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Abstract

Ecosystem Accounting provides a framework to measure and value relationships between ecosystems, society and the economy. The accounts measure ecosystem extent, condition, and services, providing the means to identify and internalise ecological degradation, as well as understanding the risks and dependencies of economic activities on the environment and tracking progress towards sustainable development. The OSPAR Convention, which concerns the protection of the Marine Environment for the North-East Atlantic, has committed to accounting for natural capital and ecosystem services, where the UN System of Environmental Economic Accounting – Ecosystem Accounting (SEEA EA) provides an international accounting standard for guidance in compiling accounts. Here, we describe the first attempt in compiling accounts aligned with SEEA EA at a Regional Sea scale. We (i) identified existing open access data, (ii) produced accounts for selected ecosystems and valued their services and asset value, and (iii) identified challenges and lessons learned. For ecosystem services, we measured fish provisioning, carbon sequestration, and outdoor recreation from coastal and marine environments across OSPAR contracting parties. The exercise identified lack of fitting data at regional level, spatially explicit linkages and harmonisation need to be overcome to further expand accounts. This work represents an initial step to progress on ecosystem accounting and demonstrates that even with limited data and incomplete timeseries, accounts can start compiling to identify data gaps, and prioritize next steps.

Keywords

System of Environmental Economic Accounting; Ecosystem accounting; Regional Seas assessment; North-East Atlantic; marine environment

Introduction

The last century has seen the widespread loss and degradation of ocean ecosystems, driven in part by undervaluing their importance to society and the economy within decision making. Globally, ocean ecosystems are among the most productive systems, providing goods and services that underpin the health, wellbeing and livelihoods of millions of people (IPBES 2019). Valuing their contribution, however, has been difficult to measure, where many services and benefits arise from the existence of ecosystem and their support of economic and human activities is not reliant on direct extraction or use (e.g., climate regulation, coastal protection, fish nurseries etc.) (United Nations et al. 2021). The failure to account for such contributions has led to the prioritization of economic values at the detriment of ocean ecosystems.

In response, holistic and integrated measures towards sustainable ocean development have been embedded within strategic plans and policy instruments at international (European Commission's Sustainable Blue Economy Agenda*[1], High Level Panel for a Sustainable Ocean Economy*[2]), regional (North-East Atlantic Environment Strategy*[3],The Baltic Sea Action Plan*[4]) and national (e.g., Fiji Ocean policy*[5], Portugal National Ocean Strategy*[6]) levels. These plans and policies support integrated assessments of the ocean environment framed through the concepts of 'natural capital' and 'ecosystem services' (Ruijs et al. 2018). Natural capital can be defined as the ecosystems and natural resources that supply the ecosystem goods and services that benefit society and the economy (European Environment Agency 2019). The measurement and monetary valuation of ecosystem services justify the conservation of ocean ecosystems by recognizing that the majority of ecosystem services are difficult or impossible to replace (European Commission 2020, Maes et al. 2020). Measuring ecosystem services in a coherent and transparent manner, however, requires standardization, which could be in part achieved through definitions and classifications contained within statistical accounting frameworks.

Countries have long maintained 'national accounts' to measure aspects of the economy (e.g., Gross Domestic Product, GDP), where most countries follow the internationally agreed UN standard System of National Accounts (SNA). The SNA, however, has long been criticised for poorly accounting for natural capital, where its depletion usually leads to a short-term increase in measures of economic growth, such as GDP (Helm 2015). The need to go 'Beyond GDP' has led to the development of the UN System of Environmental Economic Accounting (SEEA), as a complementary standard with concepts and definitions aligned to the SNA, to better recognise nature's contributions to economic output and to advance sustainability within decision making (Dasgupta 2021). The SEEA provides guidance towards accounts that contain regular and objective data (European Environment Agency 2019) that is coherent and internationally comparable in line with the UN Fundamental Principles of Official Statistics.*[7]

The SEEA is composed of the Central Framework (SEEA CF) and Ecosystem Accounting (SEEA EA, henceforth 'Ecosystem Accounts'). The SEEA CF concerns accounting for thematic stocks and flows (e.g., energy, water, and economy-wide material flow accounts), while the Ecosystem Accounts extends accounting into the spatial domain, to measure ecosystems and related flows to society and the economy. Ecosystem Accounts consider the extent and condition of ecosystems by type (e.g., seagrass, saltmarsh) and how condition may impact the ecosystem services provided (Edens and Hein 2013). Global, regional, and national initiatives*[8] have driven the uptake of the SEEA and is now being implemented in more than 90 countries. To date, 41 countries have compiled Ecosystem Accounts (UNSD 2023). However, most Ecosystem Accounts focus on the terrestrial environment and significant challenges remain to produce accounts for marine and coastal areas (Buonocore et al. 2020, Manea et al. 2019, Townsend et al. 2018).

Countries have developed thematic accounts concerning the measurement of the ocean economy (e.g., Portugal*[9]) and specific ecosystem services (e.g., United Kingdom, UK) (Office for National Statistics 2021, Thornton et al. 2019), although few have compiled ocean ecosystem accounts (e.g., Australia, Canada (see Comte et al. (2022), Gacutan et al. (2022)). The definitions, classifications and boundaries concerning ocean ecosystems drives the need for ocean-specific guidance (Geange et al. 2019, Manea et al. 2019, Townsend et al. 2018). There are ongoing efforts to address these gaps, with coordination supported by the Global Ocean Account Partnership (GOAP),*[10] which has developed a technical guidance on Ocean Accounting, which provides specific guidance for both the SNA and SEEA to the ocean domain.

While accounting aligned with the SEEA is performed predominantly at the national scale, the transboundary nature of human pressures and impacts to the ocean necessitates a regional approach to management. Regional Seas Conventions, such as OSPAR, assist in coordinating the actions of Contracting Parties to address challenges such as habitat loss and degradation, invasive species and poor water quality (Maes et al. 2020, Veretennikov 2019). Within OSPAR, environmental status is tracked by indicators reported within the so-called Quality Status Report (QSR) (OSPAR 2000, OSPAR 2010b), which also identifies the priority actions to achieve OSPAR and the Contracting Parties vision of a healthy, biologically diverse and sustainably-used sea.*[11] The compilation of Ecosystem Accounts at a regional seas scale could assist in tracking environmental status and producing indicators.

The compilation of a preliminary and experimental set of Ecosystem Accounts for the OSPAR area was performed to identify the data available for accounting, and the gaps and limitations that require further efforts and coordination to address. This paper describes the process to compile Ecosystem Accounts for the OSPAR area, presenting the first version of the accounts for the whole OSPAR region, and first attempt of marine ecosystem accounts for a regional sea. We provide an overview of (i) the methods used to compile the Ecosystem Accounts, (ii) preliminary results*[12], and (iii) a discussion of limitations, lessons learned, and recommendations for improvement. The work provides a blueprint and foundation for other regional seas to begin compiling Ecosystem Accounts.

Study area: OSPAR and the North-East Atlantic Ocean

The Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR), was ratified in March 1998, superseding the previous Oslo (1972) and Paris (1974) conventions. The convention contains 15 Contracting Parties*[13] and the European Union. The convention builds on earlier efforts to prevent marine pollution from dumping or discharges from ships and aircraft, and land-based sources of marine pollution. This paper focuses on the OSPAR Maritime area, *[14] which includes both Territorial Waters and Exclusive Economic Zone (EEZ) of Contracting Partiers within the North-East Atlantic region (Fig. 1).*[15] The OSPAR area further extends into areas beyond national jurisdiction and encompasses extensive areas in the Wider Atlantic (OSPAR Region V) and Arctic Waters (OSPAR Region I). In total, the Regional Sea covers over 13.5 million km^2, divided into five regions.*[16] Annex I of the OSPAR Convention concerns pollution of land-based sources and thus, this study includes Internal Waters*[17] (i.e., coastal areas) within the accounting activity of the OSPAR Maritime area.

OSPAR's strategic objectives are described in the North-East Atlantic Environmental Strategy (NEAES),*[18] with the state and trends described within the QSR. The NEAES aligns with other regional European Commission policies, primarily the Marine Strategy Framework Directive (MSFD)*[19], which provides descriptors for the 'Good Environmental Status' of coastal and marine ecosystems.*[20] The latest iteration, NEAES 2030 (OSPAR 2021) contains a suite of operational objectives, one of which commits OSPAR to:

"By 2025, start accounting for ecosystem services and natural capital by making maximum use of existing frameworks to recognise, assess and consistently account for human activities and their consequences in the implementation of ecosystem-based management."

Overview of SEEA Ecosystem Accounts standard

The Ecosystem Accounts are composed of several linked accounts that contain values in either physical (e.g., tons) or monetary terms (Fig. 2). The accounts measure either stocks (ecosystem extent, condition, and asset accounts) or flows (ecosystem services) between ecosystems, society, and the economy (i.e., users – industry, government, and households).

- **Ecosystem extent** accounts measure the area per ecosystem type within an accounting area. The Convention on biological diversity (CBD 2003) defines ecosystems as "*dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit".*
- The **ecosystems types** represented within the SEEA Ecosystem Accounts are classified in terms of distinct biophysical environment, where the standard endorses the use of the IUCN Global Ecosystem Typology (Keith et al. 2020). The

hierarchical typology classifies environments into 108 ecosystems, based on functional groups, such as tropical forests, seagrass meadows, annual croplands.

- **Ecosystem condition** accounts record the condition of ecosystem assets in terms of selected characteristics at specific points in time. Over time, they record the changes to their state and provide valuable information on the health of ecosystems.
- Ecosystems *supply* a range of **ecosystem services** that reflect the different characteristics and processes of the ecosystem, depending on its ecosystem type, extent and condition, and on their location and patterns of *use* by economic units (including households, businesses and governments) (United Nations et al. 2021). Ecosystem services flows are both measured in physical and monetary terms.
- The **ecosystem asset** account records the monetary value of the opening and closing stocks of all ecosystem assets within the accounting area, showing additions (enhancement) and reductions (degradation) in stocks when accounts are recorded over time (United Nations et al. 2021).

Within Fig. 2, accounts are numbered to demonstrate the flow of data, where later accounts are dependent on the compilation of the preceding account. For instance, an estimation of the supply of ecosystem services is dependent on ecosystem extent and condition.

Compilation and assessment of available ecosystems and services data at the OSPAR level

Ecosystem Accounts information presented in this paper was collected for the OSPAR Maritime area,*[21] which includes internal and territorial waters of OSPAR Contracting Parties and adjacent high seas. The compilation of ecosystem extent accounts, service (supply and use), and asset accounts for the OSPAR area accounts was produced by applying guidance from the Ecosystem Accounts standard (United Nations et al. 2021) and the GOAP technical guidance (GOAP 2020).

The methodology for the account compilation was determined through an assessment of existing Ecosystem Accounts, informal consultations with technical experts and through the OSPAR Intersessional Correspondence group on Economic and Social Analyses (ICG ESA). The Ecosystem Accounts of this study were recorded by:

- Conducting a literature review of existing marine ecosystem accounts and inventory of relevant open-source data,
- Defining Ecosystem Accounting components, including identification and selection of ecosystems and their services based on data availability.
- Assessing and compiling available data on ecosystems and services at the OSPAR level and assessing feasibility of accounts,
- Compilation of ecosystem extent accounts, service (supply and use), and asset accounts for the OSPAR area.

Experiences on ecosystem accounts were drawn from several countries, reviewed in Lange et al. (2022) and Gacutan et al. (2022).*[22] A workshop on 'Marine Natural Capital Accounts' was hosted by OSPAR,*[23] consisting of more than 60 participants from across the world, with expertise in economics, official statistics, environmental science and policy. The workshop consisted of interactive sessions exploring data availability and gaps, challenges and policy applications of accounting (see Suppl. material 3).

A literature review was conducted and data inventory compiled (see Table 5 Suppl. material 2). Data availability and evidence gaps were determined through the OSPAR Data & Information Management System (ODIMS) database, which contains extensive timeseries of periodic monitoring of chemical and ecological status of the North-East Atlantic Ocean*[24] and other publicly available datasets. The full list of data sources used in the analyses are provided in Suppl. material 2 (Table 5). In assessing the inventory of data, a preliminary accounting snapshot of the OSPAR region was produced, containing data published between 2008 and 2019.

The inventory identified ecosystem extent and their services as feasible for account compilation. However, key data gaps between linking ecosystems to their condition spatially prevented the compilation of ecosystem condition accounts.

The Ecosystem Accounts provides a "Reference List" of ecosystems services, structured into three broad categories: provisioning, regulating & maintenance, and cultural services (United Nations et al. 2021). In this study, relevant ecosystem services were selected based on OSPAR priorities and data availability (Table 1), including: (i) provision of wild aquatic animals and animals or products from aquaculture due to the importance of this economic activity in the area, (ii) climate regulation through carbon sequestration and capture since OSPAR Commission is looking for ways to reduce the negative effects of climate change, and (iii) outdoor recreation due to its social importance in the area. As leading OSPAR countries in recording Ecosystem Accounts, guidance on technical considerations were drawn from The Netherlands (de Jongh et al. 2021, Schenau et al. 2019) and UK (Grilli et al. 2022, Office for National Statistics 2021, Thornton et al. 2019) to estimate the different accounts.

Ecosystem type and extent account

The accounting treatment of marine and coastal assets is different to land-based environmental assets. Marine ecosystems are not concentrated near a single surface (e.g., land or water interface) but extend throughout the water column and seabed, which serve as natural boundaries for ecosystem types. Depicting ecosystem types vertically as a three-dimensional, however, poses numerous challenges to accounting and therefore this study used a two-dimensional (2-D) approach to characterize the seabed in the study area.

The Ecosystem Accounts endorse the use of the IUCN Global Ecosystem Typology (GET), although existing datasets for the OSPAR area were not aligned with GET classifications. This paper employs surface-based delineation which aligned with the methods of marine accounts for the UK (Thornton et al. 2019). The study uses the European Nature

Information System (EUNIS),*[25] which is a hierarchical classification that defines habitats from broad scales to species-specific scales. The seafloor types considered were infralittoral (A3) and circalittoral rock (A4), sublittoral sediments (A5) and deep-sea sedimentary habitats (A6).

Data for ecosystem extent were sourced from EUSeaMap (2019),*[26] which is hosted and maintained by the European Marine Observation and Data Network (EMODnet). The EUSeaMap 2019 covers most EUNIS Marine Habitats (A3 – A6), although lacks littoral biotic habitats (A1) and sediments (A2). Estimated extent for key intertidal ecosystems and coastal estuaries (A2) were extracted from extent accounts produced by the European Environment Agency.*[27] The intersection between EUSeaMap and the OSPAR area was extracted using regional boundaries within ODIMS, to extract the extent of EUNIS habitats. Spatial analyses and manipulation were performed using ArcMap (v10.4, ESRI).

Ecosystem condition account

A condition account for the OSPAR area would provide several metrics of the state and functioning of specific ecosystem types. An ideal starting point are existing indicators produced by OSPAR for measuring the ecosystem status or pressures. Relevant indicators compiled for OSPAR, aligned with the GOAP technical guidance and consistent with the Ecosystem Accounts framework (OSPAR 2010a, OSPAR 2010b) (see Suppl. material 1). Among these metrics are acidity, eutrophication, species diversity, ecosystem diversity, concentration, sea surface temperature, coral condition, seagrass cover, fish stocks state or grade of minerals (GOAP 2020).

Several of these indicators have already been estimated and compiled by OSPAR in the various Quality Status Reports (OSPAR 2010b). However, the indicators are currently reported as aggregates at the OSPAR level (i.e., entire North-East Atlantic) and its regions (see Fig. 1), preventing them from being disaggregated spatially, to enable attribution to specific ecosystems types (such as those assessed in the ecosystem extent account).

Ecosystem services physical supply and use accounts

Ecosystem services measured in physical terms (i.e., physical flow accounts) record the supply of ecosystem services and the beneficiaries or users (economic units including households, businesses and governments) of those services per ecosystem.

The ‘use’ of ecosystem services identifies the first direct ‘users’; industries, government and households, which further relates to their ‘dependency’ on ecosystem services (Table 4).*[28] The first direct users were identified following the main users and beneficiaries included in the initial logic chains*[29] for selected ecosystem services provided by SEEA EA.

The government is considered a direct user and beneficiary of carbon sequestration because the service benefits society as a whole (Horlings et al. 2020b). For OSPAR, ‘government’ refers to the collective of OSPAR Contracting Parties, as they all benefit from this non-exclusive service. For outdoor public recreation, values were drawn from the KIP INCA*[30] project for EU Members States that were also OSPAR Contracting Parties. The project used potential visits to coastal recreational areas per year (daily use) as a proxy for the possibility for citizens to enjoy nature within daily activities (Vallecillo Rodriguez et al. 2018) and is recorded under 'households'.*[31]

The marine natural capital accounts published by the Netherlands and UK are used as main guidance since they are the accounts available when the research was conducted within the North-East Atlantic zone (de Jongh et al. 2021, Office for National Statistics 2021 , Schenau et al. 2019, Statistics Netherlands and WUR 2021, Thornton et al. 2019). Further details on methodology and data to estimate each ecosystem service in physical terms are provided in Suppl. material 2. The main challenges faced during data compilation and accounting were (with further exploration in Suppl. material 2), including:

1. Fish provisioning was calculated based on landings reported through the UN Food and Agricultural Organization (FAO), which may not report all species of commercially caught fish provisioned by the ecosystems. Further, landing could not be spatially assigned to specific ecosystems.
2. Estimates for carbon sequestration omitted seagrass, which are important carbon sinks (Bedulli et al. 2020). Consequently, carbon sequestration included in this report is underestimated within the region.
3. Estimates of outdoor recreation were based on the results of the KIP-INCA project, which used potential visits to coastal recreational areas per year (daily use) to account for this service. As the values could not be applied to the entire OSPAR area, they serve as a preliminary estimate of the service for the North-East Atlantic.

Ecosystem services monetary supply and use accounts

In the context of ecosystem accounting, the valuation of ecosystem services in monetary terms is commonly performed by multiplying the values measured within the physical accounts with the 'exchange' value of individual ecosystem service prices (United Nations et al. 2021). For the present accounts, valuations were based on benefit transfer (Table 1), which is defined by Richardson et al. (2015) as "*the transfer of original ecosystem service value estimates from an existing 'study site' or multiple study sites to an unstudied 'policy site' with similar characteristics that is being evaluated which is the extrapolation and adaptation of benefits from one study location to another one*". While primary valuation for each context is ideal and provides a more reliable range of estimates, studies at the regional sea scale are often infeasible due to time and resource constraints (Brander 2013).

Benefit transfer of resource rent unit*[32] from the UK marine natural capital accounts was applied to the provisioning service of wild aquatic animals estimated within this study; and the results from resource rent study in the Norwegian Aquaculture Industry was applied to the provisioning service of animals or products from aquaculture. For carbon sequestration, the efficient carbon price from the low reduction scenario calculated by Horlings et al.

(2020a) was used. Finally, for outdoor recreation, the monetary accounts from the INCA project were used (only including the values for OSPAR Contracting Parties).

Ecosystem asset account

The value of an ecosystem asset can be determined by calculating the net present value (NPV) of the expected future flows of income associated with the different ecosystem services (Schenau et al. 2019, United Nations et al. 2021). The utilization of a NPV approach suggests that the value of an ecosystem asset is tied to its ability to provide ecosystem services, as well as how this ability is projected to evolve over time.

Results

Ecosystem type and extent account

The preliminary Extent accounts covered more than 9.2 million km^2 and approximately 68% of the OSPAR area (Table 2). Of the area with data coverage, deep-sea sedimentary habitats were the most extensive ecosystem, at 46% of the accounting area. In contrast, infra and circa-littoral rocky habitats only accounted for 0.006% (5281 km^2) of the OSPAR area.*[35] As seabed data was from data sources aggregated across multiple years, extent accounts for multiple years (and thus changes) could not be compiled.

Ecosystem services accounts

Ecosystem Service accounts were compiled for the period 2008 to 2019 (Table 3). For physical values, fish provisioning was estimated between 2012 and 2019, while data for provisioning from aquaculture was estimated between 2012 and 2015. Estimated flows for carbon sequestration and capture were only available for 2019, while outdoor recreation could only be estimated for 2012.

The accounts revealed that fish provisioning fluctuated between 8.1 and 9.3 Mt, peaking in 2018 (9.32 Mt), while lowest in 2019 at ~8.1 Mt. The monetary value estimated for fish provisioning, however, ranged between €1.7 billion and €2.8 billion, with no clear relationship between physical and monetary values. Provisioning services to aquaculture was stable between 2012 and 2015 in physical terms, ranging between 2.12 and 2.15 Mt, although monetary value increased from €1.3 to €3.7 billion in the same period.

Marine carbon sequestration and capture was valued at €1.6 million in 2019, calculated using coastal saltmarshes from littoral habitats (A2) and sublittoral sand and mud (A5). Crucial habitats could not be included so these estimates omit significant carbon sinks within shelf seas, thus representing a gross underestimation for the value of carbon sequestration of the OSPAR area (see Suppl. material 2). Outdoor recreation services were estimated for coastal areas and was estimated at €253 million in 2012 for OSPAR

Contracting Parties that were EU Member States (EU-28), excluding Finland due to lack of data (Table 4).

Ecosystem asset account

The monetary value of each ecosystem asset was estimated by calculating the NPV using initial estimates of ecosystem services from this study (see Suppl. material 2). The total asset value for the OSPAR region was €125.75 billion, of which more than 40% comes from carbon sequestration and outdoor recreation. The asset value estimated for carbon sequestration was €48.15 billion, and for outdoor recreation €7.56 billion. As both carbon sequestration and outdoor recreation services were underestimated, monetary estimates for the assets are also underestimated.*[41]

Discussion

This paper presented the initial Ecosystem Accounts for the OSPAR region, compiling accounts of ecosystem extent, the supply and use of their services, and a preliminary assessment of their asset value, aligned with the SEEA EA standard. As far as we are aware, this work represents the first compilation of Ecosystem Accounts for a Regional Sea. The accounts were compiled from available data, providing a ‘snapshot’ of stocks (extent, asset value), while measurement of ecosystem service flows varied in the accounting years presented. The approach to account for the different ecosystem services are experimental (in that they are not defined in any international standard), yet it establishes the groundwork and foundation for future Ecosystem Accounting practices. The following discussion will explore each of the Ecosystem Accounts compiled, limitations and future research needs. The discussion concludes with recommendations to facilitate the compilation of OSPAR accounts into the future.

Extent accounting for the OSPAR area

The OSPAR region has abundant and centralized data, relative to other Regional Seas. The study used the EUSeaMap 2019, which harmonized multiple datasets across various years to produce a seabed classification that covered approximately 68% of the OSPAR area. The seabed map used the EUNIS classification, aggregated to six broad ecosystem types, which was previously used to produce the national accounts for the United Kingdom, within the OSPAR area (see Grilli et al. (2022), Thornton et al. (2019)). The EUNIS classification system employed, however, aligns more with abiotic seabed classifications, rather than the ecosystem types, differing to international ecosystem classifications such as the IUCN Global Ecosystem Typology framework (Keith et al. 2020). Further, the EUSeaMap 2019 does not cover the land-sea interface, which omitted coastal and intertidal habitats (i.e., A1 and A2), which required additional data sourced through the European Environmental Agency Ecosystem Accounts. Future accounts should consider using datasets aligned with international ecosystem classifications and enable analyses of changes to extent over time (Townsend et al. 2018).

Ecosystem Service measurement and evaluation

While there is a large amount of literature on specific ecosystem services within the OSPAR region, few employ a regional approach and are compatible with SEEA Ecosystem Accounting (I.e., linked to specific ecosystems). The initial estimation of ecosystem services provided for the North-East Atlantic was determined through logic chains, where ecosystem services were linked to specific EUNIS classifications, drawing from existing logic chains from the UK marine accounts (Thornton et al. 2019). The use of these logic chains aligned with the SEEA Ecosystem Accounting standard (United Nations et al. 2021) and have previously been used to compile accounts for the Netherlands (Statistics Netherlands and WUR 2021). These logic chains were used to compile ecosystem service estimates for wild-catch fisheries, aquaculture, carbon sequestration and outdoor recreation, in physical and monetary terms. Greater specificity at the regional level, in linking towards specific economic sectors, requires further collection of coherent and standardized data within the OSPAR region.

The study also performed a preliminary valuation of ecosystem services in monetary terms, recognizing that the methods for valuation of specific services are controversial and most useful when analysing changes over time, rather than absolute values (Droste and Bartkowski 2017). Estimated changes to stocks and flows in monetary terms could highlight the importance of non-use and non-market ecosystem services (see Comte et al. (2022)), to quantify the benefits of sustainable ecosystem management in decision making (Hein et al. 2020).

Due to data limitations, several estimates relied on benefit transfer, and Grammatikopoulou et al. (2023) explores uses-cases of the technique to develop accounts when capacity or resources are limited. In general, benefit transfer is used because it comprehends ease of use and minimal data needs (Office for National Statistics 2021, United Nations et al. 2021), where its use is expected to increase with resource constraints for accounting activities (Johnston et al. 2015). While a primary valuation study is preferred when feasible (Johnston et al. 2015), benefit transfer provides a means to compile preliminary ecosystem accounts, for iteration as data becomes available (Brander 2013).

Fish provisioning

In this study benefit transfer of resource rent unit was implemented to value the provision of fish and aquaculture products. Further research, however, is needed to identify the valuation techniques that better relate physical and monetary values as resource rent may produce low or negative monetary estimates of the flows from ecosystem services to the national economy (Obst et al. 2015). The study identified a disconnect between benefit transfer of resource rent and unit of fish provisioning in this work. Lower fish provisioning in 2016 was valued higher (8.33 Mt landed, valued at at 2,846 mill. €), while higher fish provisioning in 2015 had lower monetary value (9.15 Mt landed, valued at 1,728 mill. €), which contrasted with the results from other years (Table 3). We would expect then, more fish provisioned or used would be translated in less amount of the service in monetary terms. A challenge with the valuation method is separating the value of human and produced capital with the ecosystem service of food provisioning, as resource rent is linked to fuel prices. Changes to fuel price has implications for the valuation of the ecosystem service, which does not reflect the state and trend of the underlying quality or health of the ecosystem.

Carbon sequestration

Estimates of carbon sequestration in physical and monetary terms revealed preliminary estimates for the OSPAR area. The service was valued in 2019 to be more than half of the value of fish provisioning in 2018, indicating the significance of the service. Carbon price was used to value the service, where Horlings et al. (2020a) discussed the advantages and disadvantages between the use of the social cost of carbon and carbon price of policy targets. The use of carbon price may be advantageous in advantages, including lower uncertainty and greater viability (see Horlings et al. (2020a)). Further studies are needed to identify the impact of the valuation methods, noting the importance of relative change against absolute values, as the former provides key information on the state of natural capital and ecosystem assets.

Outdoor recreation

Measuring outdoor recreation services was a challenge due to data harmonization, rather than data limitations, as reporting practices for recreation-and tourism-related activities varied significantly among OSPAR countries. The estimates within this study were low, relative to other ecosystem service assessments (Vysna et al. 2021), which could be linked to the omission of countries and the weak distinction between coastal and marine recreation and the use of “Potential visits”. The dataset used contained only EU members, which omitted Norway, Iceland and Switzerland OSPAR contracting parties (Vallecillo Rodriguez et al. 2018). Further, the SEEA Ecosystem Accounting makes a distinction between “capacity” and “actual visits” as an indicator for use, which contrasts with "Potential visits” used within the study (Vallecillo Rodriguez et al. 2018, Vallecillo et al. 2019).

Recommendations and future work

The process of developing Ecosystem Accounts for the North-East Atlantic has produced several illustrative lessons in accounting for Regional Seas. The main challenges faced during the Ecosystem Accounting process suggests that future accounting and data activities should (i) align with international ecosystem and ecosystem services classifications; and (ii) condition data and indicators should be spatially disaggregated to ecosystems (*c.f.*, aggregated across ecosystems). To better align OSPAR reporting with Ecosystem Accounting, and enable compilation of a condition account, data collection and reporting could shift from a region-based to ecosystem-based approach. As a Regional Sea, the OSPAR could assist in the standardization and harmonization of data collection and reporting methods for monitoring on ecosystem condition, enabling Ecosystem Accounting, while meeting the other objectives of the OSPAR mandate. This could be performed through OSPAR's ODIMS data platform, which contains relevant data for accounting.

Further, the EUNIS classification was recently revised to disaggregate marine habitats into benthic (I.e., ecosystems) and pelagic components, with datasets updated in January 2023.*[42] Future accounting activities could utilise the updated EUNIS to extend analyses to ecosystem services from specific biotic ecosystem types (e.g., kelp forests, oyster reefs) (Chen et al. 2022, Chen et al. 2020, Vondolia et al. 2019). Increasing resolution and ecosystem mapping from remote sensing provides an opportunity to determine extent changes over time (e.g., Murray et al. (2022)). The accounts could also explore the assets and services contained within the water column (i.e., vertical stratification), to understand flows across three-dimensions to improve decision making concerning dynamic stocks such as fisheries (Findlay et al. 2022).

Conclusions

This study presented the initial Ecosystem Accounts for the OSPAR region, advancing trans-boundary Ecosystem Accounting at the Regional Seas level. Specifically, the accounts provide an understanding of the state and trend of the marine environment, contributing to OSPAR's mission of monitoring the health and conservation of marine habitats. The compilation of accounts for ecosystem extent, services, and asset value, aligned with the SEEA EA standard, provides a 'snapshot' of stocks and flows and suggests processes to compile accounts as a foundation for future ecosystem accounting practices. While the accounting approach for specific ecosystem services remains experimental, operationalization through initiation estimates highlighted the need for further efforts in data collection, harmonization, and refinement of classifications to improve the accuracy and spatial scope of future accounts. The findings underscore the importance of considering relative monetary values rather than absolute numbers, as they provide key insights into the state of ecosystems and impacts to the supply of services.

Several recommendations were identified to enhance the future compilation of OSPAR Ecosystem Accounts. Firstly, a shift towards ecosystem type-based data collection would enable more direct links between condition indicators and specific ecosystem types, improving the accuracy of the accounts. The harmonization of data among OSPAR Contracting Parties is crucial, requiring the development of common methodologies and tools to facilitate data sharing and standardization. The ODIMS platform presents an opportunity for OSPAR to streamline the collection and collation of diverse data sources. Additionally, systematic and coherent data collection and recording practices should be established to enable the periodic production of accounts, facilitating the comparison and tracking of changes in ecosystems and their services over time. These recommendations, when implemented, will further enhance the relevance and usefulness of Ecosystem Accounts in informing policy decisions and promoting sustainable ecosystem management in the OSPAR region and beyond.

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Conflicts of interest

The authors have declared that no competing interests exist.

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Endnotes

*1 European Commission (2021) Making the transition from ‘Blue Growth’ to a ‘Sustainable Blue Economy’(COM/2021/240 final)

*2 The High Level Panel for a Sustainable Ocean Economy (Ocean Panel): https://oceanpanel.org/

*3 North-East Atlantic Environment Strategy 2030: https://www.ospar.org/convention/strategy

*4 The Baltic Sea Action Plan https://helcom.fi/wp-content/uploads/2021/10/Baltic-Sea-Action-Plan-2021-update.pdf

*5 Republic of Fiji National Ocean Policy 2020-2030: https://fijiclimatechangeportal.gov.fj/ppss/republic-of-fiji-national-ocean-policy-2020-2030/

*6 Direção-Geral de Política do Mar, National Strategy for the Sea 2021-2030: https://www.dgpm.mm.gov.pt/agenda-2030-en

*7 UNSD (2014) Fundamental Principles of Official Statistics (A/RES/68/261)

*8 https://seea.un.org/home/Natural-Capital-Accounting-Project ; https://www.wavespartnership.org/ ; https://maiaportal.eu/

*9 Virtual Expert Forum on SEEA Experimental Ecosystem Accounting 2020. Session 4: Thematic accounts and indicators (9-10 November). Group 3: Accounting for oceans, Portugal presentation.

*10 Global Ocean Accounts Partnership (GOAP): https://www.oceanaccounts.org

*11 OSPAR Commission, North-East Atlantic Environment Strategy: https://www.ospar.org/convention/strategy

*12 The Ecosystem Accounts compiled are not OSPAR final ecosystem accounts, they are first estimates showing what can be done to move forward at the OSPAR level in ecosystem accounting terms.

*13 Contracting parties include Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, the Netherlands, Norway, Portugal, Spain, Sweden, the United Kingdom, Luxembourg, and Switzerland.

*14 As defined by the OSPAR Convention: https://www.ospar.org/site/assets/files/1169/ospar_convention.pdf

*15 As defined by the UN Convention on the Law of the Sea (UNCLOS), Section 2

*16 OSPAR regions - Region I: Arctic Waters; Region II: Greater North Sea; Region III: Celtic Seas; Region IV: The Bay of Biscay and Iberian Coast; and Region V: Wider Atlantic.

*17 As defined by the UN Convention on the Law of the Sea (UNCLOS), Section 2, Art. 8

*18 OSPAR Commission, North-East Atlantic Environment Strategy 2030: https://www.ospar.org/convention/strategy

*19 Marine Strategy Framework Directive https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32008L0056

*20 Strategy of the OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic 2010–2020 (OSPAR Agreement 2010-3) Preamble

*21 As defined by the OSPAR Convention: https://www.ospar.org/site/assets/files/1169/ospar_convention.pdf

*22 Lange et al. (2022) reviewed ecosystem accounts in Finland, France, The Netherlands, United Kingdom, Norway, and Spain, while Gacutan et al. (2022) provides detailed descriptions of ecosystem accounts in Australia, Canada, and South Africa.

*23

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OSPAR Special Session on Marine Natural Capital Accounting: https://www.ospar.org/news/ospar-special-session-on-marine-natural-capital-accounting

*24 OSPAR Data & Information Management System: https://odims.ospar.org

*25 EUNIS habitat classification: https://www.eea.europa.eu/data-and-maps/data/eunis-habitat-classification-1

*26 EMODnet Seabed Habitats - EUSeaMap broad-scale maps: https://www.emodnet-seabedhabitats.eu/about/euseamap-broad-scale-maps/

*27 European Environment Agency, Ecosystem Extent Accounts: https://www.eea.europa.eu/data-and-maps/data/data-viewers/ecosystem-extent-accounts

*28 This aligns with the concepts, definitions, and boundaries used within national accounting by most countries.

*29 The concept of a logic chain involves a step-by-step sequence, whereby an ecosystem asset provides an ecosystem service to an economic unit that utilizes the service as an input for either production or consumption activities. The outcome of this process results in a benefit that can be measured either in terms of System of National Accounts (SNA) or non-SNA benefits. Logic chains can be visually represented through a graphic or table format (see United Nations, 2021).

*30 Knowledge Innovation Project on an Integrated system of Natural Capital and ecosystem services Accounting (KIP INCA) project provided an integrated system of ecosystem accounts for the European Union. Report on the first phase: https://ec.europa.eu/environment/nature/capital_accounting/pdf/KIP_INCA_final_report_phase-1.pdf

*31 The method assesses areas for daily recreation where people live. In these places, out-of-reach citizens involve a drop in daily usage. This approach represents only a small fraction of the total potential users, some of whom may travel a considerable distance to come to enjoy such services.

*32 Resource rent provides a gross measure of the return on the environmental asset, isolating the surplus value added to the marketed output from the environmental asset after considering other operational costs and normal returns.

*33 Henceforth referred to the service as "*fish provisioning*" in the text.

*34 Henceforth referred to as "*provisioning from aquaculture*" in the text.

*35 OSPAR area as covered in the OSPAR regions boundaries map for 2017 used from ODIMS (see Table 5 of Suppl. material 2)

*36 Relevant values within European Environmental Agency Ecosystem Accounts were saltmarsh, coastal estuaries and lagoons, and saline intertidal habitats.

*37 Estimates of provisioning services from aquaculture were extremely high compared to the unit resource rent of marine fish capture due to the benefit transfer values used. Therefore, the Provisioning of Aquaculture was excluded from Ecosystem Service use and Ecosystem Asset accounts

*38 Outdoor recreation also relies on coastal habitats (EUNIS B1 – 3), adjacent to the littoral zone.

*39 Due to lack of data, estimates are from different years.

*40 values rounded to the nearest million

*41

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The asset value presented here depends on the limited list of ecosystem services included in this study. If a larger list of ecosystem services would have been included the value would have been higher.

*42 EUNIS marine habitat classification 2021 : www.eea.europa.eu/data-and-maps/data/eunis-habitat-classification-1 (accessed 17/04/2023)

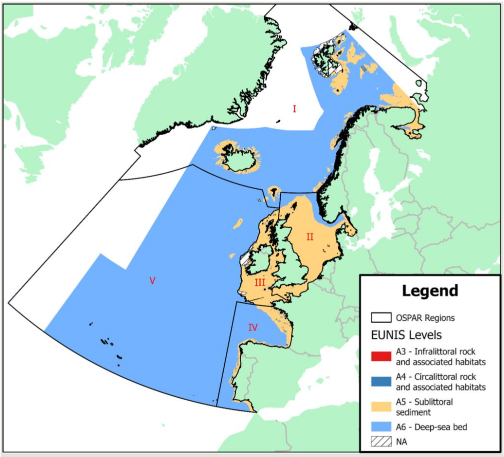

Figure 1.

A map of the OSPAR Maritime Area, denoting sub-regions I to V, as defined by the OSPAR convention. Ecosystem Accounting was performed by seafloor type (A3 – A6), according to EUNIS classifications. A map of ecosystem types further disaggregated is provided in Suppl. material 1.

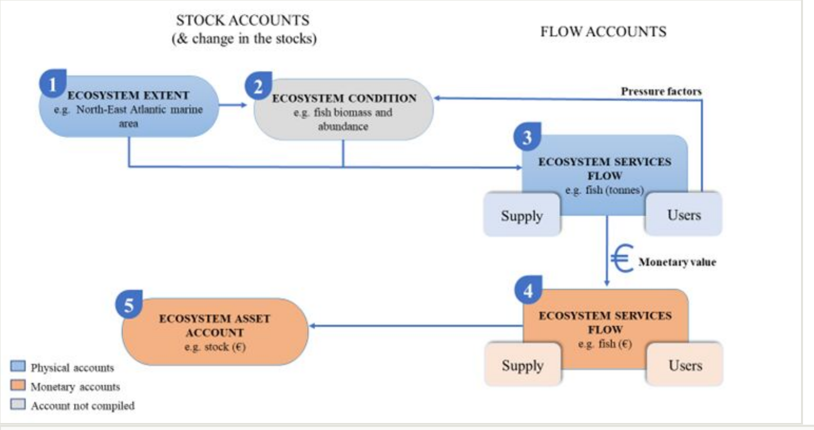

Figure 2.

The Ecosystem Accounts framework followed. The figure illustrates the set of accounts forming the accounting system, in which the accounts are strongly interconnected and provide a comprehensive and consistent view of the ecosystems. Note that Ecosystem Condition accounts were not compiled.

Table 1.

Ecosystem services assessed within this study and their relevance to Ecosystem Accounts (GOAP 2020, United Nations et al. 2021). Methods and sources used to calculate the monetary accounts are also included. Definitions drawn from CICES (Haines-Young and Potschin 2017)

Ecosystem Service type	Ecosystem Service	Relevance	Valuation method	Source
Provisioning services	Provision of wild aquatic animals for nutrition, materials, or energy[*33]	Fish and other aquatic products including from coastal aquaculture and capture fisheries and marine fisheries	Benefit transfer of resource rent unit	Office for National Statistics (2021)
	Provision of animals or products from aquaculture[*34] for nutrition, materials, or energy		Benefit transfer of resource rent unit	Flatebø Selle (2019)
Regulating services	Climate regulation (henceforth 'carbon sequestration and capture')	Measuring the carbon sequestered and stored by ecosystems (e.g., mangroves, seagrasses)	Benefit transfer of efficient Carbon price from the low reduction scenario	Horlings et al. (2020b)
Cultural services	Outdoor recreation	Tourism or local recreation-related services in coastal and marine ecosystems	Monetary values extracted from project-level accounts	Vallecillo Rodriguez et al. (2018)

Table 2.

Marine ecosystem extent accounts for the OSPAR area by EUNIS classification. Data were sourced from manipulation of the EUSeaMap (2019) and European Environmental Agency Ecosystem Accounts (2018). Disaggregation to lower EUNIS levels is provided in Suppl. material 1.

Ecosystem type (EUNIS Level 2)	**Extent area (km^2)**	**Data source**
A2: Littoral sedimentary habitats*[36]	14,989	European Environmental Agency Ecosystem Accounts (2018)
A3: Infralittoral rock and other hard substrata	2,430	EUSeaMap (2019)
A4: Circalittoral rock and other hard substrata	2,851	
A5: Sublittoral sediment	6,785	
A6: Deep-sea bed	4,200,113	
Total Area	9,237,542	-

Table 3.

Marine Ecosystem Service supply account for the OSPAR area in physical and monetary values, between 2012 and 2019. Empty cells denote unavailable data.

Value	**Ecosystem Service**	**EUNIS Habitat**	**Unit**	**Accounting year**							
				2012	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Physical	Fish provisioning	A2, A3, A4, A5, A6	Mt	8.11	8.46	8.66	9.15	8.33	9.34	9.32	8.14
	Provisioning from aquaculture*[37]	A2, A3	Mt	2.07	1.96	2.12	2.16	2.11	2.15	-	-
	Carbon sequestration and capture	A2, A5, A6	Mt CO_2 equivalent	-	-	-	-	-	-	-	40.31
	Outdoor Recreation*[38]	A2 (in addition to adjacent coastal areas)	no. visits	200,778	-	-	-	-	-	-	-
Monetary	Fish provisioning	A2, A3, A4, A5, A6	mill. €	-	-	-	1,728	2,846	2,641	2,165	-
	Provisioning from aquaculture	A2, A3	mill. €	-149	1,416	1,392	1,248	4,215	3,684	-	-
	Carbon sequestration and capture	A2, A5, A6	mill. €	-	-	-	-	-	-	-	1,612
	Outdoor Recreation*[38]	A2 (in addition to adjacent coastal areas)	mill. €	253	-	-	-	-	-	-	-

Table 4.

Marine Ecosystem Service use accounts for the OSPAR area in physical and monetary values. Empty cells denote unavailable data.

Values	**Ecosystem Services**	**Units (year*[39])**	**Industry**	**Households**	**Government**
			Agriculture, forestry, fisheries		
Physical	Fish provisioning	Mt fish landings (2019)	8.14	-	-
	Carbon sequestration	Mt CO2 equivalent captured (2019)	-	-	40.31
	Outdoor recreation	No. visits (2012)	-	200,778	-
Monetary	Fish provision	mill. € (2018)*[40]	2,165	-	-
	Carbon sequestration	mill. € (2019)*[40]	-	-	1,612
	Outdoor recreation	mill. € (2012)*[40]	-	253	-

Supplementary materials

Suppl. material 1: Ecosystem accounts additional information

Authors: Maria Granada Alarcon Blazquez
Data type: Word
Brief description: Further disaggregation of ecosystem extent and information on condition indicators
SM1.1. OSPAR habitats
Table SM1.1.a: The extent of OSPAR marine habitats (EUNIS classification 2, 3, and 4).
Figure SM1.1.b.: OSPAR seabed habitat map disaggregated based on EUSeaMap 2019 (EUNIS classification).
SM1.2. OSPAR quality status and pressure indicators
Download file (277.72 kb)

Suppl. material 2: Methodology and data used to estimate ecosystem accounts

Authors: Maria Granada Alarcon Blazquez
Data type: Word
Brief description:
- Methodology and data used to estimate ecosystem services in physical terms
- Calculating the net present value (NPV) of the future flows of income associated with the different ecosystem services
- Data and sources used in this study
Download file (349.40 kb)

Suppl. material 3: Overview information on the state, policy relevance and gaps of the OSPAR contracting parties natural capital accounts.

Authors: Maria Granada Alarcon Blazquez
Data type: Word
Download file (34.46 kb)