocks and their exploitation status. The indicator used is the headcount of stocks assessed and respecting Maximum Sustainable Yield. The data is not spatially explicit, but presented for stocks in the different ICES fishing zones that checker the EEZ. This indicator has no direct relationship with marine habitats as fish stocks are mostly found in the water column, except for benthic exploited species, and the water column is not a category of our extent account.

4. Discussion

4.1. Data availability and future needs for the biophysical accounts

In this project, the extent account is static, and no temporal evolution can be measured. The evolution of marine habitats is only analyzed with respect to their condition. Future projects should aim at producing updated extent maps for marine habitats, to be able to follow the rate of addition and reduction in different habitats. The low resolution EUNIS level 2 habitats may not be appropriate to measure the changes in surface areas of habitats over time. This is shown only for the proof of concept here, but accounting tables have also been produced at EUNIS level 4 and higher to describe habitats that have meanings for management. No reference levels are set for the extent account. Future research is needed to set targets and objectives on surface areas covered by habitats and species, potentially linked to ecological integrity and resilience or values linked to extinction risk of species and habitats [37].

The main issue is the lack of available spatial data on marine ecosystem condition. Most of the potential indicators on ecosystem functioning, including resilience indicators [50], nurseries and biologically important zones, as well as pollution and other pressures, are lacking. Biodiversity indicators are also lacking, as marine species are mobile and only abundances of birds and marine mammals are spatially explicit, with low temporal resolution. Most of the available datasets are not updated on a regular basis, and a majority only includes one temporal data point, which prevents us from constructing accounts with opening and closing values. This is problematic to create accounts that are bound in time, and for the update of the accounts in the future. These issues, in addition to high variability and low sampling, creates uncertainties that need to be addressed in order to produce useful accounts to inform management [35]. In addition, the overseas territories of

[3] Décret n° 2011–492 du 5 mai 2011 relatif au plan d'action pour le milieu marin

Table 2
Extent account for benthic habitats of the French EEZ and for each marine sub-region (in square kilometers and as percentages) for the 2010–2018 period.

	Greater North Sea		Celtic Seas		Bay of Biscay		Western Mediterranean Sea		French European EEZ	
Marine sub-regions	km²	%	km²	%	km²	%	km²	%	km²	%
A1 - Littoral rock and other hard substrata	49,43	0,17	24,43	0,05	72,80	0,04	0,42	0,00	147,08	0,04
A2 - Littoral sediment	195,56	0,65	158,55	0,35	188,50	0,10	7,83	0,01	550,44	0,14
A3 - Infralittoral rock and other hard substrata	253,38	0,85	599,04	1,32	730,02	0,38	99,39	0,08	1681,83	0,44
A4 - Circalittoral rock and other hard substrata	997,78	3,34	868,23	1,92	5099,93	2,68	119,81	0,10	7085,74	1,85
A5 - Sublittoral sediments	27379,61	91,68	39603,80	87,47	77176,95	40,61	17845,41	15,02	162005,76	42,19
A6 - Deep-sea bed			2995,87	6,62	105020,02	55,26	94894,66	79,89	202910,55	52,84
B1 - Coastal dunes and sandy shores	0,08	0,00	0,10	0,00	0,17	0,00	0,49	0,00	0,84	0,00
B2 - Coastal shingle	0,00	0,00			0,01	0,00	0,26	0,00	0,27	0,00
B3 - Rock cliffs, ledges and shores, including the supralittoral	0,27	0,00	1,02	0,00	0,47	0,00	0,01	0,00	1,77	0,00

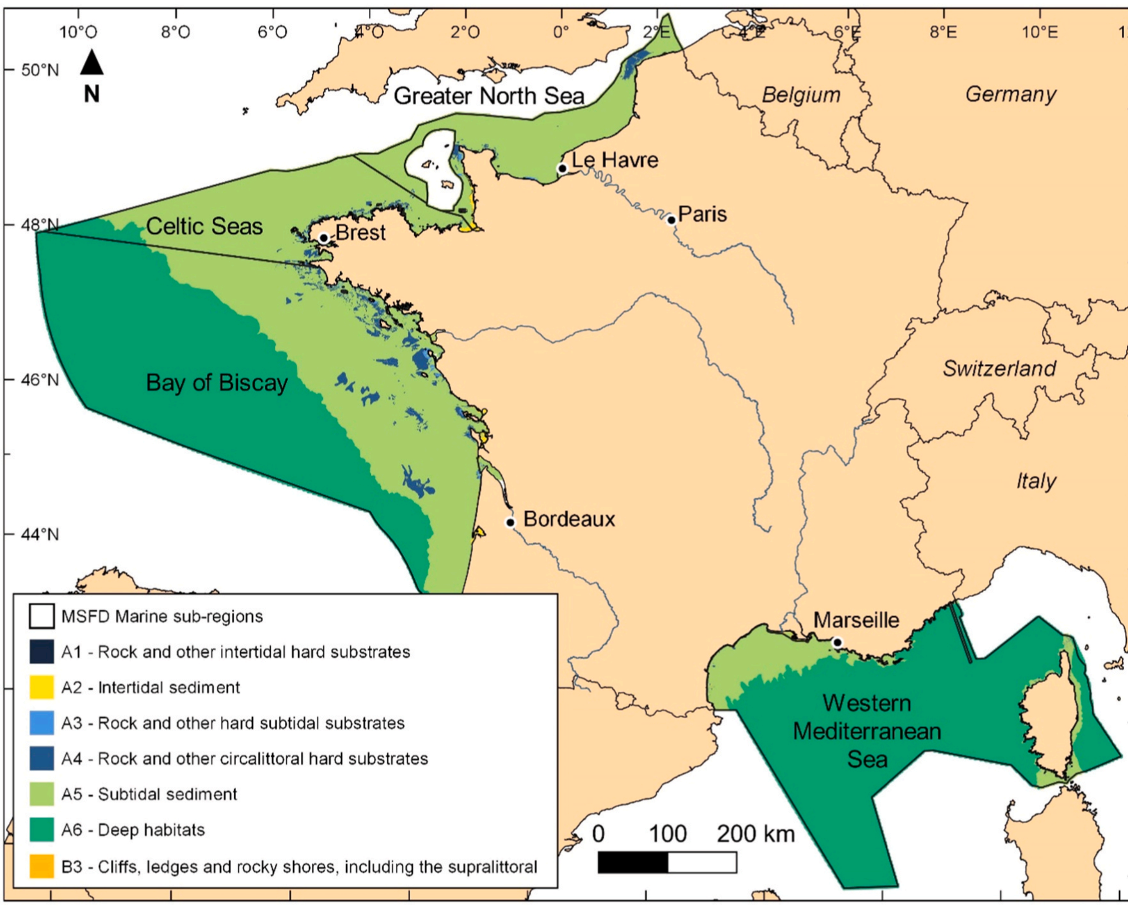


Fig. 3. Map of the extent of marine habitats in the French European EEZ, EUNIS level 2 habitats.

France could not be included due to a lack of data. Besides coral reefs that have been systematically mapped [2], no systematic information is available for other marine habitats. This is highly problematic as these habitats cover most of the French EEZ, and harbor some of the most diverse and valuable ecosystems, such as mangroves. Harmonization on data collection and delivery is therefore needed to produce meaningful integrated ecosystem accounts.

Reference conditions used here are closer to management needs and policy objectives, as opposed to historical reference conditions put forward in the SEEA EA [10]. Here, there is no desire to compare the current situation with a historical situation, where humans would have had no impact on the environment, because we often do not have the data to know in what state an ecosystem was before it was modified by human activities, and human activities have modified the environment for millennia [16]. Moreover, the SEEA EA lacks clarity on the link between pressures on ecosystems and reference conditions. The proposal experimented here moves beyond these issues, as pressures are integrated in the account, independently of the fluxes of ecosystem services. Several indicators used do not have defined reference conditions associated to them, particularly the integrity of the seafloor (Table 3). These issues highlight the disconnect that exists between different communities of practice, and between different scientific disciplines. New forums need to be put in place for interdisciplinary and practical research questions to emerge and to connect communities in order to produce integrated information that could be used to define target conditions.

4.2. *Management implications*

In the SEEA EA, a large variety of ecosystem condition indicators exist. This creates issues related to the selection of indicators and of data

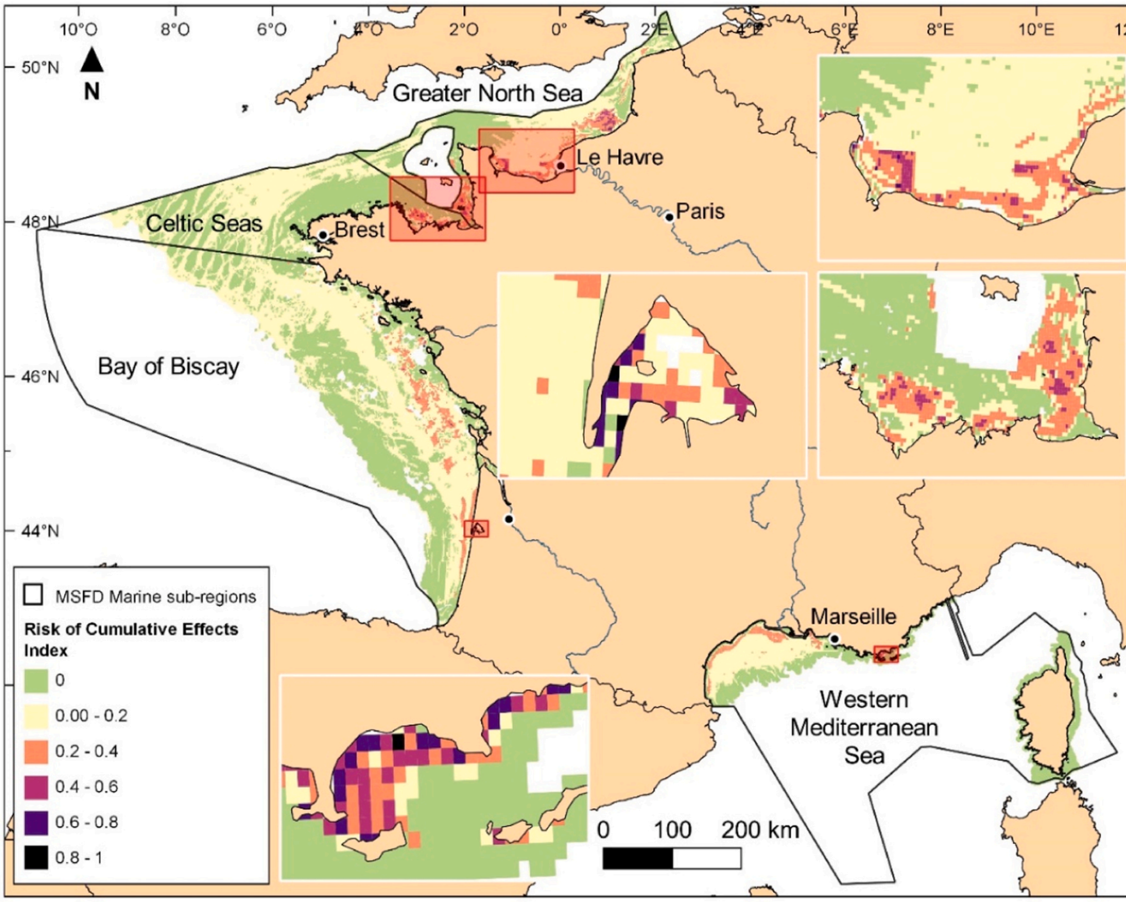


Fig. 4. Map of the risk of cumulative effects on the integrity of benthic habitats in the French European EEZ.

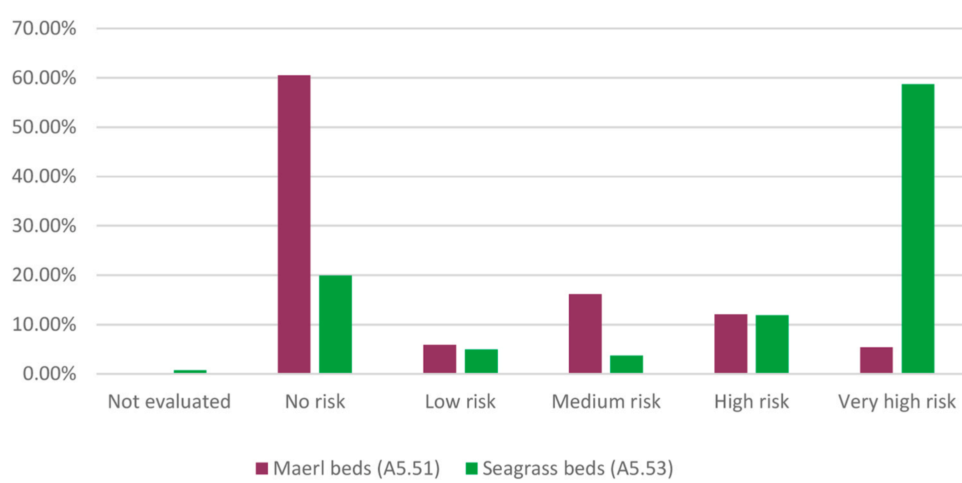
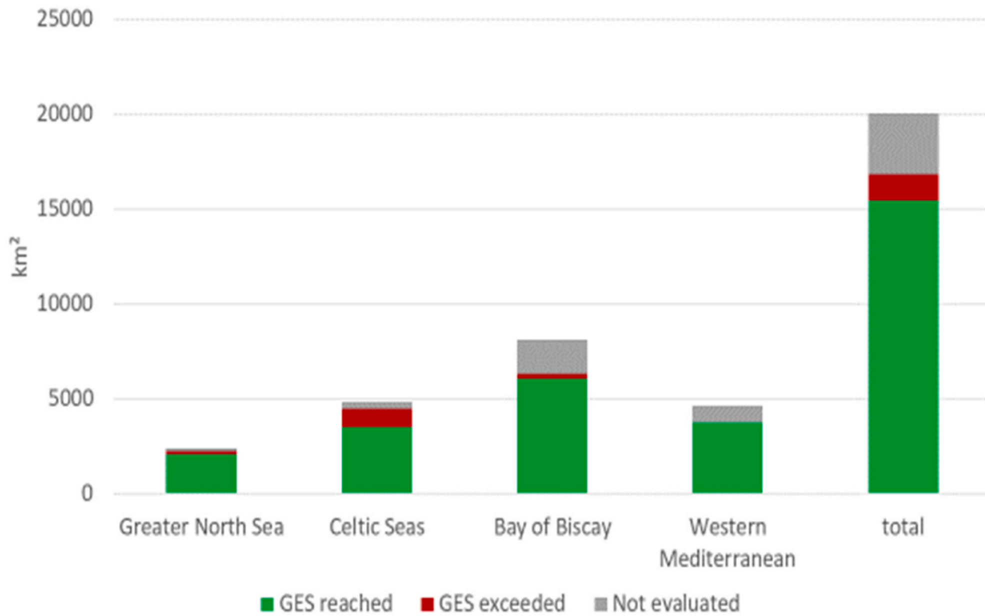


Fig. 5. Distribution of two habitats of community interest (EUNIS codes in parentheses) over categories of risk of cumulative effects on benthic habitats.

collection to fill these indicators. The approach developed here, using three dimensions of conditions based on the French Evaluation of Ecosystems and Ecosystem Services, according to the method proposed by Kervinio et al. [25], helped prioritize the selection of indicators and fit existing policy frameworks.

These accounts could steer conversations in public debates, notably on what are the investment needs at the national or European level to maintain and restore ecosystems, and who could and should pay for them [40,39]. Here, the discussion takes place between marine ecosystem and all other political issues when deciding on the State budget allocations. Within marine policy, the ecosystem approach underpinning the MSFD should, in principle, make it possible to move beyond species-based approaches and dialogue between national bodies and representatives of the main sectors of activity [3], such as fishing, renewable energies, offshore extraction and transport. It opens the door to broader governance bodies and stakeholder coordination [47]. However, 70 % of MFSD measures are still structured within other legislative frameworks [34,38]. This shows that the ecosystem approach is having difficulty gaining acceptance. In addition, the priority given to terrestrial ecosystems in the European task force on ecosystem accounts



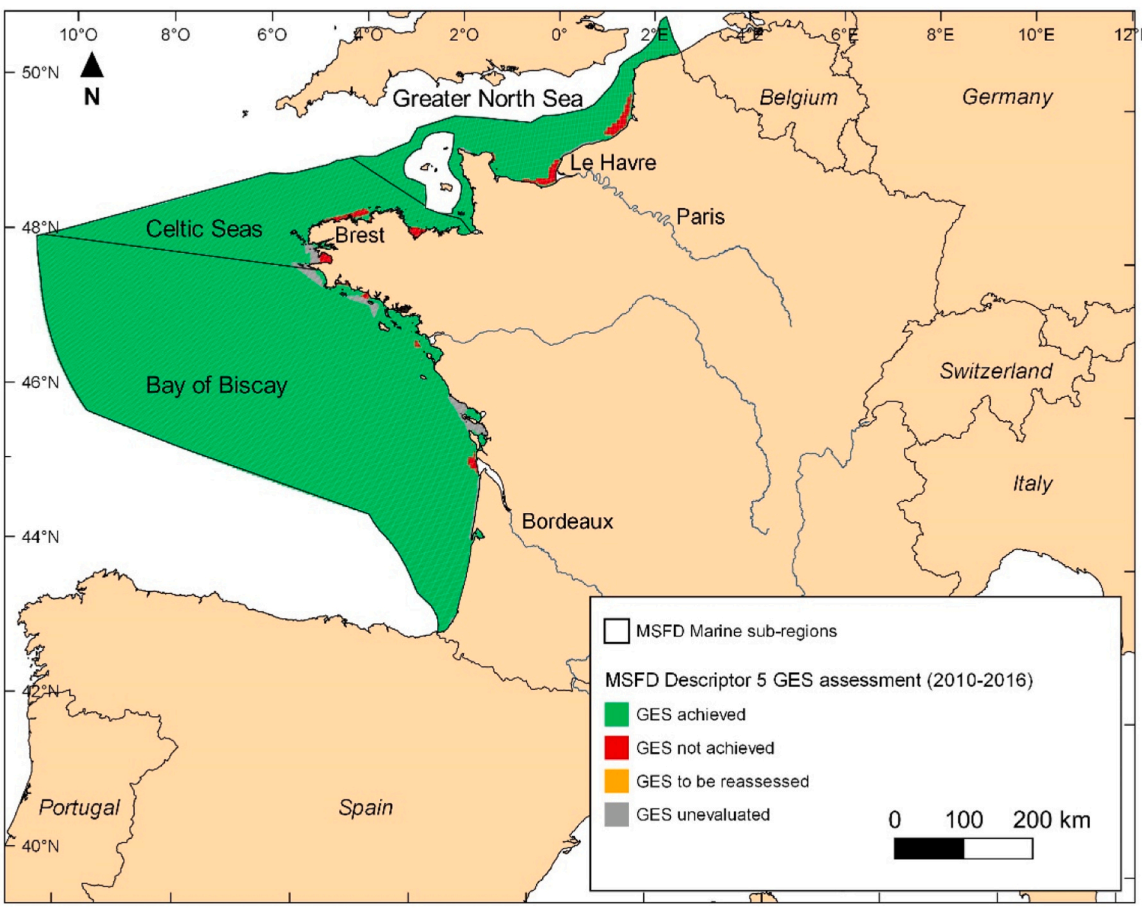


Fig. 6. Top. Aggregated assessment of the good ecological status of coastal water masses for eutrophication for the period 2010 – 2016 for each marine sub-region. Bottom. Map of eutrophication good ecological status in the Bay of Biscay, Celtic Seas, and Greater North Sea.

brings decision-makers to be less pro-active on marine ecosystems. In parallel, the accounting framework is not used in the MSFD yet. Thus, there is a need to further demonstrate the effects and usefulness of marine ecosystem accounts as a horizon for marine information systems.

To remobilize national accounting tools, which are those that already existed in sector-government relations (national or European), thus appears to be a good entry point for ecological issues. The language and tools are not fundamentally different, but ecological issues are added to them, with a pre-framing focused on environmental results. Discussions can therefore be redirected in this direction, provided that

Table 3
Condition indicators identified in the design phase of the study, and feasibility of their operationalization. Black: operational; orange: need refinement to be included in accounts; red: not available.

Dimension	Current condition	**Reference condition**	Link to policy documents
Heritage	-Abundance of species (marine mammals, birds) -Red list -State of protected areas	-Non-declining abundances and surfaces -Level of captures -No-net loss of biodiversity -Protection of species and habitats -number of strandings	MSFD, Habitat Directive, OSPAR, Barcelona, Natura2000
Capacity	-Fish stocks -Water quality	-MSY -Contaminants levels	MSFD, WFD
Functionality	-Trophic levels -Physical integrity -Eutrophication -Marine debris -Nurseries & feeding grounds -Resilience metrics	-Pollutants levels -Thresholds of chemical and biological variables -Trends in marine debris -Non-declining surfaces	MSFD, OSPAR, WFD

the new information system is strategically brought into the various discussion arenas so as not to provoke outright rejection.

In the Marine Strategic Planning, and in the national maritime spatial plans, Ehler [15], Paramana et al. [38], and Trouillet & Jay [43], describe problems of articulation and a certain asymmetry unfavorable to the MFSD are noted, with unfavorable ecological results. An interesting feature of the ecosystem accounts is that they allow the assembly of a large number of streams of information and to articulate different spatially-explicit policies. At the same time, this richness is organized and framed by accounting. As argued elsewhere [19], our piloting shows that ocean accounts can be an interesting tool to inform ocean & coastal management.

The creation of extent and condition accounts can enable powerful analysis on the health of different habitats, that was previously lacking. Using seagrass beds and maerl beds as a case study, we show how bringing together information on habitat mapping and on condition indicators can produce novel analysis. The production of marine ecosystems accounts sheds the light on the disconnect between the production of indicators of condition and how they affect different marine habitats differently.

4.3. Recommendations

Building marine ecosystem accounts is a arduous task that necessitates the collaboration of many actors, from many institutions and disciplines. The development of these accounts is not intended to be solely an academic effort because it has policy implications, neither solely a governmental endeavor, because it needs innovation and integration of complex information. This endeavor therefore requires continuous support from policy-makers and government, and inputs from scientists, which should be building on existing efforts related to advancing knowledge on ecosystems and ecosystem services. Such programs exist in many regions of the world, such as under the umbrella of the Global Ocean Accounting Partnership, and are recognized as policy targets, including the new Global Biodiversity Framework target on ecosystem accounting and the High-Level Panel for a Sustainable Ocean Economy.

Several lessons can be drowned from this exercise in order to help develop marine ecosystem accounts in other countries. The SEEA EA has set standards for the basic building blocks that are needed to construct such accounts, including definitions of ecosystem extent area, basic spatial units, and links between the different accounts. From there, the design of the accounts needs to be tailored to specific needs. In Europe, nomenclatures exist on marine habitats and marine ecosystem services, which facilitates this process, but international ones also exist, including IUCN GET for habitats and CICES for ecosystem services. For the condition account and the reference conditions, we have chosen indicators that build on existing policy demands, the Marine Strategy Framework Directive, that could be used for the other European countries.

CRediT authorship contribution statement

Clément Surun: Writing – review & editing, Writing – original draft. **Harold Levrel:** Writing – original draft, Supervision, Methodology, Funding acquisition, Conceptualization. **Rémi Mongruel:** Writing – original draft, Methodology. **Pierre Scemama:** Writing – original draft, Methodology. **Frédéric Quemerais-Amice:** Writing – original draft, Visualization, Data curation. **Adrien Comte:** Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2024.106532.

Data availability

Data will be made available on request.

References

[1] M. Alarcon Blazquez, R. van der Veeren, J. Gacutan, P. James, Compiling preliminary SEEA Ecosystem Accounts for the OSPAR regional sea: experimental findings and lessons learned, One Ecosyst. 8 (2023) e108030.
[2] S. Andréfouët, O. Bionaz, Lessons from a global remote sensing mapping project. A review of the impact of the Millennium Coral Reef Mapping Project for science and management, Sci. Total Environ. 776 (2021) 145987.
[3] G. Bouleau, C. Carter, A. Thomas, Des connaissances aux décisions: la mise en œuvre des directives européennes sur l'eau douce et marine, Participations 21 (2018) 37–64, https://doi.org/10.3917/parti.021.0037.
[4] B. Cavalletti, C. Di Fabio, E. Lagomarsino, P. Ramassa, Ecosystem accounting for marine protected areas: A proposed framework, Ecol. Econ. 173 (2020) 106623.
[5] W. Chen, K.A.M. Van Assche, S. Hynes, T. Bekkby, H.C. Christie, H. Gundersen, Ecosystem accounting's potential to support coastal and marine governance, Mar. Policy 112 (2020) 103758, https://doi.org/10.1016/j.marpol.2019.103758.
[6] A. Comte, S.C. Campagne, S. Lange, A.G. Bruzon, F. Santos, L. Hein, H. Levrel, Ecosystem accounting: past scientific developments and future challenges, Ecosyst. Serv. 58 (2022) 101486, https://doi.org/10.1016/j.ecoser.2022.101486.
[7] A. Comte, Y. Kervinio, H. Levrel, Ecosystem accounting in support of the transition to sustainable societies – the case for a parsimonious and inclusive measurement of ecosystem condition, CIRED Work. Pap. (2020) 2020–2076.
[8] M. Cordier, J.A.P. Agúndez, M. O'Connor, S. Rochette, W. Hecq, Quantification of interdependencies between economic systems and ecosystem services: An input–output model applied to the Seine estuary, Ecol. Econ. 70 (9) (2011) 1660–1671.
[9] G.H. Cummins, M.L. Navarro, K. Griffin, J. Partridge, T.J. Langlois, A global review of ocean ecosystem accounts and their data: Lessons learned and implications for marine policy, Mar. Policy 153 (2023) 105636.
[10] B. Czúcz, H. Keith, J. Maes, A. Driver, B. Jackson, E. Nicholson, C. Obst, Selection criteria for ecosystem condition indicators, Ecol. Indic. 133 (2021) 108376.
[11] Davies, C.E., Moss, D., & Hill, M.O. (2004). EUNIS habitat classification revised 2004. Report to: European environment agency-European topic centre on nature protection and biodiversity, 127-143..
[12] C.M. Duarte, S. Agusti, E. Barbier, G.L. Britten, J.C. Castilla, J.-P. Gattuso, R. W. Fulweiler, T.P. Hughes, N. Knowlton, C.E. Lovelock, H.K. Lotze, M. Predragovic, E. Poloczanska, C. Roberts, B. Worm, Rebuilding marine life, Nature 580 (7801) (2020) 39–51.
[13] A. Dvarskas, Experimental ecosystem accounting for coastal and marine areas: a pilot application of the SEEA-EEA in Long Island coastal bays, Mar. Policy 10 (2019) 141–151.
[14] B. Edens, J. Maes, L. Hein, C. Obst, J. Siikamaki, S. Schenau, A. Alfieri, Establishing the SEEA Ecosystem Accounting as a global standard, Ecosyst. Serv. 54 (2022) 101413.
[15] C.N. Ehler, Two decades of progress in Marine Spatial Planning, Mar. Policy 132 (2021) 104134, https://doi.org/10.1016/j.marpol.2020.104134.
[16] Erle C. Ellis, Nicolas Gauthier, Kees Klein Goldewijk, Rebecca Bliege Bird, Nicole Boivin, Sandra Díaz, Dorian Q. Fuller, et al., « People Have Shaped Most of Terrestrial Nature for at Least 12,000 Years », Proc. Natl. Acad. Sci. 118 (17) (2021) https://doi.org/10.1073/pnas.2023483118.
[17] E.P. Fenichel, E.T. Addicott, K.M. Grimsrud, G.M. Lange, I. Porras, B. Milligan, Modifying national accounts for sustainable ocean development, Nat. Sustain. 3 (11) (2020) 889–895.
[18] P.P. Franzese, E. Buonocore, L. Donnarumma, G.F. Russo, Natural capital accounting in marine protected areas: The case of the Islands of Ventotene and S. Stefano (Central Italy), Ecol. Model. 360 (2017) 290–299.
[19] J. Gacutan, I. Galparsoro, K. Pınarbaşı, A. Murillas, I.J. Adewumi, T. Praphotjanaporn, B.M. Milligan, Marine spatial planning and ocean accounting: Synergistic tools enhancing integration in ocean governance, Mar. Policy 136 (2022) 104936.
[20] Goap, Ocean Accounting for Sustainable Development, Detailed Technical Guidance for account compilers, data providers, and end-users (v0.9, global consultation), in: Bordt Michael, B. Milligan, T. Praphotjanaporn (Eds.), Ocean Accounting for Sustainable Development, Global Ocean Accounts Partnership, 2021.
[21] M. Greaker, K. Grimsrud, L. Lindholt, The potential resource rent from Norwegian fisheries, Mar. Policy 84 (2017) 156–166.
[22] L. Hein, K.J. Bagstad, C. Obst, B. Edens, S. Schenau, G. Castillo, A. Caparrós, Progress in natural capital accounting for ecosystems, Science 367 (6477) (2020) 514–515.
[23] T. Hooper, T. Börger, O. Langmead, O. Marcone, S.E. Rees, O. Rendon, M. Austen, Applying the natural capital approach to decision making for the marine environment, Ecosyst. Serv. 38 (2019) 100947.
[24] IPBES, 2019. Summary for policymakers of the global assessment report on biodiversity and ecosystem services. Zenodo. ⟨https://doi.org/10.5281/ZENODO.3553579⟩.
[25] Y. Kervinio, C. Surun, A. Comte, H. Levrel, Defining ecological liabilities and structuring ecosystem accounts to support the transition to sustainable societies, One Ecosyst. 8 (2023) e98100, https://doi.org/10.3897/oneeco.8.e98100.
[26] T.-Y. Lai, J. Salminen, J.-P. Jäppinen, S. Koljonen, L. Mononen, E. Nieminen, S. Oinonen, Bridging the gap between ecosystem service indicators and ecosystem accounting in Finland, Ecol. Model. 377 (2018) 51–65.
[27] S. Lange, C.S. Campagne, A. Comte, E. Bank, F. Santos-Martín, J. Maes, B. Burkhard, Progress on ecosystem accounting in Europe, Ecosyst. Serv. 57 (2022) 101473, https://doi.org/10.1016/j.ecoser.2022.101473.
[28] Harold Levrel, C.éline Jacob, Denis Bailly, Mahe Charles, Olivier Guyader, Schéhérazade Aoubid, Adeline Bas, et al., « The Maintenance Costs of Marine Natural Capital: A Case Study from the Initial Assessment of the Marine Strategy Framework Directive in France », Mar. Policy 49 (embre)) (2014) 37–47, https://doi.org/10.1016/j.marpol.2014.03.028.
[29] T.G. Loureiro, B. Milligan, J. Gacutan, I.J. Adewumi, K. Findlay, Ocean accounts as an approach to foster, monitor, and report progress towards sustainable development in a changing ocean–The Systems and Flows Model. Mar. Policy 154 (2023) 105668.
[30] Maes, Joachim; Driver, Amanda; Czúcz, Bálint; Keith, Heather; Jackson, Bethanna; Nicholson, Emily; et al. (2020). A review of ecosystem condition accounts: lessons learned and options for further development. Deakin University. Journal contribution. https://hdl.handle.net/10536/DRO/DU:30143217.
[31] J.C. Martin, R. Mongruel, H. Levrel, Integrating cultural ecosystem services in an ecosystem satellite account: a case study in the Gulf of Saint-Malo (France), Ecol. Econ. 143 (2018) 141–152.
[32] R. Mongruel, D. Bailly, et, C. Jacob, « Analyse Economique et Sociale - Rapport scientifique pour l'évaluation initiale 2018 au titre de la Directive-cadre Stratégie pour le milieu marin », Ifremer - Université de Bretagne Occidentale, Brest, France, 2019.
[33] L. Mulazzani, G. Malorgio, Blue growth and ecosystem services, Marine Policy 85 (2017) 17–24.
[34] A. Murillas-Maza, M.C. Uyarra, K.N. Papadopoulou, C.J. Smith, S. Gorjanc, K. Klancnik, T. Paramana, O. Chalkiadaki, M. Dassenakis, M. Pavicic, Programmes of measures of the marine strategy framework directive: Are they contributing to achieving good environmental status in the Mediterranean? Mar. Pollut. Bull. 161 (2020) 111715 https://doi.org/10.1016/j.marpolbul.2020.111715.
[35] M.L. Navarro, J. Monk, G.H. Cummins, T.J. Langlois, Embracing uncertainty in ocean accounts, Mar. Policy 162 (2024) 106040.
[36] C.C. O'Hara, M. Frazier, B.S. Halpern, At-risk marine biodiversity faces extensive, expanding, and intensifying human impacts, Science 372 (6537) (2021) 84–87.
[37] C.C. O'Hara, J.C. Villaseñor-Derbez, G.M. Ralph, B.S. Halpern, Mapping status and conservation of global at-risk marine biodiversity. Conserv. Lett. 12 (4) (2019) e12651.
[38] Th Paramana, M. Dassenakis, N. Bassan, C. Dallangelo, P. Campostrini, S. Raicevich, F. Ronchi, G. Giorgi, A. Murillas-Maza, M.C. Uyarra, N. Papadopoulou, C. Smith, K. Jarni, Š. Koren Bačovnik, K. Klančnik, M. Pavičić, S. Skejić, O. Vidjak, J.F. Cadiou, L. López-López, I. Alvarez, L. Giannoudi, N. Streftaris, P. Pagkou, Achieving coherence between the Marine Strategy Framework Directive and the Maritime Spatial Planning Directive, Mar. Policy 155 (2023) 105733, https://doi.org/10.1016/j.marpol.2023.105733.
[39] S. Perkiss, A. McIlgorm, R. Nichols, A.R. Lewis, K.K. Lal, M. Voyer, Can critical accounting perspectives contribute to the development of ocean accounting and ocean governance? Mar. Policy 136 (2022) 104901.
[40] S.-T. Puharinen, Achieving good marine environmental status in the EU – Implications of the marine strategy framework directive for member states and blue economic activities, Mar. Policy 155 (2023) 105712, https://doi.org/10.1016/j.marpol.2023.105712.
[41] F. Quemmerais-Amice, J. Barrere, M. La Rivière, G. Contin, D. Bailly, A Methodology and Tool for Mapping the Risk of Cumulative Effects on Benthic Habitats, Front. Mar. Sci. 7 (2020) 569205, https://doi.org/10.3389/fmars.2020.569205.
[42] Schenau, S., Rietveld, H., & Bosch D. (2019). Natural capital accounts for the North Sea: The physical SEEA EEA accounts- Final report.
[43] B. Trouillet, S. Jay, The complex relationships between marine protected areas and marine spatial planning: Towards an analytical framework, Mar. Policy 127 (2021) 104441, https://doi.org/10.1016/j.marpol.2021.104441.
[44] United Nations, European Commission, Food and Agriculture Organisation of the United Nations, Organisation for Economic Co(operation and Development, World Bank, et. 2021. « System of Environmental-Economic Accounting - Ecosystem Accounting (SEEA-EA). White Cover Publication, Pre-Edited Text Subject to Official Editing ». New York: United Nations. ⟨https://seea.un.org/ecosystem-accounting⟩.
[45] United Nations, Food and Agriculture Organisation of the United Nations, Organisation for Economic Co(operation and Development, European Commission, World Bank, et. 2014. « System of Environmental-Economic Accounting 2012 - Experimental Ecosystem Accounting ». New York, USA: United Nations. ⟨https://seea.un.org/sites/seea.un.org/files/seea_eea_final_en_1.pdf⟩.
[46] A. Usubiaga-Liano, P. Ekins, Time for science-based national targets for environmental sustainability: an assessment of existing metrics and the ESGAP framework, Front. Environ. Sci. 9 (2021) 761377.
[47] J. van Tatenhove, J. Raakjaer, J. van Leeuwen, L. van Hoof, Regional cooperation for European seas: Governance models in support of the implementation of the

MSFD, Mar. Policy, Mar. Gov. Eur. Seas. 50 (2014) 364–372, https://doi.org/10.1016/j.marpol.2014.02.020.
[48] A. Vanoli, « Reflections on Environmental Accounting Issues », Rev. Income Wealth 41 (2) (1995) 113–137, https://doi.org/10.1111/j.1475-4991.1995.tb00104.x.
[49] P. Vassallo, C. Paoli, E. Buonocore, P.P. Franzese, G.F. Russo, P. Povero, Assessing the value of natural capital in marine protected areas: A biophysical and trophodynamic environmental accounting model, Ecol. Model. 355 (2017) 12–17.
[50] B.H. Walker, L. Pearson, A resilience perspective of the SEEA, Ecol. Econ. 61 (4) (2007) 708–715.
[51] T. Wang, G.S. He, Q.L. Zhou, J.Z. Gao, L.J. Deng, Designing a framework for marine ecosystem assets accounting, Ocean Coast. Manag. 163 (2018) 92–100.
[52] Jean-Louis Weber, « Écologie et statistique: les comptes du patrimoine naturel », J. De. la Soci. été Stat. De. Paris, no 128 (1987) 137–162.