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Opinion

Challenges in Compiling Marine Ecosystem Condition Accounts

Miguel Inácio * and Paulo Pereira

Environmental Management Research Laboratory, Mykolas Romeris University, LT-08303 Vilnius, Lithuania
* Correspondence: miguel.inacio@mruni.eu

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Abstract: The importance of coastal and marine ecosystems has been extensively explored due to their capacity to supply ecosystem services and thus contribute to human wellbeing. Nevertheless, these are some of the most anthropogenically impacted ecosystems globally. It is necessary to fully account for the contribution of nature and integrate this information into countries' socio-economic dynamics. The System of Environmental-Economic Accounting—Ecosystem Accounting (SEEA-EA) was adopted by the United Nations in 2021 as a statistical standard to integrate the contribution of ecosystems and their services into the national accounts system. Since its adoption, the SEEA-EA has been increasingly implemented worldwide. However, its application in the coastal and marine environment is still limited. This is especially true when assessing ecosystem condition. As a relatively new topic within the SEEA-EA, there are many uncertainties within the community on how to assess marine ecosystem condition. The lack of standard guidelines makes it more difficult. This opinion article explored the three main challenges that hinder the operationalisation of assessing ecosystem condition. Specifically, the challenges of defining meaningful ecosystem condition variables in terms of representativeness and data availability. Then, the article explored the difficulties in rescaling condition variables into indicators by correctly defining appropriate reference conditions. Finally, it examined the challenges of calculating the condition index unbiasedly using indicator weights. Overall, there are still many critical challenges that need to be addressed. For this, it is essential to define clear guidelines and best practices for the community to accurately and meaningfully assess the condition of coastal and marine ecosystems.

Keywords: SEEA-EA; coastal; ocean accounting; ecosystem accounting; sea

1. Background

Marine and coastal ecosystems (hereafter referred to as marine ecosystems) hold significant importance in socio-ecological systems worldwide [1]. These ecosystems host a diverse range of habitats that support an enormous variety of species, from shallow waters to deep-sea systems. Moreover, marine ecosystems play a crucial role in global processes, such as climate regulation and carbon sequestration, through their ecological processes and functions [2]. These processes and functions are essential in supporting socio-economic systems through the provision of ecosystem services (ES) [3]. Marine ecosystems are among the most impacted globally [4], which consequently decreases their capacity to provide ES sustainably [5], thereby reducing their contribution to wellbeing. Restoring ecosystems and their capacity to provide ES sustainably has been a focus of several policies and directives worldwide, such as the European Marine Strategy Framework Directive (MSFD) https://eur-lex.europa.eu/eli/dir/2008/56/oj/eng (accessed on 1 June 2025) and Water Framework Directives (WFD) https://eur-lex.europa.eu/eli/dir/2000/60/oj/eng (accessed on 1 June 2025), the European Union Biodiversity

Strategy for 2030 https://environment.ec.europa.eu/strategy/biodiversity-strategy-2030_en (accessed on 12 July 2025), European Nature Restoration Law https://environment.ec.europa.eu/topics/nature-and-biodiversity/nature-restoration-regulation_en (accessed on 9 September 2025), the European Ocean Pact https://oceans-and-fisheries.ec.europa.eu/european-ocean-pact_en (accessed on 5 June 2025), the Kunming-Montreal Global Biodiversity Framework https://www.cbd.int/gbf (accessed on 12 July 2025), United Nations Decade on Ecosystem Restoration https://www.decadeonrestoration.org (accessed on 1 June 2025), and the United Nations Sustainable Development Agenda—especially Goal 14-Life Below Water https://sdgs.un.org/goals (accessed on July 2025). Also, several protected areas have been established globally with the intent of preserving and restoring marine ecosystems [6]. Despite all efforts, these ecosystems still experience significant degradation [4,6]. Integrating the value of ecosystems into decision-making by incorporating them into national socio-economic systems is seen as a promising solution [7]. In this sense, the United Nations has been developing a standard system of ecosystem accounting over the years, to be adopted globally, where both the ecological and economic values of ecosystems are integrated into countries' national accounts [8].

The System of Environmental-Economic Accounting-Ecosystem Accounting (SEEA-EA) was adopted by the United Nations in 2021, following its experimental stage. The SEEA-EA was developed to constitute "an integrated and comprehensive statistical framework for organising data about habitats and landscapes, measuring the ecosystem services, tracking changes in ecosystem assets, and linking this information to economic and other human activity" [9]. Since the adoption of the SEEA-EA (including its experimental phase), several initiatives and efforts, both institutional and scientific, have compiled information on ecosystem accounts globally https://seea.un.org/content/global-assessment-environmental-economic-accounting (accessed on 1 June 2025). Several review works (e.g., [10,11] collect information on the implementation of SEEA-EA, while several initiatives (e.g., Natural Capital Accounting and Valuation of Ecosystem Services-NCAVES https://seea.un.org/home/Natural-Capital-Accounting-Project (accessed on 1 June 2025; Wealth Accounting and the Valuation of Ecosystem Services-WAVES https://www.wavespartnership.org(accessed on 1 June 2025) collate country reports on SEEA-EA. However, despite the ongoing and growing efforts in ecosystem accounting, its implementation in marine ecosystems, also sometimes referred to as Ocean Accounting, is still in its early stages [12]. Several authors (e.g., [10–13]) highlight several reasons for the slow implementation of SEEA-EA for marine ecosystems, primarily related to data availability, both temporal and spatial, as well as the lack of clear guidelines. Nevertheless, several studies have been conducted on the implementation of SEEA-EA in marine ecosystems. For example, Alarcón Blázquez et al. [14] compiled ecosystem accounts for the OSPAR areas based on existing information from contracting parties. The authors successfully assessed all ecosystem accounts included in the SEEA-EA. Another example is the study by Comte et al. [15], in which the authors assessed the extent and condition accounts for the marine exclusive economic zone of France. The authors compiled information from existing data sources, including research and policy monitoring efforts. Dvarskas [16] implemented the SEEA-EA experimental phase (SEEA-EEA) for the Long Island (USA) coastal bays, assessing the extent, condition, and physical ecosystem services accounts. Chen et al. [17] discussed the ecosystem accounting in the context of coastal zone management and exemplified the compilation of monetary ecosystem services accounts in the Oslofjord (Norway) based on available information from literature. Ha et al. [18] applied the SEEA-EA to the Derwent Estuary in Tasmania (Australia), compiling information regarding ecosystem extent, condition and ecosystem services (physical and monetary) accounts. These are just some examples of scientific efforts to implement the SEEA-EA in coastal and marine areas. Hence, there are several more examples in grey literature (e.g., country reports), such as the Ecosystem Accounting of Port Phillip Bay in Australia, compiled by the State Government of Victoria, which provides information on ecosystem extent, condition, and ecosystem services https://www.environment.vic.gov.au (accessed on 3 September 2025).

Efforts to implement the SEEA-EA on marine ecosystems have predominantly focused on collating information on ecosystem extent and services (both physical and monetary), as highlighted by Cummins et al. [12]. These two aspects of marine ecosystems have been subject to extensive research, with a comprehensive body of scientific and grey literature supporting the compilation of these two accounts within SEEA-EA [12]. For example, ecosystem extent information can be derived from habitat mapping studies, as done by Lu & Wang [19], which utilise remote sensing imagery to map mangrove areas at a large scale. Kokkoris et al. [20] highlight the importance of remote sensing methodologies in the context of ecosystem accounting, including extent accounts. Moreover, extent can also be assessed from available databases such as the European Marine Observation and Data Network (EMODnet) Seabed Habitats https://emodnet.ec.europa.eu/en/seabed-habitats (accessed on 3 September 2025) information, as well as following guidelines and technical reports related to habitat mapping in coastal and marine areas (e.g., Report on Marine habitat mapping by the European Marine Board [21]). Ecosystem services accounts can be compiled based on the extensive literature on the topic. Several studies provide methodological frameworks for assessing ecosystem services in both physical and monetary terms. For example, Adamo et al. [22] provide a comprehensive overview of the valuation of marine ecosystem services in European seas. Inácio et al. [23] map and assess marine ecosystem services in the Baltic Sea, based on existing information from monitoring efforts (e.g., HELCOM). Additionally, there are multiple guidelines on mapping, assessing, and valuing marine ecosystem services (e.g., the report "Guide to the Economic Valuation of Marine and Coastal Ecosystem Services in Central America and the Dominican Republic" [24]). Assessing ecosystem condition is one of the newer and less explored aspects in the context of ecosystem accounting. The difficulty of assessing ecosystem condition is transversal to all ecosystem types, but is even more pronounced in marine ecosystems [25]. However, assessing ecosystem condition is crucial for implementing the SEEA-EA successfully, particularly regarding ES [26]. The studies that compile condition accounts for marine ecosystems highlight the difficulties and challenges for their operationalisation. For example, Comte et al. [15] highlight challenges related to spatio-temporal data availability and uncertainty of available data. Dvarkas [16] highlights the challenges associated with selecting proper condition indicators. This opinion article analyses the difficulties reported in the literature, focusing on what we consider to be the three most significant current scientific and technical challenges to assessing the condition of marine ecosystems in the context of SEEA-EA. It also provides suggestions on how to address these challenges.

2. Assessing Ecosystem Condition

In SEEA-EA, ecosystem condition is defined as "the quality of an ecosystem measured in terms of its abiotic and biotic characteristics. Condition is assessed with respect to an ecosystem's composition, structure and function, which, in turn, underpin the ecosystem integrity of the ecosystem, and support its capacity to supply ecosystem services on an ongoing basis. Measures of ecosystem condition may reflect multiple values and may be undertaken across a range of temporal and spatial scales." [9]. Different fields of marine sciences can provide direct knowledge outputs to assess ecosystem condition, for example, physical and chemical oceanography, marine biology and ecology. The concept of "condition" itself is not new within marine sciences, as in the past decades several metrics were developed to assess the status of marine ecosystems, like the Ocean Health Index [27], the European MSFD and WFD directives' good ecological/environmental statuses [28], the Benthic Quality index [29] or Marine Biotic Index [30]. The drawback is that each of these metrics assesses "condition" based on different data and therefore is not directly comparable. Thus, there is no systematic way of assessing ecosystem condition globally. Adopting and implementing the SEEA-EA framework seems promising. However, it is not a trivial task, and it is necessary to be cautious not to fall into the same pitfalls as other frameworks (e.g., incomparability). Despite the clear guidelines and steps to implement SEEA-EA, there is a lack of specific technical guidance for marine ecosystems, as highlighted by Cummins et al. [12]. This is important due to the complexity of ecological processes covering multiple and distinct habitats. So far, very few guidelines dedicated to marine ecosystems have been produced. One example is the technical guidelines by Global Ocean Accounts Partnership (GOAP) https://www.oceanaccounts.org (accessed on 3 September 2025) [31]. Another example is the Marine Natural Capital Assessment Guidance developed by Natural England [32]. At the European level, the "EU-wide methodology to map and assess ecosystem condition" report [33] develops guidelines that include marine ecosystems.

Assessing ecosystem condition follows different steps: (1) defining variables; (2) defining reference values/conditions; (3) calculating an overall index; and (4) compiling accounting tables. This is not an easy task [25], and within each of these steps, various challenges need to be resolved to operationalise the assessment of ecosystem condition for marine ecosystems.

2.1. Challenge 1: Defining Relevant Ecosystem Condition Variables

According to the framework of SEEA-EA, the condition is assessed using the Ecosystem Condition Typology (ECT), which comprises Abiotic, Biotic, and Landscape ecosystem characteristics [9]. Within these characteristics, there are further subdivisions into ECT classes (e.g., Abiotic—Physical state; Chemical state) (see [9]).

The first step is to define condition variables for each ECT class. However, at this stage, there are already some challenges, since it is not clear how many and which variables to choose. In the SEEA-EA guidelines, there is no defined number of variables per class; instead, there is a recommendation that at least one and possibly one to three variables should be defined. In the scientific literature, the number of variables for each ECT class varies across the few studies assessing marine ecosystem condition. For example, some studies use only one variable, as in the case of the study by Chen et al. [17], in which the condition was assessed based on the biomass of kelp forests. Others use multiple variables. For example, the study by Comte et al. [15] assessed the condition based on

10 variables, which included information on the number of bird species, the extent of protected areas, density and weight of waste in the seabed, and non-indigenous species, among other variables. Virtanen et al. [34] assessed ecosystem condition based on ecological status, biological quality, and physico-chemical quality, using WFD and MSFD information. Dvarskas [16] assessed the condition based on five variables, including dissolved oxygen, temperature, dissolved nitrogen, and Secchi depth, among others. The GOAP guidelines [31] suggest eight variables in total, while the EU-wide methodology report lists 23 variables. In synthesis, there is no clear guidance regarding the number of variables for each ECT class, with several studies not even following the typology suggested in the SEEA-EA. We emphasise the importance of considering at least one additional variable per ECT class. In this way, the plural characteristics within each of the condition classes are represented.

Already at the first step of compiling ecosystem condition accounts, there are no guidelines for selecting the variables, best practices or a master list to follow, unless officially defined by the countries For example, Germany has a defined list of condition accounts, both for the Baltic Sea and North Sea (https://www.destatis.de/EN/Themes/Society-Environment/Environment/Environmental-Economic-Accounting/ecosystem-account/Tables/B02-marinewaters.html). When a list is not available, the variable choice is based on (1) expert knowledge, (2) an available list of variables, or (3) a literature review. Choosing variables based on expert knowledge requires a multidisciplinary group of scientists who can make the process straightforward. Alternatively, variables are defined based on the lists provided in the technical guidelines, such as the SEEA-EA [9], GOAP [31], and the European Commission [28]. In this case, it is necessary to check if data for the selected variables is available for at least two different periods. This is challenging and time-consuming, as data availability and accuracy in coastal and marine ecosystems remain significant issues [12,35]. Defining ECT variables and conducting a scientific literature survey can be advantageous, as the rationale for data collection can be explained. However, some works based their condition assessment on specific data, which may not be relevant or available for other marine areas.

We consider the best option for identifying the condition variables to be by combining the three options described. However, regardless of the option chosen, it is essential never to forget to consider all the guidelines defined in the SEEA-EA and understand what the condition variables should be and represent (see [36]).

Another important aspect is the use of variables that do not belong to the ECT classes, for example, pressure indicators like chemical or physical pollution. In coastal and marine environments, the scarcity of spatial-temporal data is a significant problem. In situations where no data is available to compile condition variables based on the ECT, some studies employ pressure indicators (e.g., density of floating waste—[15]), with the rationale that higher pressure on the ecosystems would result in a lower condition. There is a comprehensive amount of global data on marine pressures (e.g., [37]) from different monitoring efforts within multiple environmental policies and directives. Since the use of alternative variables beyond the ECT is comprised in the guidelines of the SEEA-EA [9], pressure indicators can be a viable alternative to assess marine ecosystem condition when other data is not available.

Future steps to address this challenge should focus on developing a flexible ECT framework that includes core variables standard to all marine areas and alternative variables specific to each ecosystem type (e.g., coastal lagoons, estuaries). The core variables should be selected from global initiatives (e.g., SEEA-EA, GOAP, EU) to ensure standardisation and comparability across marine regions. All efforts into defining condition variables should be collected and shared in a global database to facilitate knowledge sharing and capacity building for both researchers and practitioners.

2.2. Challenge 2: Properly Defining Reference Conditions/Levels

The second step in assessing ecosystem condition is to rescale the variables (0-1) based on reference levels [9]. In the SEEA-EA, reference levels are understood as "*the value of a variable at the reference condition, against which it is meaningful to compare past, present or future measured values of the variable*" and reference conditions as *"the condition against which past, present and future ecosystem condition is compared in order to measure relative change over time"*. This defines a set of conditions (spatial or temporal), where coastal and marine ecosystems are expected to be in good ecological conditions. This is a controversial issue in all ecosystems, as some studies (e.g., [38]) suggest that finding reference values in ecosystems heavily impacted by humans is challenging. It is practically impossible to find reference conditions in coastal and marine ecosystems due to natural conditions (e.g., regime shifts) [39].

Defining reference levels can be done using: (1) a reference area; (2) a reference period; and (3) good ecological thresholds for each variable. In the first approach, an area with reduced disturbance can be selected [40]. Protected areas restrict human activities and are used as reference areas. However, they do not guarantee protection against all pressures since protected areas are open systems and pollution from outer areas can affect them [41,42]. For example, in the Baltic Sea, a network of protected areas exists. However, according to the Helsinki Commission (HELCOM) status report, several indicators fail to achieve good ecological status [43]. If a protected area in the Baltic Sea is designated as a reference area, it would not be considered the best approach because it is highly affected by the surrounding pressures. The second approach involves defining a period during which anthropogenic impacts were minimal [9,44]. It can range from several decades to centuries. However, in coastal, marine, and other ecosystems, this is extremely challenging due to a lack of data [45,46]. Through modelling, it is possible to estimate the spatio-temporal concentration levels of several variables, e.g., oxygen concentration/deficiency (e.g., [47]). Nevertheless, this would involve high uncertainty, and the accuracy could be reduced. The choice of a reference period may be politically driven, as it is often referenced in laws, policies, and directives. However, it is necessary to carefully consider whether the period is valid for all condition variables and if there is enough data for this assessment to be credible. The third option is to define (reasonable) ecological thresholds for each variable. This can be done based on literature, expert knowledge or environmental policies thresholds. Each variable has a threshold that defines good or bad conditions. All values below that threshold are considered to represent a worse ecosystem condition, and those above represent a good ecosystem condition. Although this approach is common and valid, it is essential to have a multidisciplinary team with a wide knowledge of different scientific fields. Unfortunately, this is not always the case, raising questions regarding the accuracy. Alternatively, thresholds can be derived based on the literature. Although this is valid, these thresholds are often based on local studies conducted in specific environmental settings (e.g., soil type, topography, climate zone). Extrapolating these values to other areas is erroneous because ecosystem processes can differ significantly. This can lead to important bias in the final results. Moreover, it is very challenging to find information in the literature for all variables. Finally, rescaling variables using thresholds based on established laws, policies, and directives can also be misleading because these thresholds are specific to environmental settings.

The objective of SEEA-EA is to integrate ecosystem information into national accounts. Thus, working with institutionally agreed and enforced thresholds can be positive. However, these thresholds may not cover all the condition variables. Rescaling variables will likely be done based on a combination of the options mentioned above. However, there is still a need for guidance on how to conduct these steps correctly.

Future steps to address this challenge should focus on establishing a global, open-access database of reference levels and thresholds for specific regions, ecosystem types, and condition variables, including information on how these reference levels and thresholds were defined. Furthermore, to promote the use of a complementary approach that combines reference areas, historical baselines, or ecological thresholds, based on scientifically robust methodologies. Finally, future efforts must include an uncertainty or confidence assessment for each variable reference level.

2.3. Challenge 3: Defining the Weights for an Ecosystem Condition Index

After rescaling, the variables are referred to as indicators. The indicators are unitless (0–1), allowing for their aggregation in an ecosystem condition index [9]. Although this is not obligatory in the SEEA-EA guidelines, it provides general information about the ecosystem's ecological status, which can then be related to the supply of ES [48].

According to the SEEA-EA guidelines, the overall condition index can be defined using weights for the different variables. However, it is unclear how to do this in a standardised way and determine which variables should have the most impact. Several studies in the literature have assigned weights where all indicators are given equal importance (e.g., [18]). Others applied weights (e.g., [49]). It is challenging to decide which way to follow, as there is no "correct" approach, unless specifically defined by each country compiling the SEEA-EA accounts or if there is scientifically robust knowledge about the impact of the different indicators. Additionally, the guidelines are limited in their rationale for using different weights. Two of the most used approaches rely on expert knowledge or information from the literature. In any case, it will be a biased decision, and the weights assigned to different indicators depend primarily on the group of experts involved or the interpretation of the literature results, which can be context-specific. Defining no weights is a safe approach. However, this approach also carries uncertainties, as it considers that chemical and physical ecosystem characteristics are as important as functional and structural characteristics —a notion that has been challenged by several scholars (e.g., [50]). Overall, choosing to weight indicators can lead to a biased assessment.

Future steps to address this challenge include a scenario-like modelling approach to test the impact of different weights on the final ecosystem condition index. Nevertheless, the choice of the weights should not be arbitrary but justified (e.g., weights derived based on scientific knowledge or policies).

3. Final Remarks

This article explored what the authors consider to be the three most important challenges in assessing ecosystem condition when compiling information to implement the SEEA-EA in coastal and marine environments. There are no clear guidelines to define the number and type of condition variables. However, it is essential to consider more than one variable to obtain a more accurate assessment of each ECT class. The variable choice needs to be based on ecologically grounded information, spatially and temporally representative of the studied area and the ecosystem types studied. Ongoing efforts to compile lists of variables and link them with ECT (e.g., the GOAP guidelines) are crucial for supporting the selection of variables and reducing the time required for data searching and processing. Although there are several ways to identify reference levels, it is essential to understand whether they should exist, as it is highly unlikely that pristine conditions are ever achieved. Furthermore, defining reference areas and periods may not be possible for all the variables. Finally, defining weights for calculating the overall ecosystem condition index is also challenging. Without proper guidelines, likely, each effort (at least scientific) to implement the SEEA-EA will be based on an arbitrary choice between assigning weights to ECT indicators, classes, or groups, or not assigning weights at all.

Overall, there are still many challenges in accurately assessing the condition of coastal and marine ecosystems. This is essential to be addressed, since within SEEA-EA, assessing ecosystem condition is linked with ES supply. If not performed correctly, this relation can be challenging to find. The implementation of SEEA-EA is now being endorsed and enforced by countries, and the topic is being increasingly researched scientifically. Therefore, it is essential to establish comprehensive, straightforward, and standardised guidelines and best practices for accurately assessing the condition of marine ecosystems.

Author Contributions

M.I.—conceptualisation, writing—original draft preparation. P.P.—Writing and reviewing. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

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Conflicts of Interest

Given the role as Editor-in-Chief, Paulo Pereira had no involvement in the peer review of this paper and had no access to information regarding its peer-review process. Full responsibility for the editorial process of this paper was delegated to another editor of the journal.

Use of AI and AI-assisted Technologies

During the preparation of this work, the authors used Grammarly to check grammar, spelling, and improve the clarity of the text. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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