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Ecosystem Accounting Table

Accounting of marine and coastal ecosystems at the Ramsar Site, Estuarine Delta System of the Magdalena River, Ciénaga Grande de Santa Marta, Colombia

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Abstract

The Cienaga Grande de Santa Marta Ramsar Site (CGSM) is the most important Caribbean estuarine wetland in Colombia. The site represents a strategically important ecosystem supporting the national and local economy. However, their ability to provide ecosystem services has been seriously affected mainly due to changes in land use, disturbances of water flows, man-made climate change and interannual climatic variability. These circumstances led to its inclusion in the Montreux Record, a register of wetland sites on the 'List of Wetlands of International Importance' where variations in ecological character have happened, are happening or are likely to happen as an outcome of technological developments, pollution or other human interference. This paper presents the first account of marine and coastal ecosystems developed in Colombia at the Cienaga Grande de Santa Marta. Following the principles for ecosystem accounting of the System of Environmental-Economic Accounting—Ecosystem Accounting (SEEA EA), we developed accounting tables of extent and condition of ecosystems, biophysical and monetary flows of climate regulation and fishing supply and the monetary account of ecosystem assets. Results of the ecosystem account allow visualising the importance of ecosystem services of the wetland, its capacity to provide economic benefits, social welfare and livelihoods at local and national level. Finally, we identify main gaps of information, highlight the applicability of ecosystem accounting to policy- and decision-making on economic and environmental issues and evaluate the challenges to implement it.

Keywords

ecosystem extent, ecosystem condition, marine and coastal ecosystem services, Ramsar Site, Cienaga Grande de Santa Marta

Introduction

Healthy ecosystems and biodiversity are fundamental to supporting and sustaining our welfare, local communities and economies (United Nations 2021). Therefore, ensuring a good condition of wetlands is key to providing essential ecosystem services that contribute to people's livelihoods (Convención de Ramsar sobre los Humedales 2018). However, since 1970, these ecosystems are suffering a rapid decline worldwide, reporting losses up to 35% of the natural wetlands. The quality of the remaining wetlands is also affected by factors such as drainage, pollution, invasive species, unsustainable use, alteration of flow regimes and climate change (Convención sobre los Humedales 2021).

In addition, those responsible for policy- and decision-making tend to underestimate the value of wetlands and their benefits for nature and humankind (Convención de Ramsar sobre los Humedales 2018). The formulation usually overlooks the evaluation and mapping of the ecosystems and their services, which is essential to understand how these ecosystems contribute to human welfare (Burkhard and Maes 2017). Although the concept of ecosystem services (ES) has been widely accepted, included in the formulation of policies and widely recognised with regard to better environmental management, its practical applications are still limited (Costanza et al. 2017). Likewise, in many countries, development indicators, such as the Gross National Product, are insufficient for measuring the contributions of nature to social welfare and the impacts of economic growth on nature. Consequently, the need for transforming the way in which we value nature and adopt integral approaches has been identified, thus allowing us to reflect their true value on all policies, plans and economic systems.

Recent approaches such as natural capital accounting and its official international framework, the System of Environmental-Economic Accounting (SEEA), have been created in order to give visibility to nature’s contributions to economy and people, as well as to record the social and environmental impacts of economic development (Dvarskas 2019, United Nations 2021). The SEEA’s ecosystems accounting methodology (SEEA EA) was adopted in March 2021 as a standard for international statistics by the United Nations Statistical Commission and it is an international statistical framework with a spatial approach to organise biophysical information about ecosystems, monitor changes in their extent and condition, value their services and assets and link this information to measurements of economic and human activity (United Nations 2021).

To date, economic and environmental accounting has mainly focused on the terrestrial realm (Gacutan et al. 2022). However, applying the natural capital approach requires a series of methods not yet thoroughly proved in the context of decision-making for the marine environment (Hooper et al. 2019). There are some examples of applying marine and coastal ecosystems accounting. Amongst them, the cases in Port Phillip Bay in Australia (Eigenraam et al. 2016), in Long Island Coastal Bays in the United States (Dvarskas 2019) and the oceans accounting carried out in Ilawarra Lake, New South Wales in Australia (Gacutan et al. 2022) stand out. Thereupon, the need arises to design a natural capital approach that incorporates new decision-making methods for marine ecosystems.

In order to contribute to closing this gap in literature, this paper presents a case study on applying SEEA EA to the Estuarine Delta System of the Magdalena River, Ciénaga Grande de Santa Marta (CGSM). The Estuarine Delta System of the Magdalena River in the CGSM is the most important estuarine wetland in Colombia. This is due to its extent and its role in the country's economy. Its socio-economic value is represented by the fishing resources and the agricultural activities on which the towns settled in the area depend (Ramsar 2017). It is of such importance that it has been internationally distinguished with five complementary strategies for the conservation of its biological diversity: Salamanca Island Park Way, the CGSM Flora and Fauna Sanctuary, the Biosphere Reserve, an important area for the conservation of birds (IBA/AICA), and a Ramsar wetland site (Fig. 1).

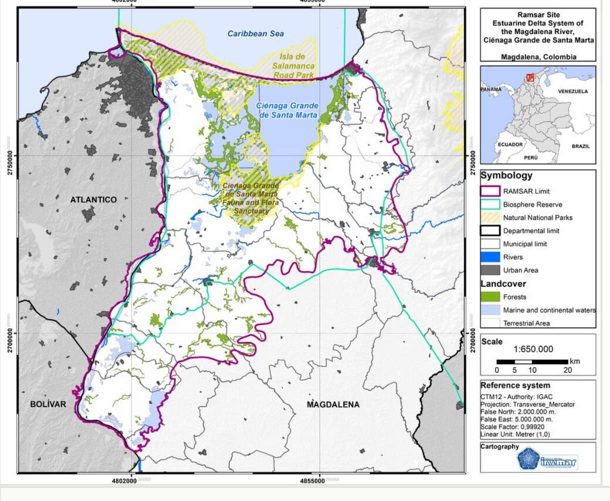

Figure 1.

Map of the CGSM Ramsar Site.

The CGSM is located in the Department of Magdalena, Colombia and shares borders in the north with the Caribbean Sea, in the south with the alluvial plains of the Fundación River, in the east with the foothills of the Sierra Nevada de Santa Marta and in the west with the Magdalena River (Moreno-Sánchez and Maldonado 2011). It harbours strategic terrestrial, freshwater and marine and coastal ecosystems, amongst which the largest mangroves in the Colombian Caribbean stand out (Ramsar 2017), performing environmental functions and generating global benefits as a carbon sink and a shelter and habitat for flora and fauna, in addition to generating livelihoods with food and raw materials extraction (Contreras 2016).

The interaction between fresh and seawater throughout the year greatly influences the physical-chemical characteristics of the wetland, especially their salinity levels. The interannual variability of the salinity, though, is related to El Niño–Southern Oscillation. These changes, in turn, affect fisheries (Vargas et al. 2022).

In 1998, the CGSM was included in the list of International Important Wetlands of the Ramsar Convention on the basis of the following criteria (Ramsar 2017):

1. It is a unique or representative wetland.
2. It has a great diversity of species associated with different types of vegetation, such as mangroves, flooded forests, tropical deciduous forests and herbaceous and aquatic vegetation, which provide said species with habitats, shelter and food.
3. It is the most important area for aquatic birds in the Colombian Caribbean.
4. It is relevant at the local, regional and global levels with regard to ES.

However, despite its great importance, the CGSM lagoon complex has reached an advanced state of environmental deterioration, as a product of anthropogenic activities related to the decrease in the Sierra Nevada de Santa Marta's river flow, given its partial diversion for agricultural purposes, in addition to the construction of the Barranquilla-Ciénaga (between 1956 and 1960) and Palermo-Sitio Nuevo (in the 1970s) roads. This construction caused the closing of some exchange inlets between the sea and the CGSM and it decreased connectivity between the Magdalena River and the CGSM, entailing an increase of salinity in mangrove soils due to the alteration of hydric flows (INVEMAR 2021).

Considering the above, according to INVEMAR- Instituto de Investigaciones Marinas y Costeras "José Benito Vives de Andréis" (2002), an "Integral program for CGSM environmental recovery" was projected in the 1990s, with inter-institutional participation. It stated "contributing to the improvement of the ecological and socio-economic conditions of CGSM and its inhabitants" as a long-term objective, highlighting the works of hydraulic ordering (dredging a five-channel network) that re-established the hydric exchanges between the Magdalena River, the different water bodies in the whole CGSM lagoon complex and the Caribbean Sea. INVEMAR then started to monitor the behaviour of the place with regard to water quality, the evolution of the CGSM's plant and fishing resources and, in general, the changes taking place there, in order to integrally evaluate the impact of the new hydrological regime in the ecological recovery process of the different habitats that are part of the ecoregion.

This process, interrupted in 1996, was taken up in 1999 as a response to the need for evaluating the potential impacts generated by the aforementioned hydraulic works. This monitoring was framed, until 2002, within a project funded by the Inter-American Development Bank (IDB) and the Ministry of the Environment, which was led by INVEMAR. Correlatively, the hydro-sedimentological monitoring started in 2017. To date, the monitoring continues to be performed by INVEMAR, with financial support of the Ministry of the Environment and CORPAMAG (Arias et al. 2021).

In addition, many of the services provided by the CGSM to society have not been valued in all their true dimensions. Thereupon, many of the decisions that have affected the CGSM ecoregion have been made, based on deeply biased analyses, which have not considered the different dimensions of its value (Vilardy and González 2011). ES are the natural nexus between natural and social systems, so their proper valuation and integration in decision-making processes facilitate an integrated management of the CGSM ecoregion.

In short, the CGSM has suffered multiple human interventions that had led to its deterioration and it has simultaneously undergone public policy actions for its conservation.

In this scenario, the Ramsar counselling mission No. 82 of 2017 assessed the CGSM's ecosystem conditions and, as a result, the place was included in the Montreux Record, given that strong changes in the system's ecological characteristics were observed, which were due to the loss of water balance and anthropogenic action. As one of the urgent actions, the mission suggested the preparation of an executive synthesis integrating different sources of information in order to facilitate the understanding of changes in the socio-ecological system (Ramsar 2017). This priority action evidences that integrating and interpreting information from multiple sources is a challenge for the actors interested in the conservation of the CGSM's ecosystems, thus exposing the need for generating tools that allow synthesising changes in ecosystems and their effects on delivering ES.

The above-presented context and the availability of information make the CGSM Ramsar site a suitable area for carrying out a SEEA EA pilot test. Therefore, this article presents the marine and coastal ecosystems accounts implemented in the Ramsar CGSM site, following the standards established by the SEEA EA 2021. Thus, this is the first ecosystems account applied in a coastal marine context in Colombia.

This is developed in Section 2, where the spatial units for ecosystems accounting are designated; a correspondence with the reference classification system of the SEEA ecosystems is established, which is based on the IUCN's global typology of ecosystems (Keith et al. 2020); condition indicators are proposed for the ecosystems and their services; and data from the study area are compiled. In Section 3, accounting tables are elaborated for the ecosystems' extent (period 2012-2018) and condition (2017-2019), as well as for the ES in biophysical and monetary terms (2015-2019) and the monetary account of the ecosystems' assets (2015-2019), following the principles for ecosystems accounting proposed by SEEA EA (United Nations 2021). Finally, in Section 4, the main information gaps and challenges for applying ecosystems accounting in marine and coastal landscapes are analysed, as well as the applicability of ecosystems accounting in decision-making and in generating environmental and economic policies.

Data and methods

Designation of spatial units for ecosystem accounting

To carry out this study, the three types of spatial units for ecosystem accounting proposed in SEEA EA 2021 were used. The primary spatial units for ecosystem accounting are called ecosystem assets (EA). EAs are contiguous spaces in a specific ecosystem type, characterised by a different set of biotic and abiotic components and their interactions. They play a key role because they are the statistical units for ecosystems accounting, that is, the ecological entities about which information is sought and statistics are finally compiled. This includes information about their extent, condition and the biophysical flows of the provided ES and their monetary value (United Nations 2021).

The second spatial unit type for ecosystems accounting is the area for ecosystems accounting (EAA), which is the geographical territory for which the ecosystems account is compiled. Therefore, the EAA determines which ecosystem assets are included in an ecosystem account (United Nations 2021).

The third type of spatial unit is the basic spatial unit (BSU), which is a geometric construction representing a small spatial area. The purpose of BSUs is to provide a fine-level data framework where data on varied characteristics can be incorporated (United Nations 2021) (Fig. 2).

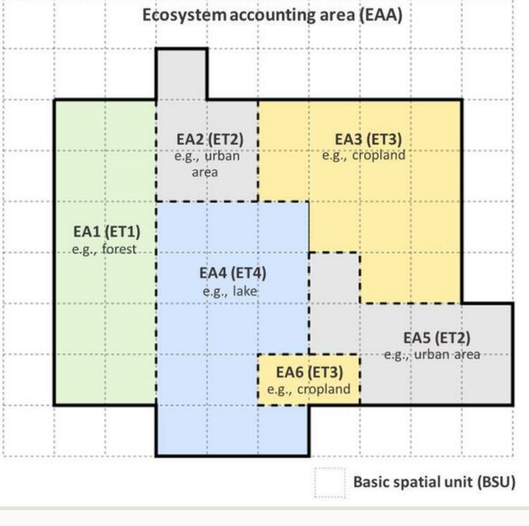

Figure 2.

Spatial units for ecosystem accounting. Source: United Nations (2021).

Table 1 shows the three types of spatial units used for ecosystems accounting in our study area.

Table 1.

Spatial units for ecosystem accounting in the CGSM Ramsar site.

Types of spatial units	**SEEA EA CGSM Ramsar Site**
Ecosystem accounting area (EAA)	Cienaga Grande de Santa Marta Ramsar Site
Ecosystem assets (EA)	Land cover types present in the CGSM Ramsar Site based on the National Legend of land cover adapted for Colombia scale 1:100,000 (IDEAM 2010)
Basic spatial units (BSU)	Minimum mapping units: 5 ha for artificialised territories, 25 ha for agricultural territories, forests and semi-natural areas, wetlands and water surfaces (IDEAM 2021)

SEEA reference ecosystem types of classification, based on the IUCN's Global Ecosystem Typology

The SEEA EA provides a reference classification for ecosystem types, based on IUCN's global ecosystem typology, which was proposed by Keith et al. (2020). However, at the national or subnational level, the SEEA EA framework establishes that it may be more appropriate to compile accounts by using an existing ecosystem types of classification and relating it to the SEEA's reference ecosystems classification for international comparison purposes (United Nations 2021).

Table 2 establishes the correspondence between the two types of coverage/ecosystem (EA) in the CGSM's Ramsar site, based on the *National Legend of Land Cover* adapted for Colombia (IDEAM 2010) and the SEEA's reference ecosystems classification, based on the IUCN's global ecosystem typology (Keith et al. 2020) (Fig. 3).

Table 2.

Correspondence between ecosystem assets (EA) and types of ecosystems according the SEEA and IUCN's global ecosystem typology. Source: Own elaboration, based on IDEAM (2010), Keith et al. (2020).

Corine Land Cover level 2 (Adapted for Colombia, IDEAM 2010)	**Biome (IUCN Typology 2020)**		**Ecosystem Functional Group (IUCN Typology 2020)**	
1.1. Urban Areas	T7	Intensive land-use systems	T7.4	Urban and industrial ecosystems
1.2. Industrial or commercial areas				
1.3. Mining extraction areas and tailings				
1.4. Artificial green areas, non-agricultural				
2.1. Transitory crops			T7.1	Annual croplands

Corine Land Cover level 2 (Adapted for Colombia, IDEAM 2010)	Biome (IUCN Typology 2020)		Ecosystem Functional Group (IUCN Typology 2020)	
2.2. Permanent crops			T7.3	Plantations
2.3. Pastures			T7.2	Sown pastures and fields
2.4. Heterogeneous agricultural areas			T7.5	Derived semi-natural pastures and oldfields
3.1. Forests	MFT1	Brackish tidal systems	MFT1.2	Intertidal forests and shrublands
3.2. Areas with herbaceous and/or shrubby vegetation	T3	Shrublands & shrubby woodlands	T3.1	Seasonally dry tropical shrublands
3.3. Open areas, with little or no vegetation	MT1	Shoreline systems	MT1.3	Sandy shores
4.1. Continental wet areas	TF1	Palustrine wetlands	TF1.3	Marshes
4.2. Coastal wet areas				
5.1. Inland waters	F1	Rivers and streams	F1.2	Permanent lowland rivers
	F2	Lakes	F2.1	Large permanent freshwater lakes
5.2. Maritime waters	FM1	Semi-confined transitional waters	FM1.3	Intermittently closed and open lakes and lagoons

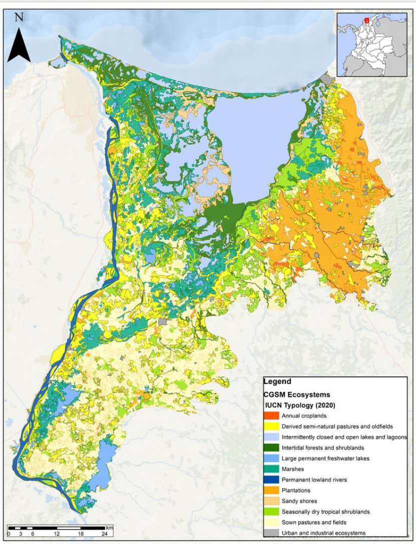

Figure 3.

Ecosystem assets (EA) in the Cienaga Grande de Santa Marta Ramsar site according to the IUCN's global ecosystem typology. Source: Own elaboration, based on Keith et al. (2020).

Data compilation and processing

To carry out this study, environmental and socio-economic data were collected and analysed which were spatially differentiated and available for the study area. These data contain information regarding ecosystem extent, condition and services. Later, with this information, the accounting tables proposed within the SEEA EA framework were elaborated.

Table 3 shows the variables and the data sources employed in this research.

Geographical data for the ecosystem extent account were obtained through a multitemporal analysis of land cover at a CORINE Land Cover scale of 1:100,000 for the years 2012 and 2018 (IDEAM 2021). This geographical information is available online. EA extent data were obtained for these two years and the calculations for gains and losses were carried out. This balance is a necessary input in order to elaborate the first table for ecosystem extent accounting in the CGSM Ramsar site during the 2012-2018 accounting period.

Table 3.

Data and information used in the study.

Variable	Measurement unit	Years	Source of data	SEEA EA application
Land Cover	ha	2012 -2018	CORINE Land Cover Methodology Adapted for Colombia (IDEAM 2021)	Ecosystem extent account
Interstitial salinity	dimensionless	2017-2019	Information System for Mangrove Management in Colombia - SIGMA (INVEMAR 2020b)	Mangrove ecosystem condition account. Abiotic characteristics, chemical state
Basal area	m^2 ha^{-1}	2017-2019	Information System for Mangrove Management in Colombia - SIGMA (INVEMAR 2020b)	Mangrove ecosystem condition account. Biotic characteristics, structural state
Seedlings and propagules density	number * m^{-2}	2017-2019	Information System for Mangrove Management in Colombia - SIGMA (INVEMAR 2020b)	Mangrove ecosystem condition account. Biotic characteristics, functional state
Bird species richness	number	2017-2019	Technical monitoring reports during the rehabilitation of the CGSM (INVEMAR 2018, INVEMAR 2019)	Mangrove ecosystem condition account. Biotic characteristics, compositional state
Changes in mangrove area (SDG 6.6.1)	ha	2017-2019	Mangrove forest extent indicator, CGSM (INVEMAR 2022)	Mangrove ecosystem condition account. Landscape/seascape characteristics

Variable	Measurement unit	Years	Source of data	SEEA EA application
Total suspended solids - SST	mg l^{-1}	2017-2019	Marine environmental quality information system REDCAM (INVEMAR 2020c)	Coastal lagoons ecosystem condition account. Abiotic characteristics, physical state
Dissolved oxygen	mg O_2 l^{-1}	2017-2019	Marine environmental quality information system REDCAM (INVEMAR 2020c)	Coastal lagoons ecosystem condition account. Abiotic characteristics, chemical state
Surface salinity	dimensionless	2017-2019	Marine environmental quality information system REDCAM (INVEMAR 2020c)	Coastal lagoons ecosystem condition account. Abiotic characteristics, chemical state
Fish species richness	number	2017-2019	INVEMAR Fisheries Information System (INVEMAR 2021)	Coastal lagoons ecosystem condition account. Biotic characteristics, compositional state
Fish catch	tonne * $year^{-1}$	2015-2019	INVEMAR Fisheries Information System - SIPEIN (INVEMAR 2021)	Fishing resources ecosystem service account
Carbon storage	tonne	2015-2019	Boden et al. (2010), INVEMAR (2020a)	Carbon storage ecosystem service account
Carbon sequestration	tonne * $year^{-1}$	2015-2019	Information System for Mangrove Management in Colombia - SIGMA (INVEMAR 2020b)	Carbon sequestration ecosystem service account

The first step was to homologate the CORINE Land Cover legend for the two geographical layers. Once the data were standardised, the total land cover area for each year of study was generated by calculating the geodesic area with the ArcGIS 10.5 software. Then, the calculations were compiled in Excel tables to facilitate their analysis and visualisation.

Later, with the area database, the transitions were calculated through the intersection geo-processing, which allows comparing the geographical layers of the two time periods in order to compile a matrix of ecosystem type changes. This matrix shows the area of different ecosystem types at the beginning of the accounting period (opening extent), the increases and decreases in this area according to the ecosystem type it was converted from (in the case of increases) or the ecosystem type it was converted to (in the case of decreases) and the area covered by different types of ecosystems at the end of the accounting period (closing extent) (United Nations 2021).

Condition accounts were applied to mangrove forests and coastal lagoons for the 2017-2019 period only, due to data availability. In these ecosystems, the values for the years 2017, 2018 and 2019 were reported for the selected indicators and variables. The information used was taken from the *Information System for Mangrove Management in Colombia* (SIGMA), the *Information System of Marine Environmental Quality* (REDCAM), *INVEMAR’s Fishing Information System* (SIPEIN) and the technical reports of CGSM’s

Monitoring of Environmental Conditions and Structural and Functional Changes of the Vegetable Communities and Fishing Resources during CGSM Rehabilitation.

The ES included in this account are the global climate regulation service and the wild fish and other natural aquatic biomass provision service. For their classification, the reference list of ecosystem services proposed by the SEEA EA framework was considered. The global climate regulation services are the ecosystems' contributions to decrease greenhouse gas (GhG) concentration in the atmosphere through carbon removal (sequestration) from the atmosphere and carbon capture (storage) in ecosystems (United Nations 2021). In this study, accounts were generated for carbon sequestration and storage in CGSM mangroves between 2015 and 2019. The model to estimate reservoirs considers above- and belowground carbon as the two main components that are stored in a mangrove. For estimating aboveground carbon stocks in the CGSM, an approach was employed which was based on the relationships established between the diameter at breast height of mangrove trees and the aboveground biomass. Diameter at breast height data were taken from the mangrove monitoring carried out in the CGSM (INVEMAR 2020).

In this way, the aboveground carbon stock contained in the aerial biomass of the trees in the six mangrove monitoring stations of the CGSM was estimated according to Kauffman and Donato (2012). The procedure described in Yepes et al. (2016) was followed to this effect. Due to the geographical closeness, the allometric equations of Smith and Whelan (2006) were used for estimating the aerial biomass of *Rhizophora mangle* and *Avicennia germinans*. On the other hand, the belowground carbon content reports from four CGSM basin mangrove stations were used (Perdomo Trujillo et al. 2020) as the total underground carbon estimates both in basin and fringe/riverine mangroves. These reports have assessed the carbon content at a 1 m depth. The total carbon corresponds to the sum of above- and bellowground carbon.

Carbon sequestration was assessed by relating the annual changes in the carbon content of the aboveground biomass of the monitoring stations in INVEMAR's mangrove to the time elapsed between year-to-year measurements. Only aboveground carbon sequestration was reported. In the CGSM, recent changes regarding the carbon in the soil have not been assessed, thus allowing us to estimate the belowground carbon sequestration.

In order to estimate the carbon price, the carbon tax rate regulated in Colombia via Article 221 of Law 1819 of 2016 was used. For the year 2017, it was set at USD 5 per tonne of CO_2 generated, with an annual adjustment dependent on national inflation (Congreso de la República de Colombia 2016); this information was obtained from The World Bank (2022).

To quantify the wild fish and other natural aquatic biomass provision, ES, SIPEIN data on the CGSM were used, taking 2015-2019 as the study period. This information allowed estimating the total catch (tonne * year^{-1}) by group of organisms (fish, crustaceans and molluscs). Data correspond to those collected and estimated by the SIPEIN, selecting 2015-2019 as the study years. The physical and monetary information of the fishing resource was presented, making specifications for four landing places, where information was collected and then distributed to all of the CGSM. In the monetary valuation of the fishing resources, the market-price method was used, as the SIPEIN collects information through surveys on the trading primary prices, that is, the exchange between the fishermen and their customers. The SIPEIN provides information on the income received by group of organisms, including only artisan fishing because it is the only one carried out in the study area.

Indicator elaboration

This study proposes indicators to measure both the ecosystems' condition and the wild fish provision and global climate regulation ES flows. For these indicators, values for the accounting period 2015-2019 were reported.

According to the ecosystem accounting framework, the ecosystem condition accounts are commonly compiled by ecosystem type, as each ecosystem type has different characteristics. Likewise, the structure of the ecosystem condition accounts depends on the variables selected, data availability, accounts usage and the general application of policies (United Nations 2021).

For our pilot, the set of indicators used to measure the ecosystems' condition was focused on mangroves and coastal lagoons for the cases of carbon capture and storage in mangrove forests. For the case of fishing resources, estimations of the total catch (tonne * year^{-1}) were carried out by group of organisms recorded in the CGSM.

To compile the ecosystem condition accounts, the ecosystem condition (SEEA ECT) typology proposed by SEEA EA was used, which is a hierarchical classification consisting of six classes grouped into three main groups, i.e. the abiotic, biotic and landscape characteristics of ecosystems (Czúcz et al. 2021). This typology has three development stages. The first stage consists of defining and selecting the system characteristics and their associated variables. For the mangroves, a total of five variables were selected: basal area (cross sectional area of trees at breast height), seedling and propagule density, interstitial salinity, bird species richness and change in extent of the ecosystems related to water over time (ODS indicator 6.6.1). These variables cover five classes of the ecosystem condition typology (ECT). For the case of coastal lagoons, four variables were selected: dissolved oxygen, total suspended solids, superficial salinity and fish species richness, which cover three ECT classes (Table 4).

The second stage involves deriving the ecosystem indicators from the variables. In the first place, establishing reference levels for specific condition variables is required. Then, the indicators are calculated, rescaling the data of the individual variables and using the reference levels as high or low limits in the variable range. Finally, the information content of indicators is added to calculate the condition indices.

Reference level values used in the ecosystem condition accounts were established from bibliographic reports. For the mangrove condition account, the reference level values used were: *Interstitial salinity.* Reference intervals to calculate the Mangrove Biological Integrity

Indicator (IBIm) for the Cienaga Grande de Santa Marta (INVEMAR 2022). At lower salinity levels, the condition of the mangrove improves. ***Bird species richness.*** Bird species reported by Moreno-Bejarano and Álvarez-León (2003). ***Basal area***. Ranges established by Department from bibliographic reports (INVEMAR 2022). ***Seedlings and propagules density***. Reference intervals to calculate the IBIm for the Cienaga Grande de Santa Marta (INVEMAR 2022). ***Changes in mangrove area (SDG 6.6.1).*** Indicator of extent of mangrove forests, case Cienaga Grande de Santa Marta - CGSM for the period 1956 - 2019 at scale 1:50000 (INVEMAR 2022).

Table 4.

Condition indicators of mangrove and coastal lagoons adapted to the ecosystem condition typology (SEEA ECT).

		Mangrove		**Coastal lagoons**	
SEEA Ecosystem Condition Typology Class		**Variable descriptor**	**Measurement unit**	**Variable descriptor**	**Measurement unit**
Abiotic characteristics	Physical state	*No variable selected*		Total suspended solids	mg l^{-1}
	Chemical state	Interstitial salinity	dimensionless	Dissolved oxygen	mg O_2 l^{-1}
				Surface salinity	dimensionless
Biotic characteristics	Compositional state	Bird species richness	number	Fish species richness	number
	Structural state	Basal area	m^2 ha^{-1}	*No variable selected*	
	Functional state	Seedlings and propagules density	number * m^{-2}	*No variable selected*	
Landscape/seascape characteristics		Changes in mangrove area (SDG 6.6.1)	ha	*No variable selected*	

The reference level values used in the coastal lagoons condition account were: *Total suspended solids.* Reference values to classify water quality (INVEMAR 2021). At lower concentration of total suspended solids, the condition of the ecosystem improves. *Dissolved oxygen.* Concentration defined by Colombian regulations for warm fresh waters, estuarine waters and marine waters (4.00 mg O_2 l^{-1}) (INVEMAR 2021). *Surface salinity.* Minimum and maximum salinity values recorded in the CGSM between October 2016 and September 2019 (INVEMAR 2018, INVEMAR 2019). At lower salinity levels, the condition of the ecosystem improves. *Fish species richness.* Commercial fishing species of the CGSM ecoregion (INVEMAR 2021).

Population of accounting tables

The charts for accounting the extent, condition and monetary assets of the ecosystems were elaborated by following the account structure suggested by the SEEA EA accounting framework. Once elaborated, the main information gaps and challenges were identified for implementing ecosystems accounting in a marine-coastal landscape, such as the CGSM Ramsar site. Challenges were identified to attribute ES provision to a specific ecosystem type, in particular for the case of the fishing provision ES. In this study, individual charts for the global climate regulation and the wild fish provision services were presented with data in physical and monetary units.

Accounting tables and results

Ecosystem extent account

Suppl. material 1 presents the table for accounting the asset extent of the CGSM Ramsar site ecosystems with the opening and closing stocks for the accounting periods 2012 and 2018.

The ecosystem assets with the highest losses in the 2012-2018 accounting period were pastures, continental wet areas and mangrove forests. The highest gains were recorded in permanent crops, areas with herbaceous and/or shrub vegetation and open areas with little or no vegetation (Fig. 4).

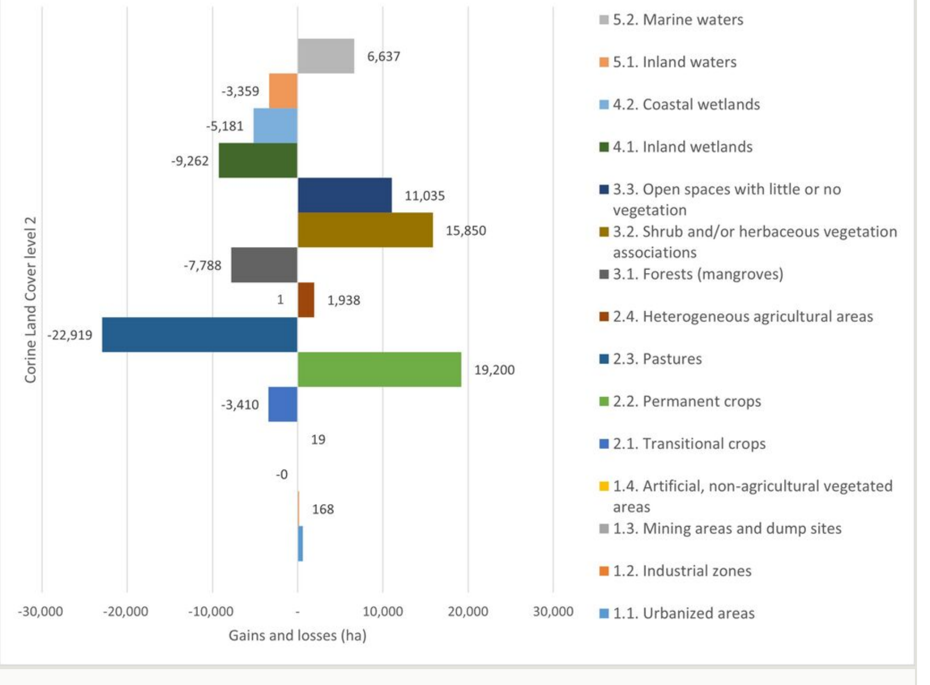

Figure 4.

Gains and losses (ha) of ecosystem assets (EA) for the accounting period 2012 - 2018.

Matrix of changes in ecosystem types

Suppl. material 2 presents the second chart model for accounting the ecosystem extent, which corresponds to the matrix of changes in the ecosystem types present in the CGSM Ramsar site during the 2012-2018 accounting period.

Mangrove forests, continental wet areas and pastures became mainly permanent crops, heterogeneous agricultural areas, areas with herbaceous and/or shrub vegetation and open areas with little or no vegetation (Fig. 5).

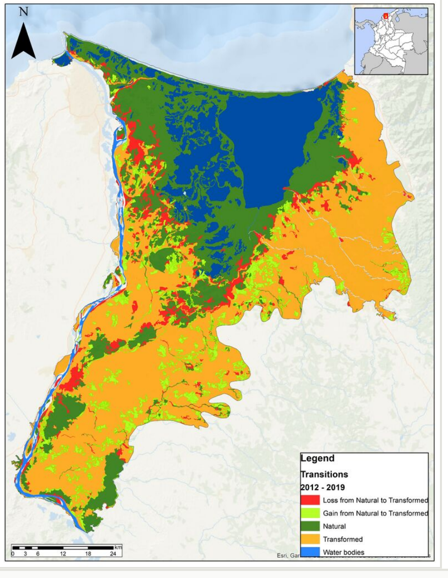

Figure 5.

Transitions between ecosystem types (CORINE Land Cover) at the CGSM Ramsar site, 2012-2018 Source: Own elaboration, based on IDEAM (2021).

Ecosystem condition account: Condition of mangroves and coastal lagoons

Suppl. material 3 corresponds to the combined version of the accounting table for the mangrove ecosystem condition in the CGSM Ramsar site for the 2017-2019 accounting period.

In the Table, the green cells represent the ecosystem condition variables, which constitute the result of the first stage of the condition accounts compilation. The yellow cells represent the ecosystem condition indicators corresponding to the second stage and the blue cells represent the ecosystem condition aggregate, which is a product of the third stage of the accounting compilation. The results show:

- An increase in the total value of the abiotic indices due to a decrease in interstitial salinity.

- An increase in the biotic indices due to an increase in bird species richness and the presence of seedlings and propagules (however, the basal area showed a decrease during this accounting period).
- An increase in the landscape indices due to an increase in mangrove forest areas in the CGSM Ramsar site during the 2017-2019 period.

Suppl. material 4 presents the combined account of the coastal lagoon ecosystem conditions in the CGSM Ramsar site for the 2017-2019 accounting period.

The results show:

- A decrease in the total values of the abiotic indices due to a decrease in the dissolved oxygen concentration and an increase in the superficial salinity.
- A decrease in the values of biotic indices as a consequence of a decrease in the fish species wealth for the coastal lagoons of the CGSM Ramsar site during the 2017-2019 accounting period.

Table 5 presents the condition indices account, showing a derivation of the aggregate measurements of the mangrove and coastal lagoon ecosystems in the CGSM for the 2017-2019 accounting period.

Table 5.

Condition indices account (2017-2019). Source: Own elaboration, based on INVEMAR (2020b) and INVEMAR (2020c).

	Mangroves	**Coastal lagoons**
Opening condition value	0.47	0.66
Change in abiotic ecosystem characteristics	0.01	-0.01
Change in biotic ecosystem characteristics	0.03	0
Change in landscape/seascape level characteristics	0.01	*
Net change in condition	0.06	-0.01
Closing condition value	0.53	0.65

The results show a net positive change in mangrove conditions, as a consequence of an increase in the values of biotic, abiotic and landscape characteristics. On its part, the coastal lagoons showed a net negative change due to a decrease in the values of the biotic and abiotic characteristics.

Ecosystem services account: Wild fish and other natural aquatic biomass provision service account

Table 6 shows the fishing resources provision ES accounting table for the period 2015-2019.

Table 6.

Fishing resources ES account: total catch (tonne * $year^{-1}$) per group of organisms recorded in the CGSM, 2015-2019 accounting period. Own elaboration, based on SIPEIN data (INVEMAR 2021).

Catch (tonne * $year^{-1}$)					**Monetary value of production (USD real prices 2015 = 100%)**
	Fish	**Crustaceans**	**Molluscs**	**Total**	
Catch 2015	4,028.70	839.4	243.5	5,111.60	3,822,273
Catch 2016	3,498.10	877.8	241.4	4,617.30	3,336,211
Catch 2017	4,027	1,410.10	362.8	5,799.90	4,019,520
Catch 2018	4,845.30	1,190	0	6,035.30	3,472,761
Catch 2019	4,455	1,369	0	5,824	3,517,142
Net change in catches 2015-2019	426.3	529.6	-243.5	712.4	-305,131

The total catch has varied between 4617 and 6035 tonne * $year^{-1}$, showing a net positive change of 721 tonne * $year^{-1}$ for the 2015-2019 accounting period. Fish, followed by crustaceans, recorded the highest catches in the CGSM during this accounting period. SIPEIN did not collect information on mollusc catches during the 2018-2019 period due to logistical issues, which entailed a catch underestimation of these resources for this year (INVEMAR 2019).

Ecosystem services account: Global climate regulation service account

Table 7 shows the accounting table for the carbon storage ES provided by the mangrove ecosystem in the CGSM Ramsar site during the 2015-2019 accounting period.

Table 7.

Carbon storage ES provided by mangrove forests at the CGSM Ramsar site (2015-2019). Own elaboration, based on Boden et al. (2010) and INVEMAR (2020a).

Above- and belowground carbon stock (tonne)				**Monetary value of production (USD real prices 2015 = 100%)**
	Fringe/ riverine	**Basin**	**Total mangrove**	
Initial stock 2015	410,000	13,250,000	13,660,000	68,300,000
Final stock 2017	400,000	10,210,000	10,610,000	51,504,854
Final stock 2018	390,000	10,740,000	11,130,000	60,102,000
Final stock 2019	400,000	11,010,000	11,410,000	55,130,561
Net change in carbon stock (2015-2019)	- 10,000	-2,240,000	-2,250,000	-13,169,439

The carbon stock account shows a decrease in the aboveground carbon content during the 2015-2019 period for the different CGSM mangrove types. By 2019, the mangrove carbon content was 16.5% lower than in 2015, evidencing the deterioration suffered by the CGSM mangrove, especially between 2015 and 2017, when the highest decrease took place in the biophysical and monetary stocks. During 2018 and 2019, a positive increase in the biophysical carbon took place, but, in monetary terms, there was a stock decrease, a situation made possible by the Colombian peso's devaluation against the dollar.

Table 8 shows the accounting table of the carbon sequestration ES provided by the mangrove ecosystem in the CGSM Ramsar site for the 2015-2019 accounting period.

Table 8.

Carbon sequestration ES (tonne * year^{-1}) provided by mangrove forests at the CGSM Ramsar site (2015 - 2019). Source: Own elaboration, based on INVEMAR (2020b).*[1]

Aboveground carbon sequestration (tonne * year^{-1})				Monetary value of production (USD real prices 2015 = 100%)
	Fringe/ riverine	**Basin**	**Total mangrove**	
2015-2017	-	-	-	-
2017-2018	-	-	-	-
2018-2019	1,780	-	1,780	8,600,56
Aboveground carbon emissions(tonne * year^{-1})				
2015-2017	2,590	349,980	352,570	- 1,711,504.85
2017-2018	10,950	401,210	412,160	- 2,225,664.00
2018-2019		171,820	171,820	- 830,195.70

In the carbon sequestration account, due to the deterioration of the mangrove, except for the fringe and riverine mangroves between 2018 and 2019, the different mangrove types generated carbon emissions during the 2015-2019 accounting period. Given that most of the mangrove cover corresponds to basin mangrove, this forest type shows the highest emissions.

Monetary ecosystem asset account

Table 9 presents the ecosystem assets account in monetary terms for the CGSM Ramsar site during the 2015-2019 accounting period. In order to provide a valuation of the mangrove assets, the monetary value of the CGSM mangrove carbon stock was included, which was estimated at USD 68,300,000 for 2015 and USD 55,130,561 for 2019. For the mangrove and coastal lagoon ecosystems, the annual supply flow of wild fishing in 2015 and 2019 was used in the valuation of the assets (Table 6), with the net present value method and the following asumptions: an asset lifecycle of 100 years and a social discount rate of 3.5% adopted in Colombia as a parameter in the evaluation of environmental investment projects of the public sector of more than 25 years old in the resolution of the National Planning Department (DNP) No: 1092/22 (Departamento Nacional de Planeacion 2022); the asset value reached USD 105,706,598 in 2015 and USD 97,268,070 in 2019.

Table 9.

Monetary ecosystem asset account (USD real prices 2015 = 100%).

	Mangroves	**Coastal lagoons & Mangroves**	**TOTAL**
Opening value (2015)	$68,300,000	$105,706,598	$174,006,598
Net change in value	($13,169,439)	($8,438,527)	($21,607,967)
Closing value (2019)	$55,130,561	$97,268,070	$152,398,631

Overall, there are considerable losses in the ecosystems' assets between 2015 and 2019: USD 21,607,967 were lost. There were losses in mangroves of USD 13,169,439 and in Coastal Lagoons & Mangroves of USD 8,438,527. These results show the critical condition of the CGSM's resources, with an emphasis on the emergence of a type of artisanal fishing in the area, on which families with high poverty levels depend.

Discussion

Interpretation of the results

SEEA EA ecosystems accounting is based on the acknowledgement that healthy ecosystems and biodiversity are fundamental for supporting and sustaining our welfare, communities and economies (United Nations 2021). Therefore, one of its main objectives is to establish a clear link between the ecosystems' extent and condition and the ES they provide (La Notte et al. 2022). This is the study case presented in this document, where the CGSM Ramsar site was used as reference and the ecosystems accounting approach was used to provide visibility to the relationships between ecosystem health, human welfare and economy.

The ecosystem extent account shows a decrease in the pasture, continental wet area and mangrove forest area for the period between 2012 and 2018. This may be attributed to changes in soil use, as these ecosystems mainly became permanent crops and heterogeneous agricultural areas. For the specific case of the mangrove, a significant cover loss occurred during the period 2015-2017, as a consequence of the El Niño event, which showed strong and very strong intensities in 2015 and 2016, generating a decrease in the rainfall in the Colombian Caribbean and an increase in the interstitial salinity of the CGSM, which had a negative effect on ecosystem health (INVEMAR 2022).

Nevertheless, since that year (2017), forest recovery has been evidenced, which reflects on the results of the mangrove condition accounts for the period 2017-2019. They show a net positive change in the indicators used to measure this ecosystem's condition. This change is due to a freshwater input into the lagoon system derived from the dredging works on the main channels coming from Magdalena River, as well as the absence of El Niño-related events. These freshwater inputs generated a decrease in the interstitial salinity and an increase in the seeds and propagules density during this accounting period (INVEMAR 2021, INVEMAR 2022).

As a consequence, a 3,503 ha extension also took place in the period 2017-2019, which corresponds to a 6.87% recovery of the live mangrove, as compared to the initial period in 1956, when 51,150 ha were reported. This increase is a response of the ecosystem to salinity variations and exposes the importance of keeping the freshwater flows coming into the CGSM in optimal conditions.

Regarding bird richness, there was an increase in the number of species. A total of 98 species were recorded in 2019, which corresponds to 50.52% of the reported birds for the Magdalena River delta-estuarine complex (Moreno-Bejarano and Álvarez-León 2003). It is worth highlighting that the registry of species of interest for conservation – such as the northern screamer (*Chauna chavaria*), the sapphire-bellied hummingbird (*Chrysuronia lilliae*) and the bronzed cowbird (*Molothrus aeneus*), in addition to a high number of migratory species – account for the importance of this ecosystem for the birds in the area and their conservation (INVEMAR 2019).

A clear example of the bond between the ecosystem extent and condition and ES provision can be seen in the carbon sequestration ES accounts, whose results show that the cover and/or aerial biomass losses generated carbon emissions during the period 2015-2019 (this record excludes the fringe/riverine mangrove between 2018 and 2019). This is due to the hydric stress undergone by mangroves as a consequence of El Niño event reaching strong to very strong intensities between 2015 and 2016, in addition to other disturbances, such as burnings to obtain charcoal and wetland desiccation. However, the mangrove forest emitted 182,000 less tonnes of carbon than in 2015-2017, reflecting a positive balance with regard to carbon sequestration and mangrove recovery.

The carbon storage account also presented, as it did between 2015 and 2017, the highest decrease in stored carbon for the different mangrove types in these CGSM. From these years on, there was a progressive increase in the carbon stock, as a result of the recovery in ecosystem extent and condition. However, despite the deterioration undergone by the CGSM mangroves, this system shows carbon reservoirs in the order of million tonnes. Likewise, the carbon stocks presented herein are underestimated because mangroves have carbon reservoirs at several metres in depth and the soil carbon measurements used as reference only consider 1 m.

This study's results regarding coverage and carbon sequestration follow the trend of mangroves in Ramsar sites worldwide (Convención sobre los Humedales 2021). On the one hand, the mangrove extent decreased by an average of 4% between 1997 and 2016, a loss rate estimated at 0.2% a year, which is an order of magnitude lower than the worldwide mean annual loss, estimated at 2% (Convention on Wetlands 2021). Despite that, more than two thirds of the Ramsar sites' mangroves lost surface area, which means that, not only did they lose the capacity to sequester carbon, but also suffered inevitable losses as the carbon stored in soils and biomass were liberated into the atmosphere. Another 20% of the Ramsar sites showed an increase in mangrove area and are, therefore, sequestering more carbon (Convention on Wetlands 2021).

Another link between the ecosystem condition and the provision of services can be seen in the wild fish provision ES account. The analysis performed from the monitoring of INVEMAR fishing resources allows concluding that the changes in resource availability are a response to changes in water salinity, which, in turn, is conditioned by climate variability (INVEMAR 2021). The results of the fishing resources ES account for the period 2015-2019 show that the total catch varied between 4,617 and 6,035 tonne year^{-1}, highlighting a drastic decrease in 2016, when the highest salinity records of the last two decades were obtained (INVEMAR 2019). Later, between 2017 and 2018, there was a decrease in the salinity values and a recovery of fishery – although another El Niño event took place in 2019 – showing an apparent improvement in the environmental condition of the CGSM, without evidence of a massive fish death toll as in previous years (INVEMAR 2019).

Regarding the annual composition of catch per fish species, the fish monitoring allowed identifying changes in their represention. Due to a salinity increase during El Niño event between 2014 and 2016, fishery was supported by the extraction of estuarine species. Later, in 2017, there was a La Niña event, albeit preceded by El Niño. This climate pattern favoured the estuarine species that showed the greatest appearances, also recording increases in marine species. In 2018, the La Niña event trend of 2017 continued, accordingly reporting a decrease in salinity, a condition that continued even in 2019, despite the occurrence of an El Niño event, with evident improvements in the production of freshwater species (INVEMAR 2019, INVEMAR 2021). These data coincide with the results obtained by Vargas et al. (2022), who, in a study seeking to evaluate the contribution of catch diversity to the stabilisation of fishing income in the CGSM's biosphere reserve, found that changes in the catch composition during 2012-2018 were related to the seasonal and year-to-year variations of salinity conditions and that catch mean values per effort unit were higher at intermediate salinity levels.

In short, CGSM ecosystems provide a set of services that are fundamental for the human communities inhabiting the area or interacting with the system at other geographical scales (Vilardy and González 2011). However, these ecosystem conditions, as well as their ability to provide services, has been seriously affected by changes in their biotic and abiotic characteristics, especially by the increases in the salinity levels that mainly occurred as a consequence of the alteration of hydric flows and the year-to-year climate variability. In turn, these ecosystems have also responded positively to the interventions orientated towards re-establishing the hydric regime in some CGSM areas.

This pilot study confirms the viability of ecosystems accounting with regard to providing visibility to the contributions of CGSM marine and coastal ecosystems to people and the economy, as well as the usefulness of the accounting framework to providing information for decision-making when integrating information from multiple sources about ecosystem changes and their effects on the provision of ES. Future research should focus on studying and understanding the ecological and management conditions under which the ecosystem services can be sustainably produced. It must aim at identifying management strategies that allow ensuring the continuity of key CGSM ecosystem services, such as food provision, climate regulation and tourism, amongst others. In the SEEA EA accounting context, the ecosystems' ability to provide ES is defined by their ability to generate them under management conditions and uses at the highest performance or level without affecting its future supply or that of other ES. The evaluation of the capacity of ecosystems to provide ES will depend on the complex interrelationships of multiple indicators to determine the threshold levels that define sustainability (United Nations 2021).

Data gaps and challenges for accounting in marine and coastal ecosystems

Given the complexity of the marine environment and the difficulty to collect data about it, applying the natural capital approach for the coastal marine environment poses a series of particular challenges that often require modifying methods and strategies (Hooper et al. 2019). To date, the efforts in environmental and economic accounting have focused mainly on the terrestrial domain and have given limited attention to the application of concepts, definitions and classifications to the ocean (Gacutan et al. 2022). Likewise, data and methods to evaluate the provision of marine and coastal ecosystem services are much more limited when compared to terrestrial evaluations (Liquete et al. 2013). Therefore, data availability is a key challenge, especially in the marine environment. To overcome this, a greater effort is required to develop interdisciplinary methodologies that are coherent with policies and applicable in a variety of contexts (Hooper et al. 2019). According to Barbier (2017), the greatest challenge to quantify and value marine ecosystem services is the inadequacy of the available knowledge in order to link changes in the ecosystems' structure and function to the production of valuable goods and services.

By developing the accounting tables, information gaps were identified which hindered their full elaboration with regard to extent, condition, ecosystem services and monetary assets for the CGSM Ramsar site, as data were not collected at the required spatial or temporal disaggregation level.

For the extent accounts, opening and closing extent data were obtained for all the ecosystems' assets in the CGSM Ramsar site, thanks to the availability of the land cover layers at a 1:100,000 scale of IDEAM's CORINE Land Cover for the period 2012-2018. However, difficulties were identified in attributing gains and/or losses in the ecosystem extent to natural events or anthropogenic actions.

The ecosystem condition accounts were limited to mangroves and coastal lagoons because of the data availability for these ecosystems, which stem from the monitoring of water quality, mangrove forest conditions and fishing resources published yearly by INVEMAR. However, information gaps were identified which hindered the reporting of data for all six classes of abiotic, biotic and landscape variables suggested by SEEA EA to measure the ecosystems' condition.

Regarding the ES flow accounts, difficulties were identified with regard to delimiting the specific contribution of each ecosystem to synergically generated matter and energy flows, for example, estimating the contribution of the coastal marine landscape ecosystems to the commercially important biomass of fish, crustaceans and molluscs. This is because data on fish catch are collected at CGSM landing sites and they are not specifically associated with an ecosystem. In this regard, Barbier (2017) highlights that marine and coastal ecosystems do not exist in isolation, but they are often interconnected through a continuous sea-land or marine landscape (seascape) interface. Therefore, the challenge for future research is to evaluate the benefits that arise in a highly interconnected marine landscape. An emergent and increasingly common approach to evaluating multiple ecosystem services, which is sensitive to the sociological context, is studying them as recurring sets of ecosystem services or *ecosystem services bundles* (Meacham et al. 2022).

Another important relationship in the way society receives ES corresponds to markets, whose prices were used for valuation in the case of fishing resources. It was evidenced that the biophysical increase in catches is not always directly related to the received monetary income, a situation that may be caused by price elasticity – fishing resources show inelastic supply and elastic demand. It is also necessary considering that fishing income comes from a multi-species basket of offerings with different degrees of replacement depending on consumer preferences. On the other hand, for commercialising CGSM fishing, there are institutional arrangements that influence the income received by fishermen, for instance, fishing pre-sales agreements.

Applications of ecosystem accounting

Due to its spatial approach, ecosystem accounting (SEEA EA) allows highlighting and identifying the location of ecosystems and ecosystem services of special interest for those responsible for making policies and decisions orientated towards maintaining the ecosystems' condition and the continuity of the CGSM's key ecosystem service flows. Likewise, the construction of ecosystem accounts for several years provides a common baseline that is useful for monitoring the extent, condition and service flow of the ecosystems.

The accounts compiled in this study contribute directly to collecting, organising and integrating spatially referenced data on changes in the ecosystems' extent and condition, as well as on flows of key ecosystem services, such as fishing resources provision and climate regulation, changes that are associated with the year-to-year climate variation and their effects on the CGSM's salinity, both in its water bodies and in the soil's interstitial salinity. Thus, ecosystems accounting evidenced the link between climate variability and the flow of services and benefits for the local communities.

The correspondence between the types of cover/ecosystem (EA) in the CGSM Ramsar site (IDEAM 2010) to the SEEA's reference ecosystem classification system (Keith et al. 2020) provides a common baseline that can be used for international comparison purposes, which implies an abundance of ecosystem types.

The ecosystem extent account, besides generating information about the gains and losses of ecosystem assets during the period 2012-2018, allowed identifying the nature of these ecosystems' transitions and spatially locating the critical spots where the gains and losses of natural to transformed cover have concentrated (Fig. 5). This information shows the landscape configuration change during this accounting period and sets the grounds for a complementary analysis on the possible factors that drove these transformations. That is how the decrease in the extent of strategic ecosystems, such as continental wetlands and mangrove forests between 2012 and 2018, exposes the need for monitoring coverages that are growing at the expense of these ecosystems, as well as of continuing with the management measures of channels to maintain the system's salinity in tolerable conditions in the face future high-intensity El Niño events.

Regarding the climate regulation ES, this study shows that fringe and riverine mangroves are less fluctuating than basin mangroves, which have larger extent and are more susceptible to generating carbon emissions in the face of hydric stress situations under El Niño conditions. Therefore, special management strategies are required such as carrying out channel maintenance at the beginning and during high-intensity El Niño events in order to maintain the mangrove's ability to contribute to climate regulation through carbon sequestration and storage.

Finally, this ecosystems accounting exercise in the CGSM Ramsar site allowed identifying and giving visibility to the magnitude of coastal and marine ecosystems' contributions to the economy, social welfare and livelihoods at local and global scales, contributions that, in general, have received less attention than those of terrestrial ecosystems. At a local scale, between 3,000 and 3,500 artisan workers obtain their livelihoods through the provision of fishing resources in the CGSM and they obtain much of their food security from fishing (INVEMAR 2021). At a global scale, the climate regulation ES reveals, in the carbon capture and storage accounts, that CGSM mangroves have carbon reservoirs in the order of million tonnes and that the stocks estimated for 2015 and 2019 equate to the annual carbon dioxide emissions of 19.6-25.2 million Colombians – or 2.1-2.7 million US citizens.

Articulation to the System of National Accounts and linkages to other global environmental monitoring and evaluation initiatives

The central framework and the ecosystem accounting that make up the SEEA have been designed to complement each other and have been developed within the context of the *National Accounts System* in order to provide a more complete understanding of the interrelationship between economy and environment (Edens and Hein 2013, United Nations 2021).

In Colombia, environmental and economic accounts are part of the derived statistics performed by the *Directorate of Synthesis and National Accounts of the National Administrative Department of Statistics* (DANE). SEEA materialisation is done through the environmental satellite account, which is organised and integrated into the National System of Accounts (Departamento Administrativo Nacional de Estadística 2017).

At the international level, there is a growing demand for the adoption of a systems approach and the generation of integrated information that allows reflecting the true value of nature in decision-making and the generation of economic and environmental policies. Natural capital accounting is an approach that does exactly that, integrating the environment into a more holistic analysis of policies through the compilation of economic and environmental accounts (Coates et al. 2020). Ecosystems accounting (SEEA EA), as an international statistical standard framework orientated towards supporting comparable measurements about the extent, condition and services flow of ecosystems, provides a solid basis and associated data that can be used to support the measurement activity and the presentation of reports for a series of global environmental and sustainability initiatives, including biodiversity and climate agenda (United Nations 2021).

SEEA provides a flexible framework for collecting and integrating data to support the presentation of reports on the progress towards SDOs, especially SDO 6.6.1 (i.e. changes in the extent of ecosystems related to water, which can be calculated from the extent accounts, as was demonstrated in this study). This will also help countries on other commitments to present international reports, in particular, within the framework of the Ramsar International Convention on Wetlands (UNSD 2020). The Ramsar Convention is the co-safekeeper of this indicator (SDO 6.6.1), together with the United Nations Programme for the Environment. The agreeing parties in the Convention must report on the extent of their wetlands through their national reports (Convención sobre los Humedales 2021).

Likewise, SEEA accounts can collect useful information for the elaboration of national action plans and strategies regarding biological diversity, within the world biological diversity framework after 2020 and the SDGs related to biological diversity (Coates et al. 2020). Regarding climate change, blue carbon coastal ecosystems can be included in the determined national contributions (NDC) as part of the planned solutions with respect to climate mitigation and adaptation. However, there are critical elements, such as mapping the changes in wetland extent and the determination of biomass carbon content, dead organic matter and the required soils to support effective contributions (Convention on Wetlands 2021). Therefore, ecosystem accounting has a high potential to support the measurement and reporting of these kinds of initiatives.

Finally, the high-level plan for a sustainable ocean economy launched in 2018, whose objective is to develop an action agenda for the transition towards a sustainable ocean economy, prioritises considering the total value of the assets and the ocean economy in order to guide the sustainable development of the oceans and it establishes the goal that “decision-making that affects the ocean reflects the value and impacts on the ocean’s natural capital by 2030” (United Nations 2022).

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Hosting institution

Institute of Marine and Coastal Research (Instituto de Investigaciones Marinas y Costeras José Benito Vives de Andréis – INVEMAR).

Conflicts of interest

The authors declare that this research was conducted in the absence of any commercial or financial agreement that could constitute a potential conflict of interest.

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Supplementary materials

Suppl. material 1: Ecosystem extent account (ha) in the CGSM Ramsar Site for the 2012-2018 accounting period_ doi

Authors: INVEMAR
Data type: Accounting table
Brief description: Source: Own elaboration, based on IDEAM (2021).
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Suppl. material 2: Ecosystem type change matrix (ha) in the CGSM Ramsar site for the period 2012-2018 doi

Authors: INVEMAR
Data type: Accounting table
Brief description: Source: Own elaboration, based on IDEAM (2021).
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Suppl. material 3: Combined condition account for the mangrove ecosystem types present in the CGSM Ramsar site (2017-2019) doi

Authors: INVEMAR
Data type: Accounting table
Brief description: Own elaboration, based on SIGMA (INVEMAR 2020b). Reference level values used in the mangrove condition account – Interstitial salinity: reference intervals to calculate the Biological Integrity Indicator for mangroves (IBIm) for the Ciénaga Grande de Santa Marta (INVEMAR 2022). At lower salinity levels, the condition of the mangrove improves. Bird species richness: Bird species reported by Moreno-Bejarano and Álvarez-León (2003). Basal area: Ranges established by Department from bibliographic reports (INVEMAR 2022). Seedlings and propagules: Reference intervals to calculate the IBIm for the Ciénaga Grande de Santa Marta (INVEMAR 2022). Changes in mangrove area (SDG 6.6.1): Indicator of extent of mangrove forests for the CGSM in the period 1956-2019 at a scale of 1:50000 (INVEMAR 2022).
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Suppl. material 4: Combined condition account for the coastal lagoons ecosystem types present in the CGSM Ramsar site (2017-2019) doi

Authors: INVEMAR
Data type: Accounting table
Brief description: Own elaboration, based on REDCAM (INVEMAR 2020c). Reference level values used in the coastal lagoons condition account – Total suspended solids: Reference values to classify water quality (INVEMAR 2021). At lower concentrations of total suspended solids, the condition of the ecosystem improves. Dissolved oxygen: Concentration defined by Colombian regulations for warm fresh waters, estuarine waters, and marine waters (4,00 mg O_2 l^{-1}) (INVEMAR 2021). Surface salinity: Minimum and maximum salinity values recorded in the CGSM between October 2016 and September 2019 (INVEMAR 2018, 2019). At lower salinity levels, the condition of the ecosystem improves. Fish species richness: Commercial species of the CGSM ecoregion's fishery (INVEMAR 2021).
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Endnotes

*1 Note: data of carbon fluxes are derived from five monitoring stations.