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Integrating a conceptual framework for the sustainable development goals in the mangrove ecosystem: A systematic review

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ABSTRACT

Mangrove forests are highly productive wetlands and provide essential ecosystem services for the well-being of human communities, with the Ramsar Convention being the main international agreement for planning conservation strategies for these areas of great international relevance. The present study carried out a systematic review to envision a conceptual framework on the alignment of these strategies with sustainable development (SD) and its objectives (SDGs), based on the identification of ecosystem services and their possible threats related to mangrove forest in the Ramsar classification. The study was carried out using the PSALSAR (Protocol-Search-Appraisal-Synthesis-Analysis-Report) framework and an open-access database, where the search for studies was not restricted to Ramsar Sites only. Since 1991, interest in questions about sustainable development in mangrove areas has increased, almost a decade after the first article was registered in search databases and repositories on this topic. The main SDGs addressed are related to SDG 13 (Action on Global Climate Change; 30%) and SDG 14 (Life in Water; 3%), while the goals with low performance in countries that have mangrove forests are: SDG 1 (No Poverty), SDG 2 (Zero Hunger), SDG 8 (Decent Work), SDG 13 (Climate Change), SDG 14 (Life in Water), and SDG 15 (Life on Land). However, it is still necessary to fill gaps in knowledge about the role of mangroves in the SDGs through the systematization of methods and the use of indicators that capture the socio-ecological dimensions, in order to assist in the evaluation of the SD. This requires a conceptual framework with five key elements, knowing the plan of the 2030 Agenda, SDG implementation based on ecosystem services and threats, collection and monitoring of data of the SDGs, promoting transparent and decentralized governance, and effectiveness SDGs in all countries based on the science-policy interface, which address the SDGs in this ecosystem to comply with the Ramsar Sites Strategic Plan and the 2030 Agenda, both based on the ecosystem services offered by mangroves, in order to address the identified threats and create a set of indicators for the purpose of monitoring the SDGs in relation to this ecosystem.

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1. Introduction

Mangrove forests cover more than 137,000 km^2 around the world (Giri et al., 2011), 90% of which are in developing countries (López-Angarita et al., 2016). Areas with the greatest extension of mangrove vegetation are located in Indonesia (23%), Brazil (7%), and Mexico (5%). This ecosystem is highly productive (Alongi, 2012) due to the quality and quantity of the ecosystem services it provides, such as harvesting wood and the provision of crabs (Duke and Bochove, 2014) for the well-being of coastal communities (Barbier et al., 2011). The mangrove wetland is a complex socio-ecological system (Dahdouh-Guebas et al., 2021) of worldwide importance (Duke et al., 2007) that has been suffering various threats around the world (Semeniuk and Cresswell, 2018). The main pressure vectors have been the loss of mangrove forests to replacement by aquaculture and agriculture (Thomas et al., 2017). These pressures threaten the maintenance of mangrove ecosystem services (Islam et al., 2018) and their sustainability, since tropical forests play an important role in contributing to the SDG (Swamy et al., 2018).

Sustainable development (SD) means the use of natural resources without jeopardizing the basic needs of future generations (IPCC, 2021) and designed to achieve a balance of the environmental, economic and social axes (Mensah, 2019). In 2015, the 2030 Agenda was proposed which involves commitment to the so-called five Ps: People, Planet, Prosperity, Peace, and Partnerships adopted by the United Nations (UN, 2015). Member countries of the United Nations adopted this Agenda in order to plan a prosperous future based on 17 SDGs, 169 targets, and more than 200 indicators proposed within a strategic, indivisible, and universal plan (Bennich et al., 2020), in order to solve problems in the world with the main focus on eradicating poverty (UN, 2021a). These objectives stem from the union of great efforts and treaties made since the Earth Convention in Rio de Janeiro (UN, 1992) to achieve the fulfilment of the Millennium Development Goals (UN, 2000) and came into force in 2016 to promote economic growth while protecting the environment and including social participation (Mensah, 2019).

Worldwide discussion of wetlands conservation led to the Ramsar Convention, one of the first international agreements designed to conserve and promote the sustainable use of wetlands, including mangrove forests (RAMSAR, 1971; Kingsford et al., 2021), including mangrove areas, which are currently represented at 305 Ramsar Sites throughout the world (RAMSAR, 2021). In 2015, the Ramsar Strategic Plan for 2016–2024 was also defined, proposing four objectives and 19 targets linked to the SDGs to deal with the drivers of wetland degradation and to conserve, and effectively manage a network of Ramsar Sites (RAMSAR, 2022). There is little evidence of the real impact of treaties such as the Ramsar Convention, inspection legislation or even conservation legislation (IPCC, 2022) on mangrove wetlands. Thus, the effective management of these sites is still a challenge, mainly due to the lack of commitment on the part of the stakeholders and of incentives for legislation to protect these areas (Shah and Atisa, 2021).

In that sense, the first step towards achieving SD in wetlands is to increase the number of Ramsar Sites and implement a conceptual framework for adaptive management (Kingsford et al., 2021). There is currently no agreement on how SDGs can impact policy through science (Bennich et al., 2020) but there are global methodologies to assess SDG targets based on metrics that provide data (Fraisl et al., 2020). Even so, there are gaps in knowledge as to how far SDG goals are being met (Zeng et al., 2020), mainly related to effectiveness issues and to the lack of contextualized compliance metrics that go beyond statistics (Ordaz, 2019). Thus, to prevent sustainable development and its goals from becoming a mere fad due to the lack of a precise and exact definition of its advances (Menash and Enu-Kwesi, 2019), as, for example, in the role of mangrove forests in the 2030 Agenda, it is necessary to carry out theoretical studies in order to propose a framework whereby these SDG can be better organized. In addition, integrating ecosystem services and their main threats into SDG assessment studies is of paramount importance (Wood et al., 2018) because this knowledge is still lacking (Bennich et al., 2020). One of the important ways to expand knowledge on the subject is to fill these gaps with review studies integrated with open-access databases (Davidson et al., 2019) and it is the first step to take.

The SD, SDG, and Ramsar Sites in the present study, have mangrove forests as a common factor. They are a unique ecosystem that safeguards biological diversity under the criteria of RAMSAR groups A (rare or unique sites) and B (sites of importance for biological conservation) (RAMSAR, 2021). For that reason, to assess the SDGs, it is necessary to identify knowledge gaps, relating them to ecosystem services and threats to the mangrove formations that are linked to natural or anthropogenic pressures (Liao et al., 2019). Review studies, based on standardized protocols (O'Hagan et al., 2018), have been one of the ways to identify gaps in knowledge (Cook et al., 2013) regarding the science of SDG studies in the mangrove ecosystem, as they support decision-making (Higgins et al., 2019) and are the basis for proposing a theoretical framework as some previous studies have already done (Govindan et al., 2021). Accordingly, this study formulated the following guiding questions: i) what are the topics addressed in the conceptual framework of the SDG in the mangrove ecosystem (not necessarily declared as Ramsar Sites)? ii) What is the theoretical status of the Ramsar Sites, in the mangrove category, in regard to the SDG? and iii) What are the challenges and gaps in studies on SDG focusing on the reality (ecosystem services and threats) of Ramsar Sites that include mangroves? Thus, the present study aimed to propose a conceptual framework for SDG in relation to the mangrove ecosystem, as a baseline scenario, based on a systematic review relating them to Ramsar Sites. Specifically, the objectives are 1) to identify the main topics studied that involve the science of the SDG and Ramsar Sites in the mangrove ecosystem through systematic review and 2) to define a conceptual framework to think about the SD of the mangrove ecosystem in the context of the SDG, and the main threats to, and services provided by the mangrove ecosystem defined in the Ramsar Sites that contain it.

2. Methods

The design, search, and analysis of the data obtained followed review study protocols (O'Hagan et al., 2018) such as PSALSAR (Protocol-Search-Appraisal-Synthesis-Analysis-Report) based on the PIPOC (Population, Intervention, Comparison, Outcome, and Context) framework, applying steps to perform the systematic review (Mengist et al., 2020) (Appendix A.1). In addition, inclusion and

exclusion criteria were defined, as follows: i) keywords inserted in the title and abstract sections; ii) type of documents such as article and review paper; and iii) research carried out in the mangrove ecosystem, and the search was not restricted to those studies involving Ramsar Sites.

2.1. Data collection

For the present study, the 'title' and 'abstract' sections of two databases: Scopus and Web of Science (WoS) were searched as it is more efficient to search for documents in these sections (Mateen et al., 2013). Scopus and WoS were used as the main databases (Gusenbauer and Haddaway, 2020), without including grey literature. The timeframe was the period between 1945 and 2021. The search words and phrases were 'sustainable development', 'sustainable Development Goal*', 'SDG' and 'Ramsar*' combined with 'mangrove*' in order to obtain more accurate documents (Bramer et al., 2017). The first search stage returned 782 documents, from which scientific documents irrelevant to the guiding questions were eliminated. The second stage returned 262 documents, with 42 scientific documents chosen to be evaluated according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses - PRISMA (Fig. A.1), since they were the only documents that directly mentioned some SDG and Ramsar Sites. The low-performance

Table 1
Status of the SDGs in the scientific papers found on the mangrove related to information from the RAMSAR Strategic Plan.

Countries		Indonesia	Brazil	Mexico	Malaysia	Bangladesh	India	China	Total
# Scientific papers (SP)		3	2	4	2	6	3	3	23
# Ramsar Sites		5	8	64	6	1	4	7	95
Ramsar Site extension (km^2)		11,302.76	92,998.34	44,150.68	957.36	6017	5326.40	481.68	161,234.22
Mangrove extension (km^2)		27,729.48	10,521.26	7260.03	5554.21	4435.33	3848.50	171.34	59,520.15
Main ES		educational (7); food (7); hazard (7); inspirational (7); recreation (7); scientific (7); spiritual (7); tourism (7); biodiversity (6); control (6); detoxification (6); erosion (6); protection (6); water (6)							14
Main Threats		water (101); harvesting (100); use (95); agricultural (92); human (91); aquaculture (77); urban (75); pollution (73); modifications (63); waste (63); settlements (60); tourism (60); aquatic (59); fishing (59); regulation (55); effluents (54); agriculture (52); conversion (51); land (51); housing (43); logging (41); forestry (32); household (32); hunting (32); industrial (32); sewage (32); disturbance (31); garbage (31); intrusions (31); transportation (26); mining (23); military (22); alien (20)							33
Threats in SP		deforestation (3); aquaculture (2); climate change (2); conversion (2); degradation (2); erosion (2); disasters (storm, cyclones) (2); logging (2); population (2); corruption (1); growth (1); cultivation (1); depletion (1); development (1); destruction (1); economic (1); encroachment (1); farming (1)							18
SDGs in SP		SDG 1, SDG 2, SDG 6, SDG 13, SDG 14, SDG 15							6
Indicator in SP		Social, Natural, Economic and Productivity							4
Relative performances (score) related SDG targets		SDG 1, SDG 2, SDG 3, SDG 6, SDG 7, SDG 8, SDG 9, SDG 11, SDG 12, SDG 13, SDG 14, SDG 15							12
		1.5.3, 2.5.1, 3.3.5, 9.a.1, 9.2.2, 9.2.1, 9.1.2, 8.9.1, 7.2.1, 6.a.1, 6.6.1, 6.5.2, 15.c.1, 15.b.1, 15.a.1, 15.8.1, 15.7.1, 15.6.1, 15.2.1, 15.1.1, 14.4.4, 14.1.1, 13.1.3, 13.1.2, 12.c.1, 12.6.1, 11.b.1, 11.4.1, 11.2.1							29
Ramsar Plan Goals	Targets	SDG 1; SDG 2; SDG 3; SDG 4; SDG 5; SDG 6; SDG 8; SDG 9; SDG 10; SDG 11; SDG 12; SDG 13; SDG 14; SDG 15; SDG 16; SDG 17							16
Address wetland loss/degradation	1	**6.6,** 6.5, 15.4, 15.3, **15.2, 15.1,** 14.2, 13.1, 12.4, 11.b, 11.a, **11.4,** 11.3							13
	2	11.3, 11.4, 11.a, **11.b, 13.1,** 14.2, **15.1, 15.2,** 15.3, 15.4, **6.5, 6.6**							12
	3	11.3, **11.4,** 11.a, **11.b, 13.1,** 14.2, **15.1, 15.2,** 15.3, 15.4, 6.3, 6.4, **6.5, 6.6**							14
	4	**15.8**							1
Conserve and manage the RAMSAR site network effectively	5	**11.4,** 11.5, 11.6, 11.7, 12.2, **12.6, 14.1,** 14.2, 14.3, **14.4,** 14.5, 14.7, 14.b, **15.1, 15.2,** 15.3, 15.4, 15.5, **15.6, 15.7,** 2.3, 2.5, 3.9, 6.3, 6.4, **6.5, 6.6, 6.a,** 6.b, 8.4, **9.1,** 9.5							32
	6	6.4, **6.5, 6.6**							3
	7	1.b, 11.3, **11.4,** 11.a, **11.b,** 13.2, **14.4,** 14.5, 14.c, 15.9, 2.4, 6.1, 6.2, **6.5,** 8.3, 8.9							16
Use wetlands wisely	8	**6.6, 15.1,** 14.5, **11.4**							4
	9	5.a, 14.7, **6.5,** 14.c, **11.b,** 1.4, 8.4							7
	10	2.5, **15.c,** 2.3, 5.5, 5.a, 6.b, 12.8							7
	11	15.9, **1.5,** 14.7							3
	12	**14.4, 6.6, 15.1,** 14.2, **15.2,** 15.3							6
	13	1.b, 11.3, **11.4,** 11.a, **11.b,** 12.b, 13.2, **14.4,** 14.5, 14.c, 15.9, 2.4, **6.5,** 8.3, **8.9**							15
Enhance implementation	14	17.6, **9.a,** 14.5, 9.5, 14.3, **14.4**							6
	15	17.9, **2.5, 6.5, 6.6, 15.1,** 17.6, 17.7, **9.1,** 11.a, 14.2							10
	16	**6.a,** 17.9, 2.4, 11.3, **13.1,** 13.3, 4.7, 4.a, **15.7**							9
	17	10.6, **9.a, 15.a, 15.b,** 17.3							5
	18	2.5, **6.a,** 17.9, 1.b, **6.5, 6.6,** 10.6, 12.4, 14.5, 14.c, **15.1, 15.6,** 16.8, 17.6, 17.7							15
	19	2.4, **2.5, 6.a,** 11.3, **13.1,** 13.3, **15.c,** 17.9							8
Method contribution in SP		Focus group, Discussions, Household, Surveys, Questionnaire, Interviews, Review, GIS and RS							9
Recommendation in SP		management (7); protection (5); conservation (4); information (4); research (4); restoration (4); awareness (3); community (3); government (3); organizations (3); training (3); adaptation (2); adaptive (2); ecotourism (2); education (2); effective (2)							16

scores of the SDGs by countries (Table A.1) were obtained from a study based on compliance with the metrics of targets around the world (Zeng et al., 2020). For that purpose, mangrove information was systematized (Giri et al., 2011) by selecting the low-performance scores of the countries that contain this forest, based on the calculation of SDG status targets (Zeng et al., 2020). In addition, the Ramsar Sites, the main ecosystem services and the main threats were obtained from the open access database (RAMSAR, 2021).

2.2. Data analysis

The choice of documents for full-text analysis was based on the application of inclusion and exclusion criteria, in addition to the relevant search words. The selected studies were classified according to the five principles of the 2030 Agenda (5Ps) and the SDGs mentioned directly based on the frequency of words in all documents. For the analysis of the data obtained from the scientific papers, the following software was used: i) Xlstat for the quantitative statistical analysis, ii) Voyant Tools (Sampsel, 2018), Iramuteq v0.7 alpha 2 (Analyses Multidimensionelles de Textes et de Questionnaires) for data visualization and analysis (Ratinaud, 2009), and iii) QGIS v3.16 for spatial data visualization (GLOBIL, 2021; Natural Earth, 2021).

The documents were classified and analyzed by abstract, keywords, objectives, and conclusions according to their similarity in semantic networks (Alexander et al., 2018). Likewise, Cluster analysis (Reinert's method) was used through a Descending Hierarchical Classification (DHC) of evaluation by textual segments of documents evaluating the association between words (Ratinaud, 2009). The DHC indicates the proximity and similarity of the words throughout the content analysis of the documents, whereby the dimensions that make up the SD contextualizing the mangrove were identified.

3. Results

3.1. Space-time distribution of the SDG and mangrove

Of the countries that have mangrove ecosystems, 118 are located in tropical and subtropical regions around the world (GLOBIL, 2021) and ~90% of them are in developing countries (López-Angarita et al., 2016). The scientific papers found referred to research carried out in 24 countries and 305 Ramsar Sites that have mangrove forests (Fig. 1). The documents mostly address information about SDG (43%), SD (36%), and Ramsar Sites (21%), most of which are in Asia and Africa, and, to a lesser extent, South America. The evaluated studies represent 0.3% of the total studies on SD, 0.6% of those on Ramsar Sites and 1.8% of the total studies worldwide on SDG registered in databases. The study made a full-text analysis of forty-two scientific articles with information on Ramsar Sites (21%) and the direct relationship between mangrove wetlands and SD (36%) and SDG (43%) for the period between 1991 and 2021 (Fig. 2).

In general, increase of Ramsar Sites in mangrove areas has been somewhat erratic over the last four decades around the world (Fig. 2). The Ramsar Convention was held in 1971 and the first Ramsar Site was declared in 1974 in the mangrove forests of the Cobourg Peninsula in Australia (RAMSAR, 1974). Studies on the Ramsar Sites began 33 years later, addressing issues of land use change such as the introduction of aquaculture in the mangrove ecosystem (Seto and Fragkias, 2007). Although SD was discussed in the Brundtland Report "Our Common Future" back in 1987 (Mistry et al., 2014), the interest of the academic community in SD and SDG related to mangrove ecosystems has not been continuous over the last three decades (Fig. 2). The first scientific paper on SD in mangroves was registered in 1991 (Pons and Fiselier, 1991), a decade after the first registered general study on SD and one year before the celebration of the Commission on Sustainable Development when Agenda 21 was generated at the Rio 1992 Conference (UN, 1992). The growth of interest in studies relating the mangrove ecosystem to SDG started with the declaration of the 2030 Agenda (UN, 2015), in the same year of the RAMSAR Strategic Plan launch, which began by directly relating SDGs, (mainly 13, 14, and 15), with the mangrove ecosystem. Those first studies date from 2018 (Fakhruddin et al., 2018a), five years after the first registered study on SDG addressing climate change issues.

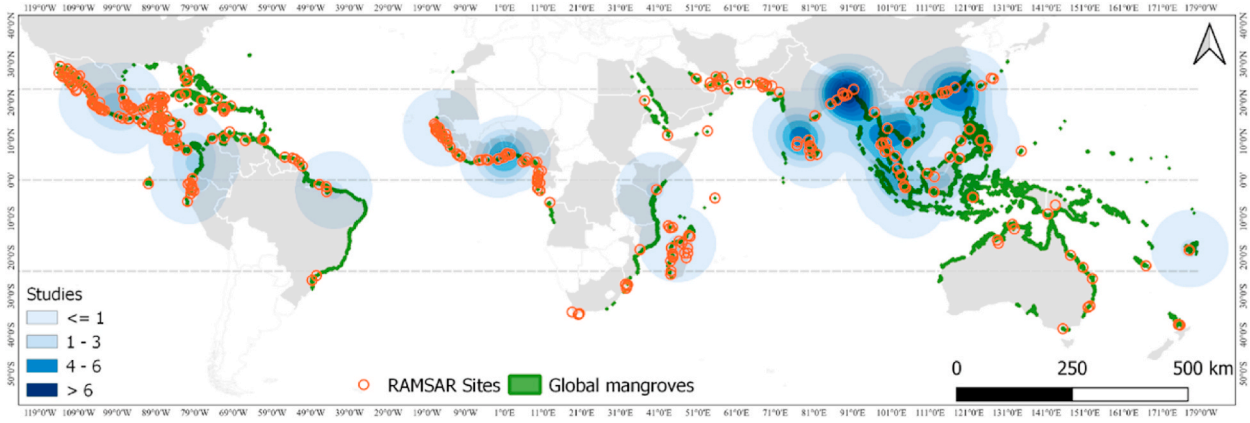

Fig. 1. Spatial distribution of scientific papers, mangrove forests and Ramsar Sites around the world (GLOBIL, 2021; RAMSAR, 2021).

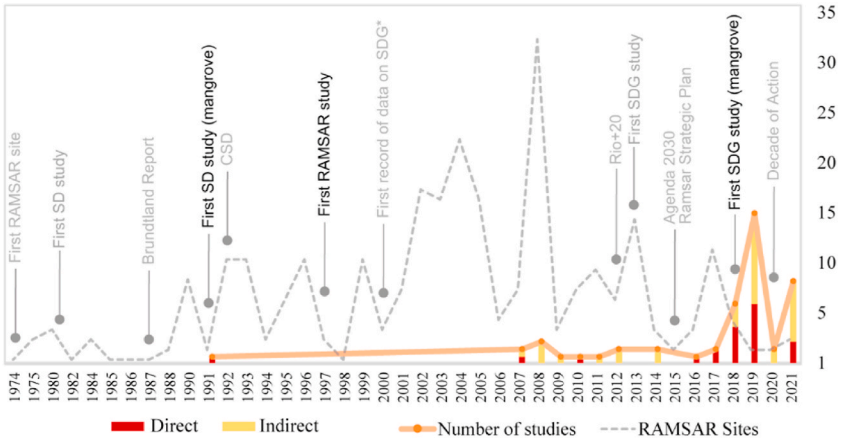

Fig. 2. Temporal distribution of documents on SD with direct and indirect relation to mangrove ecosystems. CSD: Commission on Sustainable Development created in Agenda 21 at the Rio 1992 Conference. *First record of data related to SDG in countries with mangrove formations.

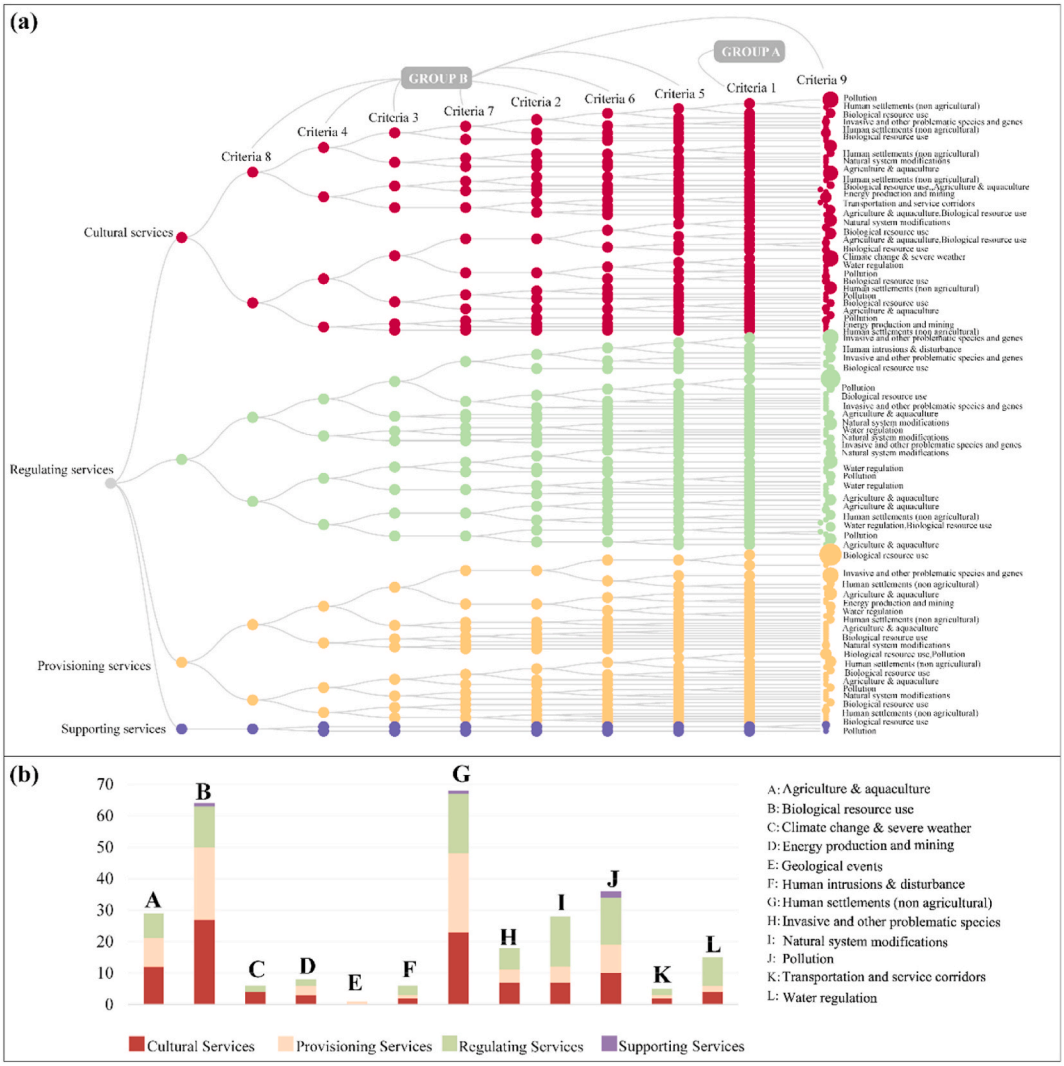

Fig. 3. Ecosystem services and main threats declared at Ramsar Sites harboring mangroves.

3.2. The experience of Ramsar Sites with mangroves: ecosystem services and threats

Although the study did not focus solely on Ramsar Sites, it highlights studies on areas that have mangroves in order to identify the main ecosystem services and their threats (Fig. A.2). There are currently 305 Ramsar Sites in mangrove wetlands worldwide (see dataset in (Eyzaguirre, 2023) and nine criteria have been defined to classify these sites, and several criteria can be applied to them at the same time. They form two groups: Group A: Sites with representative, rare or unique wetlands and B: sites for the conservation of biological diversity (Fig. 3a). On the one hand, the main threats identified are (non-agricultural) Human settlements (27%), Biological resource use (22%), and, to a lesser extent, Transportation and service corridors (1%). On the other hand, in some of the ecosystem services systematized, there were greater numbers of cultural services - recreation and tourism (37%), regulatory services - Erosion protection (34%), provisioning services - food for humans (28%), and a smaller quantity of supporting services - biodiversity (1%). The biggest threat to the regulatory services is 'Human settlements' (Fig. 3b), affecting, to a greater extent, the sites of group A and the main threat to the sites of group B is 'Fishing and harvesting aquatic resources'.

The countries with the highest number of Ramsar Sites and their main threats are the following: 1) Mexico with 64 sites, 4,415,068 km^2, threatened by Agricultural and forestry effluents and (non-agricultural) Human settlements; 2) Australia with 12 sites, 2,969,423 km^2, and threatened by Dams and water management/use, Energy production and mining, Mining and quarrying, 3) Honduras with 9 sites, 2177.98 km^2, and threats such as Urban wastewater and Agriculture & aquaculture and 4) Brazil with 8 sites, 9,299,834 km^2, and with threats stemming from Logging and wood harvesting, Fishing and harvesting aquatic resources, Housing and urban areas and Marine and freshwater aquaculture. In this last country, there is the largest Ramsar Site in the mangrove category in the world, N° 2337 'Amazon Estuary and its Mangroves', 38,502.53 km^2 declared in 2018, and the main threats are (non-agricultural) Human settlements and Housing and urban areas (RAMSAR, 2018). Both information about ecosystem services and threats are relevant as part of the construction of the framework proposed here for the conservation of this wetland.

3.3. Mangrove wetland and the 2030 Agenda

There are fewer SD studies of the worldwide review type being presented here (20%), with the majority being studies carried out in Asian mangrove forests (60%). Most of the scientific papers addressed the SD theme in general (67%), few directly addressed the SDGs, and the studies that did address those objectives directly were on SDG-13 (30%) and SDG-14 (3%). In addition, climate change (19%), development (16%), human well-being (13%) and gender (13%) were SD-related themes found in studies that addressed mangrove ecosystems indirectly, that is, establishing no direct relationship with the SDGs, but that discussed the topic in a general way. Sustainable development in the mangrove is mainly related to two aspects: management (n = 27) and conservation (n = 22). These guide the approaches of the respective studies, addressing aspects such as ecosystem services, climate change, restoration, blue carbon associated to Greenhouse Gas capture by marine ecosystems (Macreadie et al., 2019), and local communities. For example, conservation is linked to management through decision-making by local communities that depend on mangrove ecosystem services, and mangrove management is addressed through participatory management models.

The main themes of the studies according to the 5Ps of the 2030 Agenda were planet (40%), people (38%), prosperity (21%), and partnership (1%) (Fig. 4). The SDG science on the mangrove ecosystem, for the most part, mentions the SDG in a general way, with few

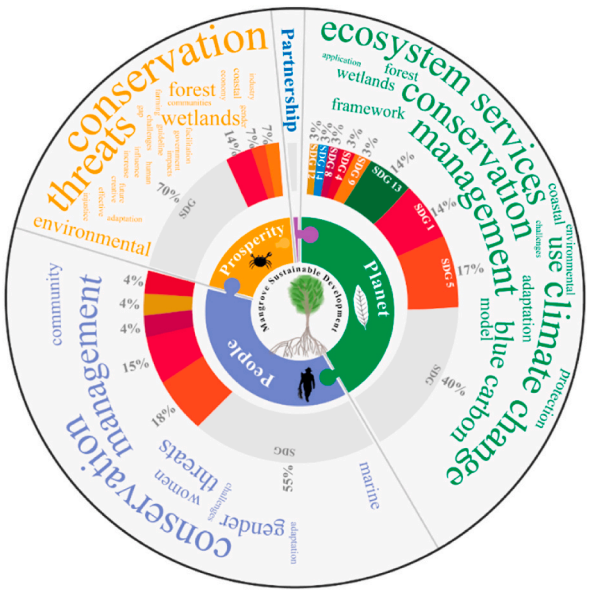

Fig. 4. Themes of the 2030 Agenda and themes related to the SDG.

studies that directly address them (e.g., availability of quantitative data directly related to their goals). The main SDGs addressed in the scientific articles were those related to gender equality (SDG5), poverty eradication (SDG1), action against climate change (SDG13), and other SDGs (SDG9, SDG4, SDG8, SDG14, and SDG12). The Peace theme was not addressed by any scientific paper in this study. Studies on the Planet theme mainly addressed studies on management, conservation, ecosystem services, climate change, and blue carbon. Similarly to the People theme, where studies on conservation, management, and threats relating to gender issues and communities were addressed, on the Prosperity them, threats to, and conservation in mangrove formations were addressed, and finally, in the Partnership aspect, monitoring was the main topic addressed.

The DHC shows six classes that make up the scientific papers on SD in regard to the mangrove ecosystems (Fig. 5). Classes 3, 4, and 5 include words related to the environmental pillar of the SD found in scientific papers, such as climate change directly related to SDG 13 and human activities in class 3, which is closer to class 4 because they are studies about the challenges to the sustainability of the mangrove forest. These two classes are close to class 5 which addresses studies on blue carbon and land use with pressures from aquaculture and agriculture. In the social pillar of the SD, studies related to ecosystem services and their economic value related to the livelihood of communities are part of class 6, which is close to class 2, as it addresses topics such as mangrove management effectiveness. Class 1 is close to the environmental pillar and refers to the economic pillar through the socioeconomic benefits generated for the communities, including preferences and decision-making. The main topics addressed in the science of SDGs based on the 2030 Agenda and the SDG targets are presented in this subsection (3.3. The, 2030 Agenda and mangroves) and below (Section 3.4. The SDG targets and mangroves) as key elements serving as theoretical basis for the construction of the proposed conceptual framework.

3.4. The SDG targets and mangroves

The countries with the largest extensions of mangrove forests are Indonesia, Brazil, and Mexico, and the first two have the largest Ramsar Sites. The countries where more scientific papers were found are Bangladesh and Mexico (Table 1). The commonest ecosystem services among these countries are cultural services (e.g., educational, inspirational, recreational, and scientific services), provisioning service (e.g., food), and regulatory services (e.g., hazard reduction, detoxification, and pollution control). Among the most common threats found in scientific papers and Ramsar Sites were those associated to water management, harvesting aquatic resources, agriculture and aquaculture, and (non-agricultural) Human settlements. Likewise, the key element 'recovery' retrieved papers highlighting corruption and power conflicts linked to REDD + projects in mangrove ecosystems (Rahman et al., 2018) thus signaling the need for further studies to understand the relationship between projects for recovery and restoration in the face of 'contracts' with a bias of corruption.

The SDGs addressed in the scientific papers were mainly SDG 1, SDG 2, SDG 13, SDG 14, and SDG 15, that is, the mangrove is directly related to these SDGs. The only SDG not covered by the Ramsar Sites Strategic Plan is SDG7 (Fig. A.3). Although the data on the targets of these objectives are national, they could be a reflection of the reality of the status of the mangrove formations. In that sense, the targets with low SDG performance scores were 1.5.3 (disaster risk reduction); 2.5.1 (number of resources earmarked for food and agriculture protected and those under long-term conservation); 13.1.3 (local government action on disaster risk reduction strategies);

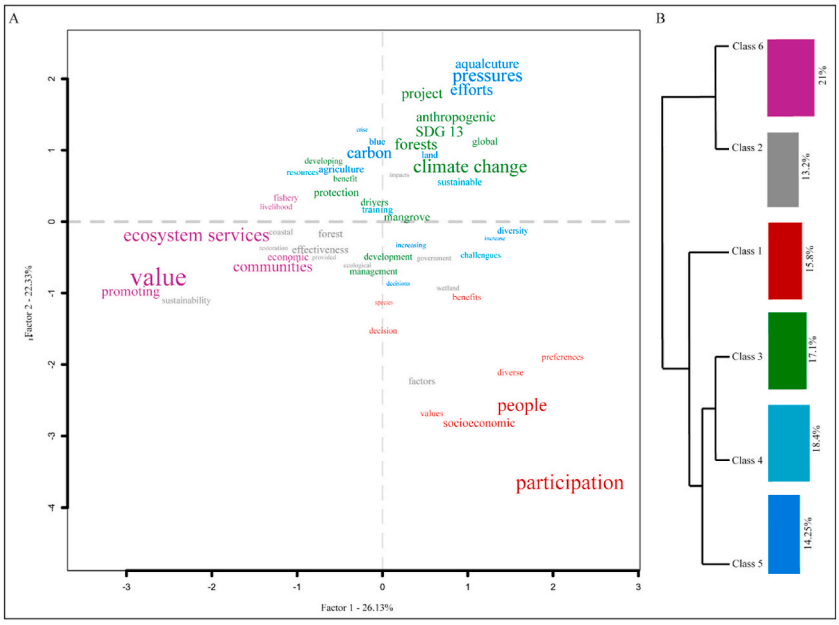

Fig. 5. Pillars of studies on SD in the mangrove ecosystem (DHC): Environmental (classes 3, 4 and 5), Social (classes 6 and 2), and Economic (class 1).

14.4.4 (data on illegal overfishing); 15.a.1 (assistance for the sustainable use of biodiversity); 15.b.1 (funding for biodiversity conservation); 15.c.1 (proportion of wildlife traded or illicitly trafficked); 15.1.1 (Forest area as a percentage of total land area); 15.2.1 (progress in forest management); 15.6.1 (countries adopting equitable social and environmental legislation); 15.7.1 (urgent measures to curb wildlife trade and poaching); and 15.8.1 (countries adopting legislation on resource use and control of invasive alien species) (Zeng et al., 2020). In addition, other scientific papers systematized methods and tools, such as Geographic Information Systems and Remote Sensing, interviews, focus group discussion, and social indicators, such as knowledge transfer, perception; natural indicators such as coastline stabilization, water levels, sea-level rise, soil characteristics; economic indicators such as socioeconomic data; and political indicators such as extant legislation related to conservation, all of which helps in the evaluation of the SDGs and their targets in the mangrove ecosystem.

See the complete table in Table S1. Scientific Paper (SP) has been compiled and summarized (Bahinipati and Sahu, 2012; Chakraborty et al., 2019; Chow, 2017; Duangjai et al., 2013; Fakhruddin et al., 2018b; Garcia et al., 2013; Hardin et al., 2019; Jia et al., 2021; Liao et al., 2019; Magalhães et al., 2007; Ottoni et al., 2021; Quintero-Morales et al., 2021; Rahman et al., 2018; Razali et al., 2020; Razzaque, 2017). Targets are from the RAMSAR Plan (numbers in bold) of low-scoring in mangrove countries (Zeng et al., 2020).

3.5. *Conceptual framework for SDG assessment in the mangrove context*

A conceptual framework for the assessment of SDGs in relation to the mangrove ecosystem is needed to fulfil the Ramsar Sites Strategic Plan and the 2030 Agenda based on their ecosystem services in order to address the identified threats (Fig. 6). In that sense, the inclusion of key actors, the definition of clear objectives, risk assessment, and the inclusion of co-management (Kingsford et al., 2021) based on the investment in science in order to generate data (Burford et al., 2013), are all indispensable to ensuring the sustainable future of mangrove ecosystem. The main challenge to complying with the targets of the SDGs is the statistics included in the targets (Ordaz, 2019), that is, to get beyond the numbers merely questioning the direction of the SD. Although the conceptual framework is not a finished recipe, it can offer support to fill gaps present in mangrove ecosystem science associated with SDGs (A). One of the goals of the Ramsar Strategic Plan for the Sustainable Use of Mangrove Forests embodies the need to carry out studies that identify (biotic and abiotic) ecosystem services in a holistic way while using methodologies that avoid any disconnection. Therefore, studies on ecosystem services and threats should use scientific and traditional knowledge in a complementary way (B) combining methods (Borges et al., 2021).

On the one hand, threats to mangrove swamps should be monitored and related to the advancement of SDG targets (Zeng et al., 2020), mainly those addressing mangrove degradation/loss. On the other hand, to comply with the two pillars of SD, conservation and management, the generation of data in a contextualized way must be strengthened through diagnoses and systematization of the

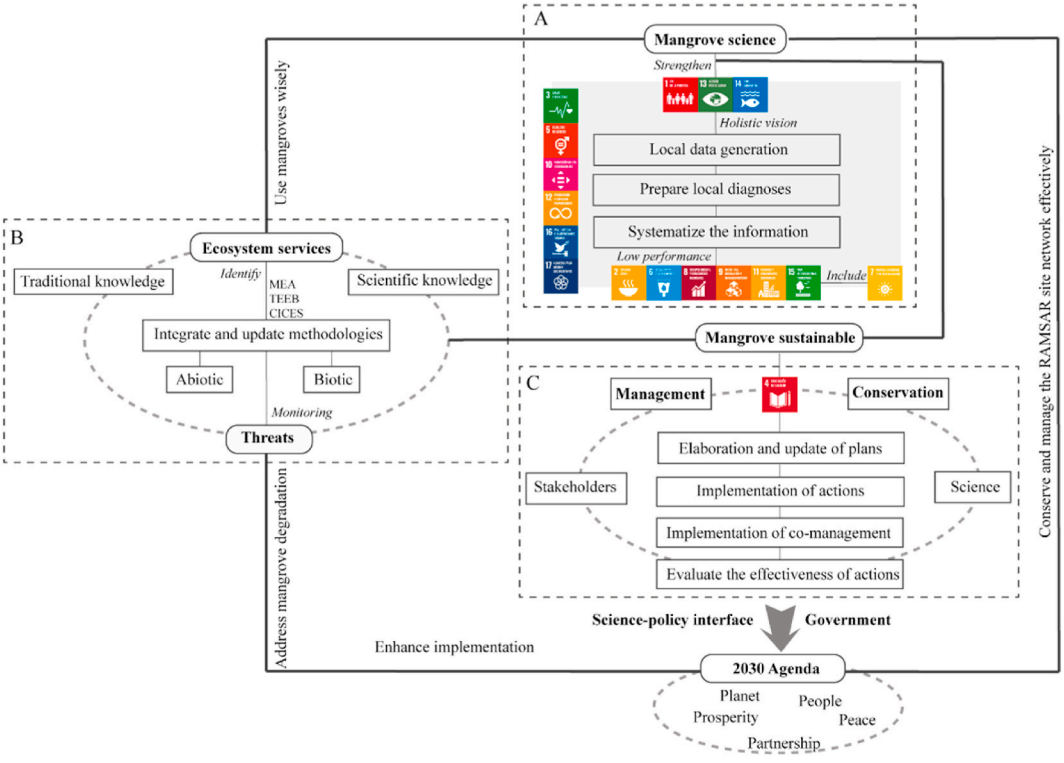

Fig. 6. Conceptual framework to integrate SDGs in mangrove.

science produced, addressing SDG themes in mangrove ecosystems or listing the results of science with the targets situated in context. There are SDGs with low-performance scores in countries with mangrove formations where it is recommended to include the objective associated with renewable energies (SDG7) in traditional communities that depends on mangrove ecosystem services as part of the path towards sustainability. This is one of the SDGs that is not included in the Ramsar Plan. Conservation and management, key elements in this systematic review, towards mangrove forest sustainability must be supported by education (SDG 4) including science-based stakeholder participation (SDG 17) to develop and update plans and jointly implement actions (C). Designing a sustainable future for the mangrove (planet) must include the populations that depend on it (people) considering its ecosystem services (prosperity and peace) in a joint and participatory way (partnership) towards achieving the 2030 Agenda.

4. Discussion

4.1. Mangrove on sustainable development science

The first SD studies were reported in the 70s (Fig. 2) and in the 80s the Brundtland Conference released its report for our common future (UN, 1983). Although the first studies on mangrove ecology were recorded in the late 1940s in WoS (Davis and Williams, 1950; Lawrence, 1949), only a single study on mangroves directly addressed the SD in the 1990s (Pons and Fiselier, 1991). The 2030 Agenda was adopted by the UN in 2015, when the 17 SDGs were defined (UN, 2021a), and from that date on studies on the mangrove ecosystem related to the SDGs have increased. In general, however, scientific interest in this area is still incipient, leaving gaps to be filled (Bennich et al., 2020).

The main purpose of the SDG is to eradicate poverty, protect the planet and guarantee peace, and prosperity to all people, comprising the 5Ps of the 2030 Agenda (Mensah, 2019); these objectives are formally listed and are indivisible (Leal Filho et al., 2019). The only P not addressed in a direct way by any scientific paper in this study was 'peace', although the feeling of peace is part of the mangrove cultural services in their provision of human well-being and prosperity (Hsieh et al., 2015). In that respect, including cultural services in decision-making is indispensable (de Souza Queiroz et al., 2017), since it is related to the feeling of peace that the mangrove forest offers to its populations (Knowlton et al., 2021) and through its maintenance and subsistence they enjoy the ecosystem on a day-to-day basis.

Most of the documents retrieved by this paper were reports of studies located on the Asian continent, although similarities were found in ecosystem services and threats identified in Ramsar Sites among other countries that have mangrove forests such as Indonesia, Mexico, Australia, Honduras, and Brazil. The Ramsar strategic plan lists 16 of the 17 wetlands SDGs, although the mangrove wetlands could also be included in SDG7 since, in addition to these forests being used in some countries as renewable energy (Numbere, 2020), they can be a path to generate sustainable development through access to clean energy in traditional communities, that depend on mangrove ecosystem services (Kerr et al., 2015).

The mangrove forested Ramsar Sites mainly provide cultural services, also linked to recreation and tourism. That service can become a conservation action because it is a Nature-based Solution (NbS) related to sustainable tourism linked to SDG11 (Musavengane et al., 2020). Provision of services such as food security through resource use (Fernandes et al., 2018) can be directly linked to SDG2 (Mensi and Udenigwe, 2021). Furthermore, fishing in mangrove areas supports food security and human well-being related to SDG1, SDG2, SDG3, SDG6, SDG8, SDG12, SDG14, and SDG15 (De Cock et al., 2021; Fakhruddin et al., 2018b; Seary et al., 2021). Among the regulatory services, the main one is coastal protection, which is linked to SDG13, SDG14, and SDG15 (Chow, 2017). Furthermore, regulation of climate change (Chakraborty et al., 2019; Simard et al., 2019) and blue carbon capture (Chow, 2017; Rovai et al., 2022; Wang et al., 2021) are services related to SDG-13 (Chow, 2017; Fakhruddin et al., 2018b).

The SD's main need is to face threats, including anthropogenic ones (Mensah, 2019) such as the threat that urban expansion represents for mangrove forests in Asia (Chen and Shih, 2019). Indonesia was the country where the highest number of studies on SD was found and, where the main threats to its mangrove formations are logging exploitation (Yudha et al., 2021) and aquaculture (Fitzgerald, 2000; Malik et al., 2015). Countries like Brazil and Malaysia, with fewer studies on this topic, present the threats posed by housing and urban areas (Hayashi et al., 2019; Kanniah et al., 2015; Moschetto et al., 2021), and agriculture and aquaculture activities (Alongi et al., 2003; Guimarães et al., 2010). Various topics are addressed in the SDG context in studies on mangrove forests but the great challenge is still how to better direct them in a contextualized way in order to assess the role of this ecosystem and go beyond the statistics. In other words, studies that glimpse the challenges and gaps in SGDs and their targets must be carried out in order to prevent the SDG from serving as a mere 'smokescreen', while environmental degradation continues throughout the decade (Zeng et al., 2020).

In addition, attention should be paid to low-performance targets in mangrove harboring countries, such as the SDG6 targets, since mangrove wetlands and the supply of drinking water are closely linked (Sanford, 2009) due to the filtering function performed by the trees in this ecosystem (Lin and Dushoff, 2004). At the same time, the mangrove forest formation plays an important role in SDG1 in strengthening the resilience of vulnerable populations (Berke et al., 2008; Soanes et al., 2021). SDG8 is also related to mangrove forests and is underperforming in countries that have mangrove wetlands, but sustainable tourism, such as community-based tourism, can be a way to generate employment and economic growth in communities that depend on them (Ahmad and Suratman, 2021; Marasinghe et al., 2021). Thus it is necessary to understand how essential it is to propose and effectuate sustainable management and conservation strategies for these wetlands that envisage their rehabilitation (Chen and Shih, 2019) as, for example, in aquaculture activities (Pons and Fiselier, 1991) where the strategy mentioned is recovery with the inclusion of stakeholders (Chakraborty et al., 2019; Chow, 2017; Fakhruddin et al., 2018b; Menéndez et al., 2018). In addition, knowledge of ecosystem services including human well-being can be the basis for forming policy for the conservation and management of mangrove forest resources (Menéndez et al., 2018).

4.2. Pillars of mangrove sustainable development: management and conservation

Conservation and sustainable management are important issues for mangrove wetlands (Chen and Shih, 2019) and are two essential pillars of SD in general (Mensah, 2019). Management is closely linked to conservation through local actions together with communities (Ladia et al., 2019), and for decision-making (Sangchumnong, 2018) that includes their participation (Mensah, 2019). Sustainable tourism, through actions in education and creative economy (Garcia et al., 2013) can serve as an important tool for a sustainability model for mangrove wetlands (Ladia et al., 2019; Sukuryadi et al., 2021), and should include the cooperation of local stakeholders (Garcia et al., 2013). The inclusion of these stakeholders through community training, strengthening participatory techniques, and carrying out projects with sustainability over time (Sangchumnong, 2018) is essential to the planning of a sustainable future for the mangrove ecosystems. In that sense, the protection of mangrove resources with future generations in mind makes it possible to guarantee equity and access to food for people, based on provision services, and generating prosperity and inclusion.

Furthermore, apart from promoting fair and inclusive societies in the mangrove ecosystem, its governance must be established (Yonvitner et al., 2020) in fulfilment of those principles (Eyzaguirre and Fernandes, 2018) and with sustainable management in mind. Therefore, mangrove ecosystem management with a focus on SD should be approached through collaboratively based management models addressing governance dimensions, as has been done in Indonesia together with coastal communities (Sukuryadi et al., 2021). The ecological, social, economic, and institutional indicators support the assessment of mangrove forest sustainable development (Sangchumnong, 2018; Sukuryadi et al., 2021). That can be done from a perspective that addresses important SD issues like gender, since too few studies assess the relationship between gender and mangrove forest conservation (Ladia et al., 2019), ecosystem services (Menéndez et al., 2018), and climate change (Chow, 2017).

Management and conservation strategies need to be strengthened, and in the SDG in general, it is necessary to include education (Shah and Atisa, 2021), and communication for holistic, sustainable development of the mangrove wetlands, applying Education for Sustainable Development (EDS) advocated by the United Nations (UN, 2019) that connects the SDG4 with other SDGs to think about the sustainable development, for example for the mangrove ecosystem. Recently, the United Nations Ocean Decade initiated the Ocean Literacy program (UNESCO-IOC, 2021) in order to build science around marine-coastal ecosystems (UN, 2021b), such as mangroves (Lecours et al., 2021). In addition to education, it is also expected that scientific interest can give more visibility to the role of mangroves in the decade of action, listing the SDGs in order to fill in the knowledge gaps.

Sustainability does not mean avoiding or ceasing to carry out activities such as forestry, aquaculture or agriculture, on which many people and communities depend, but rather, it is carrying out these activities in a more sustainable way considering the environment, people, and well-being (Pons and Fiselier, 1991). Thus, the economic pillar of SD means that these activities should be better planned, thinking about creative production, with sustainable tourism linked to the development of local populations (Sangchumnong, 2018). This can be done by joining efforts to carry out this activity in a way that respects human health, human rights, and gender equality (SDG5), and generates decent work for neighboring communities (SDG8) (Mensah, 2019).

The main way to successfully link management and sustainability is the identification of major problems and social conflicts that affect the mangrove forest, in addition to including ecological, social, economic, and institutional indicators when addressing them (Sangchumnong, 2018). It is necessary to join forces to contribute information and carry out actions in partnerships to ensure the successful conservation of this ecosystem (Sangchumnong, 2018) and to face the main threats to the mangrove ecosystems' contributions to SD. For example, restoration and sustainable tourism are valued approaches to mangrove forest management and conservation around the world. However, it is important to think about management beyond restoration and reforestation efforts, which are often unsuccessful (Garcia et al., 2013), since there are still gaps in conservation strategies, mainly related to the responsibility and commitment of stakeholders involved in the rehabilitation of mangrove forests (Garcia et al., 2013).

4.3. Key elements of the framework for the sustainable development of mangroves

The framework is proposed based on the literature that directly addresses the SDG experience and recommendations, in addition to the Ramsar Sites database with mangroves in order to promote the SD of this ecosystem in a contextualized manner:

a. Knowing the plan of the 2030 Agenda (UN, 2015) to go beyond theory: a process of raising awareness regarding the meaning of the SDG, their impact, and importance, and an assessment of the applicability of SDG targets is necessary and urgent. That will only be possible through investment in science, technology, and above all, equitable and inclusive education (Leal Filho et al., 2019) in order to strengthen the management and conservation of the mangrove ecosystems. Not only the academic community should be aware of the SDG, but also all organizations, especially those that work collecting data from primary sources and that can contribute with contextualized information and situated in the geographic place.
b. SDG implementation and the mangrove: the information provided by the Ramsar database on ecosystem services available in the mangroves and their threats (Fig. 3) can be a guide to start research that diagnoses and identifies priority SDGs for this ecosystem in a contextualizes manner. In addition, relating the role of ecosystem services to the SDG is necessary to reduce the knowledge gaps (Wood et al., 2018). Cultural services, for example, are the most neglected due to the lack of sociocultural valuation in one of the countries with the most mangroves in South America, which is Brazil (de Souza Queiroz et al., 2017). The implementation of the SDGs must be horizontal and focus on the main threats as drivers of preventive strategies to conserve mangroves and promote sustainable development in the communities that depend on them, for example, through the formulation of public policies arising from the definition of existing problems (Allen et al., 2018). There is no doubt that this implementation process is a great challenge, leaving a relevant question about the second principle of the 2030 Agenda: how far are we to "Leave No One Behind" in mangrove

areas? mainly in coastal communities and countries that have the largest mangrove areas such as Indonesia (Martinez-Alier, 2001), Brazil (Gillam and Charles, 2019), and Mexico (Rodríguez Aguilera, 2022), which still suffer from environmental racism.

c. Collection and monitoring of data on the SDGs: The environmental, social, and economic spheres of SD are complex, therefore, studies on the SDGs in relation to mangrove forests need to be evaluated in a contextualized way, since the lack of contextualization will lead to failure, especially when producing statistical information for decision making, management (Pons and Fiselier, 1991), and conservation. Likewise, it is considered that the literature does not directly address the SDGs and has many gaps (Del Río Castro et al., 2021), as well as considering its data source and level of confidence in these data (data quality) to be fundamental. On the one hand, the source can come from different social actors and through the use of different tools (Fritz et al., 2019), such as those mentioned in Table 1. Citizen science, together with techniques such as Artificial Intelligence (McClure et al., 2020), for exemple, can be a fundamental link to narrow information gaps on SDG data in a contextualized manner, including monitoring (Fritz et al., 2019), such as Mangrove Watch in Australia (Duke, 2009). On the other hand, data quality is certainly the most challenging and complex factor to be obtained, as it involves monetary and human efforts. In addition, data coverage on SDGs is higher in Europe compared to other continents such as Africa and Oceania (Fritz et al., 2019), but this depends on the level of adaptation that each government has regarding the digitization process (ElMassah and Mohieldin, 2020).

d. Transparent and decentralized governance: Open and transparent data governance, although still emerging (Wirtz et al., 2022) in populous countries with large territorial extensions, is a way to promote the decentralization of monitoring and access to SDG data in the digitization process (MacFeely, 2019), as is practiced in Brazil (Tinoco et al., 2022). A global example is UN Data (http://data.un.org/), which makes SDG targets available, although it is still necessary to contextualize and monitor them. This can be done by prioritizing the SDGs in order to promote data collection more effectively and according to the context (Schmidt-Traub et al., 2017), as in the case of SDG 1, 13, and 14 regarding mangrove ecosystem (Figs. 4 and 5).

e. Effectiveness of the SDGs in countries that have mangroves: The science-policy interface through dialogue is the basis for enforcing the 2030 Agenda (Del Río Castro et al., 2021) and implementing wetland conservation and management processes (Clare and Creed, 2022). On the one hand, the exchange of knowledge at the science-policy interface with coastal communities that includes the involvement of communities in the management, planning, and zoning of this ecosystem (Garcia et al., 2013; Pons and Fiselier, 1991) is also indispensable, since in many coastal countries marine spatial planning is still incipient (Borges et al., 2020). On the other hand, the involvement of stakeholders such as government, civil society, academia, citizen, and business (Rashed and Shah, 2021) is essential to meet the goals of the 2030 Agenda. Consequently, this makes the SDGs indispensable, not in isolation but in an integrated manner (Del Río Castro et al., 2021), especially with the use of a transdisciplinary approach to address socio-environmental issues related to mangroves and the use of data from primary sources such as data repositories. UN Data (http://data.un.org/), for example, is a data repository that offers an overview of the indicators, although it is still necessary to contextualize and monitor such information.

5. Conclusion

Mangrove wetlands are complex socio-ecological systems that provide important ecosystem services. In that sense, planning conservation strategies is necessary to insert SDG science and promote the 2030 Agenda. The first study on mangrove wetlands from an SDG perspective was not until 2018 and mainly concerned climate change, development, human well-being, and gender, thus directly related to SDG 13 and SDG 14. Studies on SDGs must be related to the Ramsar Sites that harbor mangrove forests and must include ecosystem services such as recreation and science production, food provision, and regulation, such as hazard reduction. They must also address threats associated to water management, harvesting aquatic resources, agriculture and aquaculture, and (non-agricultural) Human settlements. The SDG targets with the most deficiencies in countries that have mangrove forests and low score performances in relation to the SDG metrics, according to the study consulted, are those of: disaster risk reduction, the number of resources earmarked for food and agriculture protected and under long-term conservation, local government action on disaster risk reduction, data on illegal overfishing, assistance for the sustainable use of biodiversity, funding for biodiversity conservation, ensuring proportion of the forest area under conservation in relation to the territory as a whole, progress in forest management, countries adopting equitable social and environmental legislation, urgent measures to curb wildlife trade and poaching, and countries adopting legislation on resource use and control of invasive alien species. The database review and analysis studies are a relevant basis for proposals for a conceptual framework, and in the case of the mangrove wetlands, they are indispensable for identifying the main gaps and challenges related to the conservation of this world-renowned ecosystem. Conservation and management are related to decision-making by the social groups such as communities that manage this forest, as they depend on its ecosystem services and are the main ones affected by threats to it. In that sense, the conceptual framework proposed here envisions the importance of: key actors, the definition of clear objectives, the inclusion of co-management in addition to the production of information, based on scientific and traditional knowledge, to fill gaps in the scientific knowledge of mangrove wetlands. Finally, in order to comply with the environmental agendas in favor of the sustainable development of mangroves, it is essential to know the 2030 Agenda plan in order to adhere to the SDG in a contextualized way, reduce the gaps in its implementation by decision makers, rethink the methodology for collecting and monitoring indicators, defining a decentralized plan for data governance and sovereignty, and, above all, including stakeholder participation.

Ethical standards

None.

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Authors contributions

Conceived and designed this study: I.A.L.E. and M.E.B.F. Collected and analyzed the data: I.A.L.E. and M.E.B.F. Wrote original draft: I.A.L.E., AYI, and M.E.B.F. Wrote, reviewed & edited: I.A.L.E., M.E.B.F., and AYI.

Declaration of competing interest

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

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envdev.2023.100895.

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