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Global patterns of mangrove resource utilization: a systematic review

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Ecosystem services, encompassing the direct and indirect benefits of natural systems, are extensively studied in the context of mangroves. These carbon-rich ecosystems support coastal fisheries, shorelines, and harvestable resources to local communities. However, research on mangrove ecosystem services primarily are at a local scale, with limited exploration of global variations in resource utilization. This paper aims to bridge this knowledge gap through a systematic review of the existing literature conducted in Web of Science to assess the geographical variations in the coverage of mangrove use and ecosystem services. Out of 310 papers analyzed, Asia had the highest coverage (43%) with support to fisheries (39%) being the most researched ecosystem service worldwide. Direct use of mangrove resources exhibited regional variations, particularly in Asia, Africa, and North America. Mangrove wood, primarily used for fuel (16%) and construction (15%), was the most documented resource, with its usage persisting in low-income countries. Notably, a shift from being a primary income source to subsistence use was observed in Asia, Africa, and South America. Intrinsic and cultural services were less mentioned in the literature, emphasizing the need for future studies to focus on these areas to ensure culturally sensitive conservation efforts.

KEYWORDS

conservation, ecosystem services, mangroves, natural resource use, systematic review

1 Introduction

Mangroves are trees and shrubs that grow in the intertidal areas of tropical and subtropical coasts (Spalding et al., 2010; Duke, 2017) covering about 136,000 km^2 in 108 countries (Spalding and Leal, 2021). They occur in all continents except Europe and Antarctica, with the largest extent found in Asia (39%), followed by Africa (20%), North and Central America (15%), South America (14%) and Oceania (12%) (Spalding and Leal, 2021). The largest contiguous mangrove forests include the Sundarbans (India and Bangladesh), the Niger Delta (Nigeria), the coastlines of Northern Brazil and the Southern Papua, which together comprise 16.5% of the world's mangrove forests (Spalding et al., 2010). Mangrove distribution falls into two biogeographical regions, the Indo-West Pacific (IWP) and Atlantic East Pacific (AEP). The IWP includes the mangroves of East Africa, Asia, and Australia while the AEP constitutes the mangroves of West Africa, East, and West America (Alongi, 2002). There are 73 mangrove species globally, the IWP region is the most diverse with 62 species whereas AEP has 12 species with one common species (*Auchrosticum Aureum*) (Spalding et al., 2010). Species richness decrease from 30 species in South East Asia to about <10 species in West Africa and the Americas (Duke, 2017).

The distribution of mangroves is strongly influenced by geomorphic and climatic drivers (e.g., temperature and moisture) (Alongi, 2002; Njiru et al., 2022) and exposure to low temperatures is a key constraint. Warming temperatures are enabling mangroves to expand poleward (Giri and Long, 2016; Coldren et al., 2019; Cohen et al., 2020) and landward (Lucas et al., 2018; Visschers et al., 2022) as tidal incursion progresses with rising sea levels. While mangroves are expanding into saltmarsh ecotones, there is a net loss of mangroves globally (Goldberg et al., 2020; Hagger et al., 2022) due to the effects of major storms (Sippo et al., 2018; Lagomasino et al., 2021) and human pressures (Goldberg et al., 2020). Mangrove loss affects the provision of ecosystem services (ES) that directly support millions of livelihoods, particularly in the Global South (Malik et al., 2017; Nyangoko et al., 2022).

Mangroves provide a wide variety of ES (Walters et al., 2008; Donato et al., 2011; Lee et al., 2014; Mukherjee et al., 2014). They are carbon-rich ecosystems (Donato et al., 2011; Alongi, 2020), that support fisheries (zu Ermgassen et al., 2020), provide shoreline protection (Barbier et al., 2011; Barbier, 2020), and wood and non-wood resources to coastal communities (Lee et al., 2014). The concept of ES has created an effective bridge between ecological and economic approaches, challenging the established views about the "value" of nature and the long-lasting and wider economic impacts of resource degradation (Costanza et al., 2017; Cifuentes, 2021). In the context of this paper, ES refer to all services and benefits offered by mangroves to people, while mangrove use focuses on the direct use/provisioning services.

Studies have attempted to review several aspects of mangrove ES including disservices (Friess, 2016). Most reviews focus on the valuation of mangrove ES at a local scale (Himes-Cornell et al., 2018; Barbier, 2020; Getzner and Islam, 2020; Afonso et al., 2022) or on specific types, e.g. cultural services (Moore et al., 2022). There is a paucity of evidence on how the utilization of mangrove resources varies globally, despite evidence of the rate of change in mangrove cover being influenced by use (Sasmito et al., 2019; Goldberg et al., 2020). Understanding these global utilization patterns is important for developing effective conservation strategies and ensuring sustainable use of mangrove ecosystems. Hence, this systematic review aimed to provide a comprehensive overview of the current state of knowledge on mangrove resource utilization, focusing on the coverage of ecosystem services (ES), the geographical distribution of studies, and the types of uses identified globally. To achieve these aims, the objectives of this review are to: (a) identify the range and frequency of different ES covered in the literature and determine knowledge gaps; (b) map the global distribution of studies and evaluate regional differences; and (c) categorize and compare uses (e.g., timber, fisheries, tourism) studied in different regions.

2 Methods

A systematic review was undertaken following the methods of previous studies (e.g., Berrang-Ford et al., 2011; Xu et al., 2019). The search was conducted in March 2023 on the Web of Science (WoS), as this database is widely used and covers interdisciplinary peer-reviewed literature published since 1900 (Jacsó, 2005). No papers published after March 2023 were included in the review. The search criteria were:

Indexes = SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI

Timespan = All years (1900 to March 2023)

Language: English

Document types: Article OR Book Chapter OR Proceedings Paper OR Review

Topic search (TS) within the title, author keywords, Keywords Plus® or abstract:

1. TS=(Mangrove* NEAR Use*) OR
2. TS=(Mangrove* NEAR Valu*); OR
3. TS=(Mangrove* NEAR Utili*).

The search yielded a total of 3,238 articles. The titles, authors' keywords, and abstracts of these articles were exported to Excel. A keyword search was done on the Excel file to identify which papers mentioned the different services (using the search function and the results were exported to a different Excel sheet) (Figure 1). Titles and abstracts were screened, and articles covering experimental/isotope analysis, analysis of the physicochemical composition, mangrove mapping, genetics studies, or other studies not focusing on mangrove use or ES were excluded. Supplementary material 1 provides the justification for exclusion of articles. A total of 310 articles were retained for full-text reading and extraction of information (Table 1) and were categorized based on the main ES covered. If the paper mentioned one service, but the focus was on another, the paper was moved to the relevant category, which was the basis for the geographical analysis.

3 Results

The earliest paper included in the analysis was published in 1993 and the number of publications covering mangrove ES increased over time, with the highest numbers published in 2018 (16%) and 2019 (13%) (Figure 2).

3.1 Overview of mangrove ecosystem services presented in analyzed articles

The articles analyzed captured 11 mangrove ES including wood for construction and fuel, provision of food and fodder, tanning/dye, and medicines for different ailments (Figure 3). The role of mangroves in supporting fisheries is the most often mentioned topic, covered in 39% (120) of the papers, followed by the provision of habitat, covered in 22% of the papers (Figure 3).

3.2 Continental representation of mangrove ecosystem services

Studies on mangrove use and ES in Asia dominate in numbers of papers (43% of all papers), followed by North America (16%) (Figure 4), and only these two regions have publications on all

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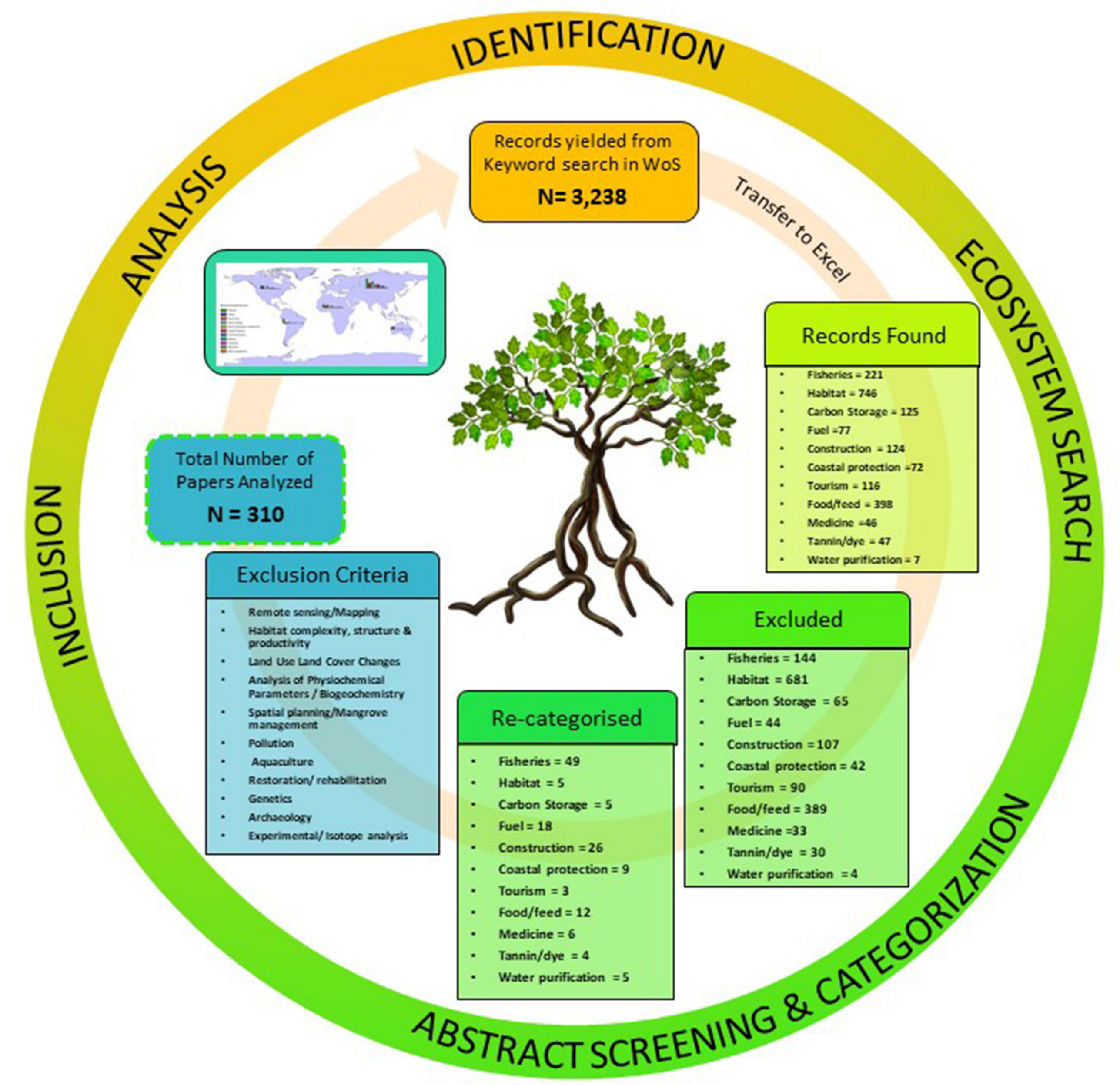

FIGURE 1
Records identified, included and excluded per ecosystem service and the reason of exclusion.

11 types of ES (Figure 5). For simplicity, papers covering Central America and the Caribbean were aggregated with North America, and they are the focus in the majority of articles in this group. Oceania was mentioned the least in the scientific literature (9%) and papers covered fewer ES types.

Only three ES were covered in all regions: the contribution of mangroves to fisheries, provision for habitat and carbon storage. The coastal protection service was not captured in papers from South America, while papers from Africa missed the service of waste management. Uses of mangrove wood for construction and fuel, tourism/recreation and tannin/dye were not mentioned in papers from Oceania. Articles reviewing mangrove ES on a global scale (7% of all articles, $n = 23$) mention all 11 ES and represent 30% of papers that mention the use of mangroves for tannin/dye and 29% of papers that mention for medicine (Figure 4).

3.2.1 Mangrove utilization in Asia

The contribution to fisheries was the mangrove ES cited most often in publications covering locations in Asia (35%), followed by carbon storage (25%) and the use of wood for fuel (20%). Other ES were covered in <20% of articles (Figure 6). Most literature from Asia was from Indonesia (26%), China (14%), India (13%) and the Philippines (11%).

TABLE 1 The number of articles found in the WoS search, excluded during the review process, and included in the analysis per type of ecosystem service.

Excel keywords	Number of articles found	Excluded after screening	Included after screening	Included after re-categorization	Number of articles analyzed
Fisheries	221	144	77	49	126
Habitat	746	681	67	5	72
Carbon sequestration and storage	125	65	60	5	65
Fuel and cooking	77	44	33	18	51
Construction	124	107	16	26	42
Coastal protection	72	42	30	9	39
Tourism and recreation	116	90	26	3	29
Food and Feed	398	389	8	12	20
Medicine	46	33	13	6	19
Tannin and dye	47	30	17	4	21
Water purification and waste management	7	4	3	5	8

Like in most regions, products harvested from mangrove forests in Asia include wood for fuel and construction and/or furniture making. In the construction of houses, mangrove wood is used in columns and beams as observed in the Bajo community in Indonesia (Rahim et al., 2019) and in the Philippines (Walters, 2005; Agaton and Collera, 2022). Mangrove wood is also used to make fences in India (Dahdouh-Guebas et al., 2006) and Vietnam (Quoc Vo et al., 2015), and fishing gears, such as fish traps, paddles, and boats in Malaysia and India (Bennett and Reynolds, 1993; Pattanaik et al., 2008). The traditional use of mangrove wood as fuel by several communities in Asia was noted in India (Meynell, 1999; Dahdouh-Guebas et al., 2006; Pattanaik et al., 2008; Hussain and Badola, 2010), Malaysia (Bennett and Reynolds, 1993), Vietnam (Quoc Vo et al., 2015; Veettil et al., 2019), Indonesia (Furukawa et al., 2015; Suharti et al., 2016; Purida and Patria, 2019; Rumahorbo et al., 2020), Bangladesh (Arefin et al., 2017; Rahman et al., 2018) and Myanmar (Feurer et al., 2018). In some areas in Bangladesh detritus and leaves from mangroves are also used as fuel by local communities (Chow, 2015; Rahman et al., 2018; Barua and Rahman, 2019). Although there has been a decrease in the use of fuelwood in the Philippines (Walters, 2003), consumption of fuelwood always exceeded that of house and fence construction (Walters, 2005). Other reported uses of mangrove wood in Asia include transmission and telephone poles, railway girders, and mine timbers (Walters et al., 2008; Arunprasath and Gomathinayagam, 2015).

The use of mangrove tannin and dye was noted more in Asia than in any other region. In Indonesia, the extraction of tannin from mangroves dates to 1900 with the potential to develop into an industrial activity (Kusmana, 2018). The tanning and dye from the bark of *Avicennia sp.* are used for coloring and preserving fishing nets, coloring clothes, and used in mat making (Kusmana, 2018). Like in Indonesia, extraction of tannin from the bark of mangroves (mostly *Ceriops decandra*) is a common practice in most coastal areas in India used by fishers to dye their nets and increase durability (Dahdouh-Guebas et al., 2006; Arunprasath and Gomathinayagam, 2015).

The use of mangroves for medicinal values is also quite common in Asia (Arefin et al., 2017; Bibi et al., 2019; Veettil et al., 2019). Mangroves are used to treat diabetes, hypertension, and gastrointestinal disorders such as constipation, diarrhea, dysentery, dyspepsia, haematuria, and stomach pain. Species such as *Bruguiera gymnorrhiza* and *Rhizophora mucronata* are widely used traditionally and are believed to possess several medicinal values compared to other species (Bibi et al., 2019). In India, the fruits of *Acanthus ilicifolius* are crushed and used as a dressing for snake bites, while the whole plant can be boiled to create a decoction consumed for kidney stone removal. Other uses of this species are in the treatment of asthma, diabetes, hepatitis, and rheumatism. Another medicinal species is *Xylocarpus granatum*, although poorly exploited in India it is used for treating cholera and diarrhea (Bibi et al., 2019). Communities in India have used different mangrove plants in different forms as medicine to treat fever, malaria, cold and cough, bronchitis, asthma, skin diseases, ulcers, leprosy, smallpox, diarrhea, dysentery, diabetes, infertility, gonorrhea (Mondal et al., 2012; Johnson et al., 2020). The inhabitants of Bhitarkanika wildlife sanctuary, Kendrapara district in India, depend on the mangrove forests for medicine and other traditional products (Pattanaik et al., 2008). In Indonesia, ointment made from *Avicennia sp.* is used to treat smallpox ulceration. It is also used by many as a contraceptive for birth control (Kusmana, 2018). Fruit of *Rhizophora mucronata* is used to treat leukemia in Indonesia (Sibero et al., 2020). Other medicinal uses obtained from *Ceriops sp.* and other mangrove species include medication for toothache, used as hair loss treatments, dressing for boils, curing sore eyes, tumor inhibitor, and mosquito repellent (Kusmana, 2018).

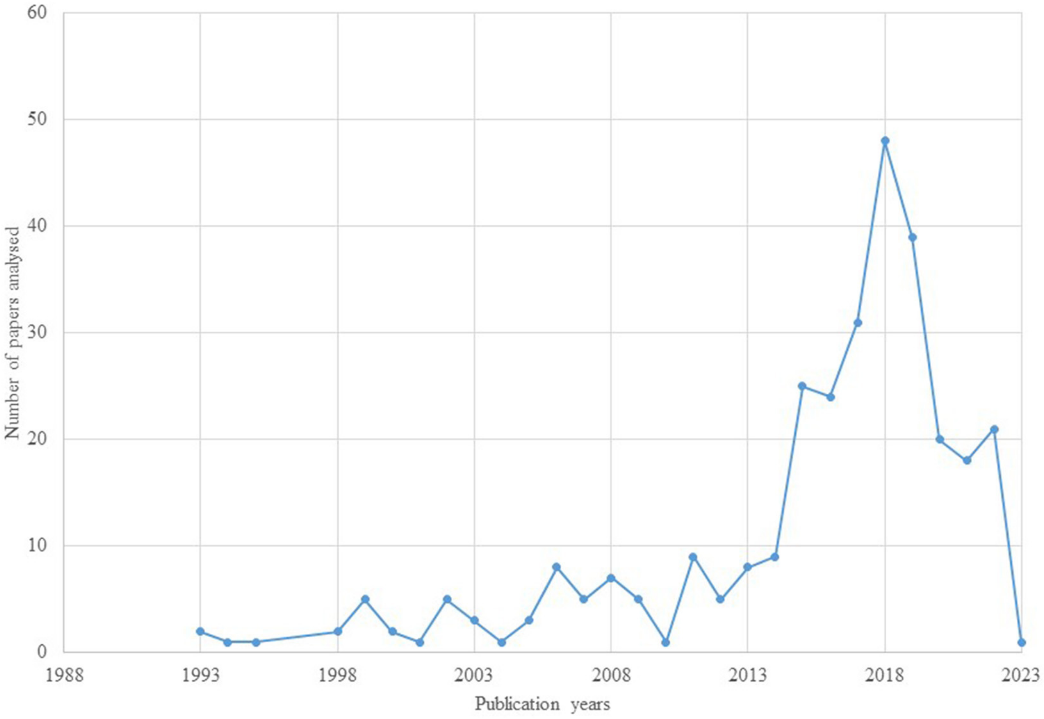

FIGURE 2
Number of papers included in the analysis per year of publication (up to the end of March 2023).

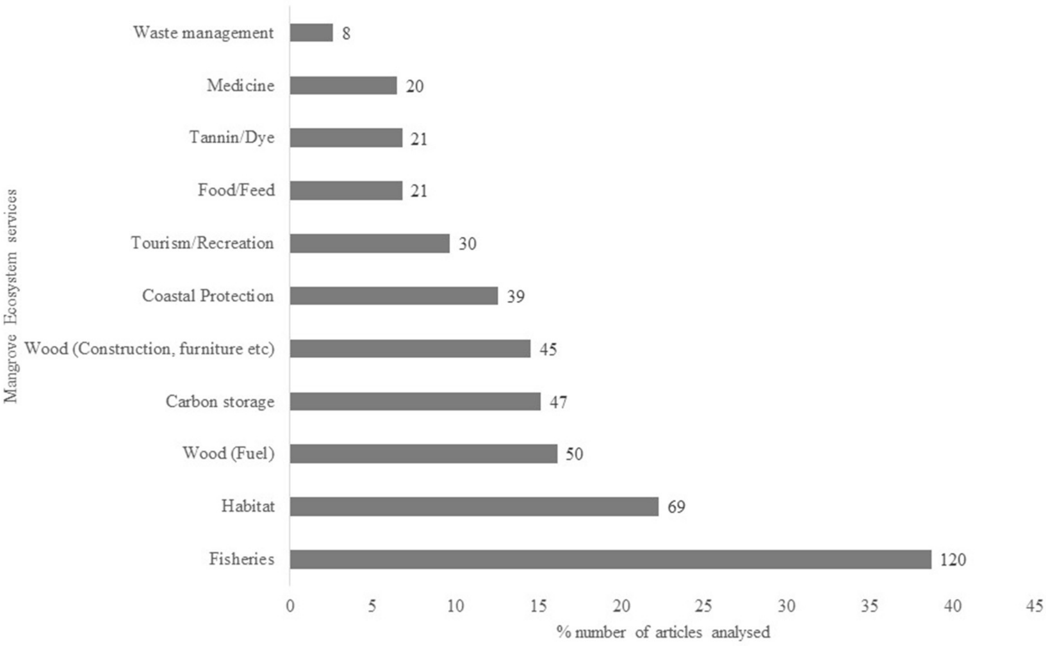

FIGURE 3
Mangrove ecosystem services covered in the 310 articles analyzed.

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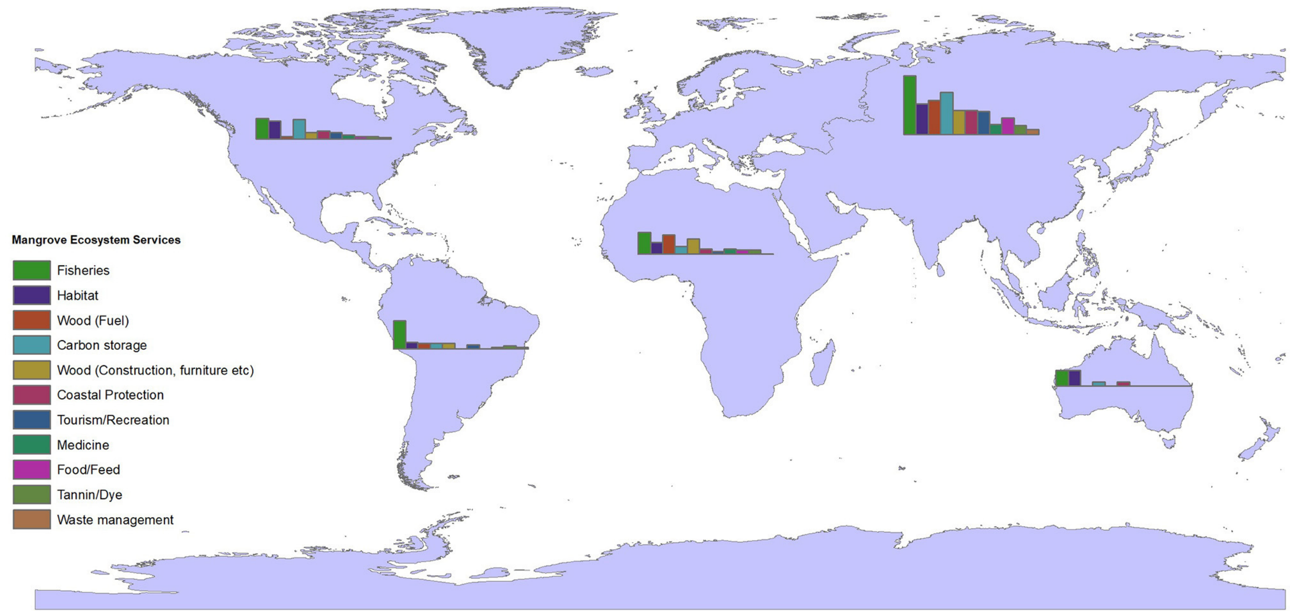

FIGURE 4
Coverage of ecosystem services in Asia, Africa, Oceania and North and South America.

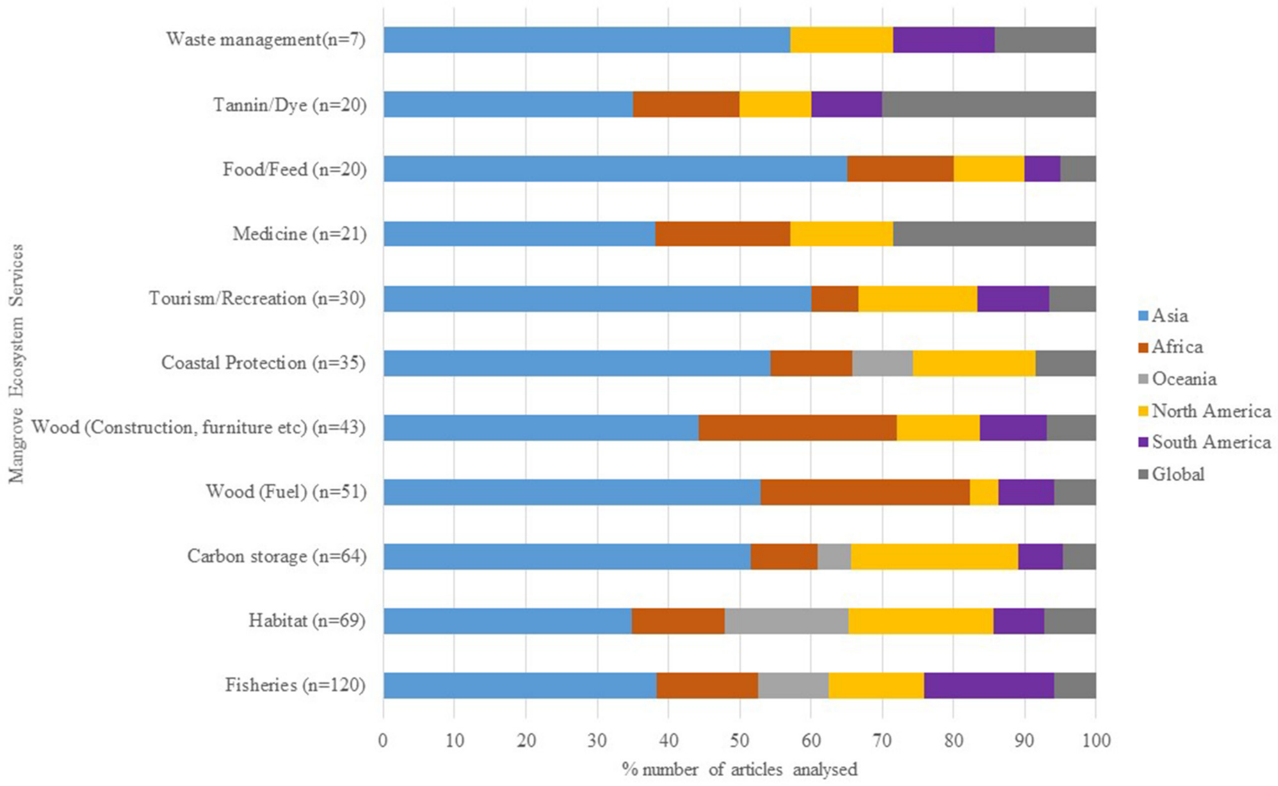

FIGURE 5
Distribution of articles analyzed across the world.

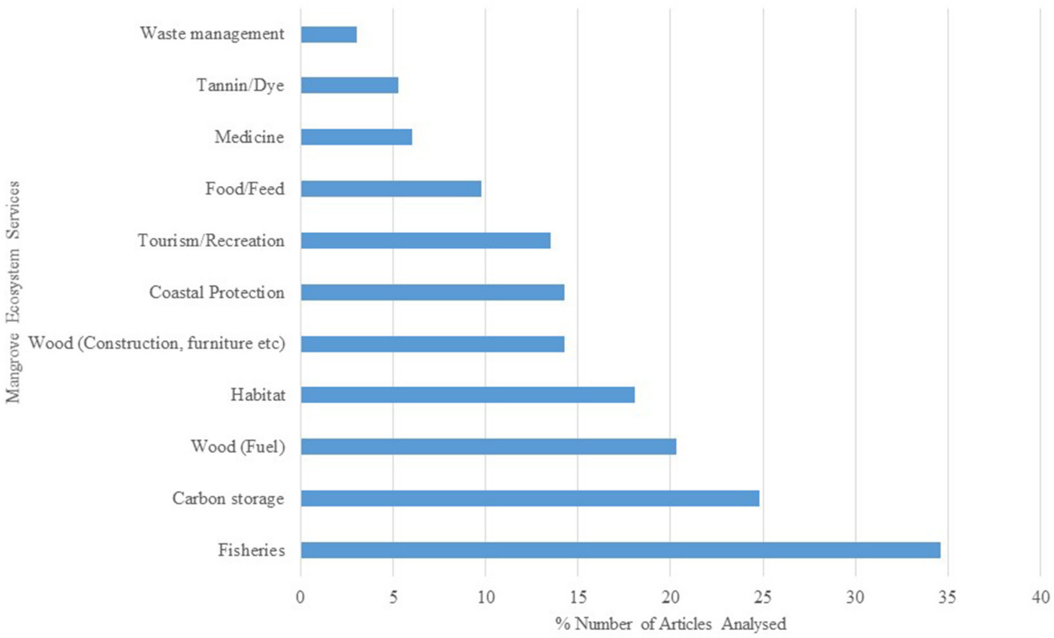

FIGURE 6
Distribution of mangrove ES mentioned in the articles covering studies in Asia ($n = 133$).

Mangroves in Indonesia are used as food and in beverages (Kusmana, 2018), as also seen in Sri Lanka, where locals make beverages from the leaves of *Sonneratia caseolaris* (Satyanarayana et al., 2013). The bark of the *Bruguiera gymnorrhiza* and *B. parviflora* has been used for centuries in seasoning fish while the young leaves, fruits, and embryos are cooked and eaten as vegetables (Kusmana, 2018). In India, fruits of *B. gymnorrhiza*, *Sonneratia alba*, and *S. caseolaris* are also eaten cooked as vegetables or raw in salads (Pattanaik et al., 2008). In China, tannins from *B. gymnorrhiza* are used to preserve freshly cut fruits (Liu et al., 2021). Although reported as an activity of the past, locals in Indonesia and Bangladesh have been consuming raw seeds, leaves, and fruits of *Bruguiera cylindrica* and *B. gymnorrhiza* for sustenance (Furukawa et al., 2015; Arefin et al., 2017). Another product collected from mangrove forests is honey, mostly reported in India (Badola and Hussain, 2005; Pattanaik et al., 2008) and Indonesia (Rahman et al., 2018).

Communities all over Asia obtain proteins from shellfish such as oysters, snails, and crabs collected from mangrove areas (Rahman et al., 2018; Rumahorbo et al., 2020; Singgalen, 2020; Joy and Paul, 2021; Agaton and Collera, 2022). In addition to being used as food for humans, the literature identifies the use of mangrove leaves as fodder/feed for animals. In Indonesia, leaves of *Sonneratia sp*., *Avicennia sp*. and *Rhizophora sp*. are collected and fed to goats (Kusmana, 2018; Rahman et al., 2018). In India, cattle are left to feed in mangrove areas (Dahdouh-Guebas et al., 2006; Hussain and Badola, 2010) and mangrove associates *Phragmites karka*, *Porteresia coarctata*, and *Myriostachya wightiana* are used as livestock fodder (Pattanaik et al., 2008). The use of mangroves as fodder for livestock is reported to have reduced pressure on pasture lands in India (Arunprasath and Gomathinayagam, 2015). Historical use of mangroves for camel grazing is seen in the Indus Delta in Pakistan (Meynell, 1999). Stable isotope analysis show that sesarmid crab (*Parasesarma bidens*) feeds on cellulose-rich mangrove detritus and leaf litter in the Urauchi River in Japan (Kawaida et al., 2019).

Commercial harvesting of mangrove wood for fuel has been linked to the degradation of mangroves in Asia. Charcoal manufacturing was identified as a major cause of mangrove loss in Bintan, Indonesia (Winarno et al., 2016) and Myanmar (Estoque et al., 2018) hence calling for potential alternative sustainable solutions (Estoque et al., 2018). Mangrove wood is also used as fuel for commercial brick kilns in India (Arunprasath and Gomathinayagam, 2015). In the Philippines, intense mangrove cutting for the commercial sale of firewood between the 1930s and 1979 (Walters, 2003) led to restrictions placed on mangrove harvesting. Efforts were made to restore mangrove areas degraded due to charcoal production after natural regeneration failed in Matang, Malaysia (Eong, 1993).

3.2.2 Mangrove utilization in North America

The contribution to fisheries was captured in 33% of the article, followed by carbon storage (31%) and habitat utilization services (29%) (Figure 7). Like in Asia, all 11 ES were covered in this continent.

The literature indicates that mangroves were used before the arrival of Europeans, with some uses shifting through time and others persisting today. Archaeological findings showed that around 440–490 A.D. the Mayas were clearing mangrove areas to create saltpans and using black mangrove (*Avicennia germinans*) for fuel and in construction in southern Belize (Robinson and McKillop, 2013). This study shows that the use of mangrove wood

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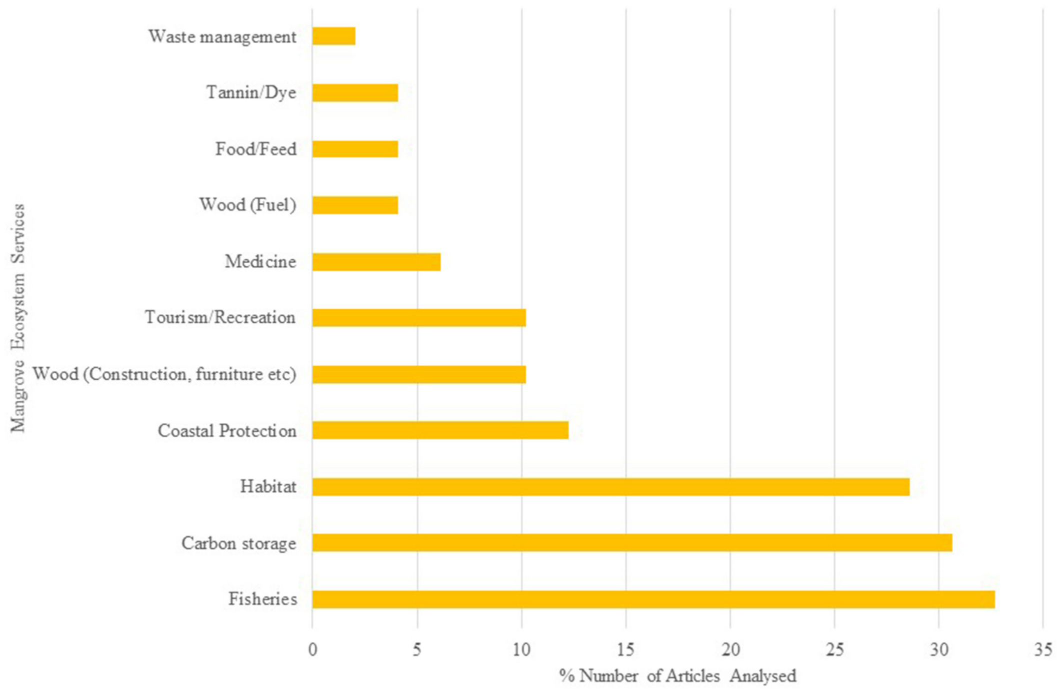

FIGURE 7
Distribution of mangrove ES mentioned in the articles covering studies in North America ($n = 49$).

was dominant at the time but was absent in later periods substituted by other types of wood, indicating that exploitation led to the depletion of local mangrove resources. Cutting of mangrove wood for fuel and charcoal production has been practiced since the 18th century in Mankòtè Basin, the large mangrove area in the Caribbean island of St. Lucia (Geoghegan and Smith, 2002). The authors describe the efforts that started in the 1980s to engage with and support local charcoal producers for the implementation of management measures and practices aiming to reduce mangrove loss and enable sustainable resource use.

A wider range of mangrove uses was mentioned in studies in Mexico than any other countries in North America. Extraction of mangrove wood for fuel and construction (e.g., walls, ceiling, fences, fishing traps) is common by fishing communities surrounding coastal lagoons by the Gulf of California, Sinaloa state (Cornejo et al., 2005) and on the Pacific coast, Nayarit state (Kovacs, 1999). However, use of mangrove wood in construction is not prominent in communities within La Encrucijada Biosphere Reserve on the Pacific coast (Chiapas state), where the most valued mangrove ES are coastal protection, fisheries and climate regulation (Reyes-Arroyo et al., 2021). Fishing in mangrove areas is a common practice as reported in Mahahual on the Caribbean coast (Jadin and Rousseau, 2022). Tea made from the bark of *Rhizophora mangle* and from leaves of *Avicennia germinas* are used as medicines by fishing communities in Mexico (Kovacs, 1999; Cornejo et al., 2005; Reyes-Arroyo et al., 2021), while in some areas this is considered a practice of the past (Kovacs, 1999). Infusion of *A. germinas* are used to treat gastric diseases (Cornejo et al., 2005), while the bark and root of *R. mangle* are used to alleviate stomach illness (Reyes-Arroyo et al., 2021), diabetes, kidney stones, skin diseases and purify the blood (Kovacs, 1999). Tea made from the bark of *L. racemosa* is said to have similar medicinal purposes, except for skin problems (Kovacs, 1999). In the past, tannin produced from *R. mangle was* used to painting buildings and dyeing clothes (Kovacs, 1999), while it is still used in toughening fishing nets (Cornejo et al., 2005). Mangroves are also identified as places that give tranquility and happiness to locals in La Encrucijada in Mexico (Reyes-Arroyo et al., 2021).

3.2.3 Mangrove utilization in Africa

Africa was covered in 13% ($n = 41$) of the articles analyzed making it the third most covered continent after Asia and North America. Fisheries were mentioned in 41% of the articles from this continent, followed by mangrove wood for fuel (37%) and construction (29%) (Figure 8). Except for waste management, all the other mangrove ecosystem goods and services were identified in the literature reporting studies on mangrove ES in Africa.

The use of mangrove wood for the construction of houses is practiced in several countries in Africa, including Kenya (Abuodha and Kairo, 2001; Rönnbäck et al., 2007; Hamza et al., 2020), Senegal (Scales et al., 2018), and Madagascar (Conchedda et al., 2011). Domestic use of mangrove wood for fuel is common in Africa (Semesi, 1998; Dahdouh-Guebas et al., 2000; Abuodha and Kairo, 2001; Nfotabong-Atheull et al., 2009; Conchedda et al., 2011; Satyanarayana et al., 2012; Carney, 2017; Gallup et al., 2020; Afonso et al., 2022). Commercial uses of mangroves as fuel are practiced in Cameroon in smoking fish (Feka and Manzano, 2008; Nfotabong-Atheull et al., 2009; Jiazet and Hans, 2019), and lime production in Madagascar (Scales et al., 2018; Scales and Friess,

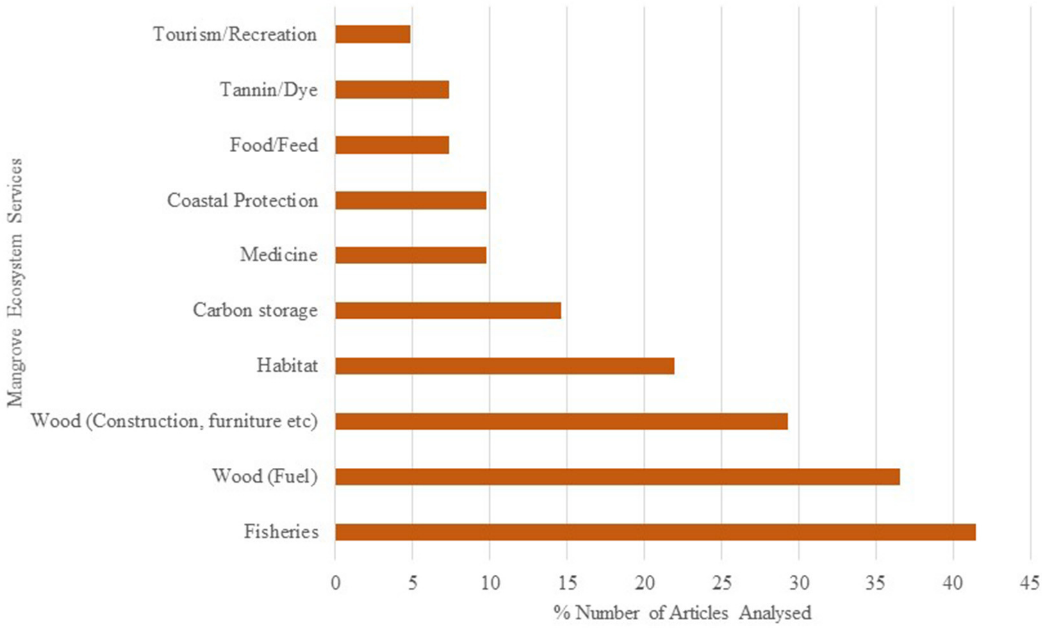

FIGURE 8
Distribution of mangrove ES mentioned in the articles covering studies in Africa ($n = 41$)

2019). In Cameroon and most West-Central African coastal states, fuelwood extraction for commercial fish smoking was identified as a threat to the sustainability of mangrove ecosystems (Feka and Manzano, 2008; Feka et al., 2009). Mangrove wood is also used to build fences in Madagascar (Scales and Friess, 2019) and Cameroon (Nfotabong-Atheull et al., 2009) and fishing gears e.g., fish traps, paddles and boats (Rönnbäck et al., 2007), as also seen in Asia.

Other products harvested from mangrove forests in Africa include food and fodder for animals, medicine, tannin, and dye. Sao Tome community in Guinea obtain wild food (mostly shellfish such as oysters, snails and crabs) from the mangroves (Afonso et al., 2022), as also seen in other parts of West Africa (Carney, 2017). In Kenya, mangrove dye is used to produce tie and dye fabrics and use to seal up tiny pores in trays woven from reeds and palm leaves (Dahdouh-Guebas et al., 2000). Medicinal products are made from the bark of the mangrove trees in Mida Creek, Kenya (Dahdouh-Guebas et al., 2000). Tree stems of different ages provide medicines for different ailments e.g., roots of *Rhizophora mucronata* provide curative properties for constipation, fertility, and menstrual disorders (Dahdouh-Guebas et al., 2000). *Xylocarpus granatum* is used to soothe aching muscles and limbs resulting from injuries (Dahdouh-Guebas et al., 2000), stomach problems and cure rashes (Semesi, 1998). Traditional use of medicine from mangroves in West Africa is also reported (Carney, 2017). Like in Asia and South America, making beverages from mangroves is reported in West Africa, where in the Gambia tea is made from *Avicennia germinas* (Satyanarayana et al., 2012). The use of *Avicennia sp.* for animal fodder is also customary practice in East Africa (Semesi, 1998). Mangrove honey is highly prized and while it is predominantly collected from modern hives in Senegal some mangrove honey is still collected in traditional hives (Gallup et al., 2020).

3.2.4 Mangrove utilization in South America

Most of the articles from South America were from Brazil covering 53% of the total literature from this region ($n = 36$). Articles from South America were mostly on the contribution to fisheries, which was covered in 61% of the articles from the region, followed by provision of habitat (14%), with other ES mentioned in 11% of the papers or less (Figure 9). Mangrove resource use was better represented in this region than in North America and Oceania.

Mangrove roots were used in the construction of houses and boats by the Warao people in Venezuela for over 7,000 years (Bibi et al., 2019). Villate Daza et al. (2020) reports overexploitation of *Lumnitzera racemose* used for the construction of huts that provide shade to tourists visiting beaches in Colombia. Commercial uses of mangrove wood for fuel are observed in Colombia in charcoal production (Palacios and Cantera, 2017) and in brick kilns in Brazil, where domestic uses are also reported (Saint-Paul, 2006).

As in other regions worldwide, mangroves are an important source of food, fodder for animals and medicines in South America. Mangrove are an important food supplement for Antillean manatees in northeast Brazil, as the roots are rich in fibers and the high water content in the leaves are a source of freshwater (Rodrigues et al., 2021). Carney (2017) reports traditional uses of mangroves for medicinal purposes in Colombia, Peru and Brazil, while tannin and dye from *Rhizophora sp.* are still currently used in the latter (Moreira dos Santos and Lana, 2017). Extensive deforestation was recorded in Brazil due to the increased production of leather tannin from bark of *Rhizophora mangle* (Saint-Paul, 2006). Historically, bark was removed from tree trunks and branches and boiled to extract dye that was used in fishing nets, wood floors, and leather production. The literature reports a shift from using mangrove resources as a main source

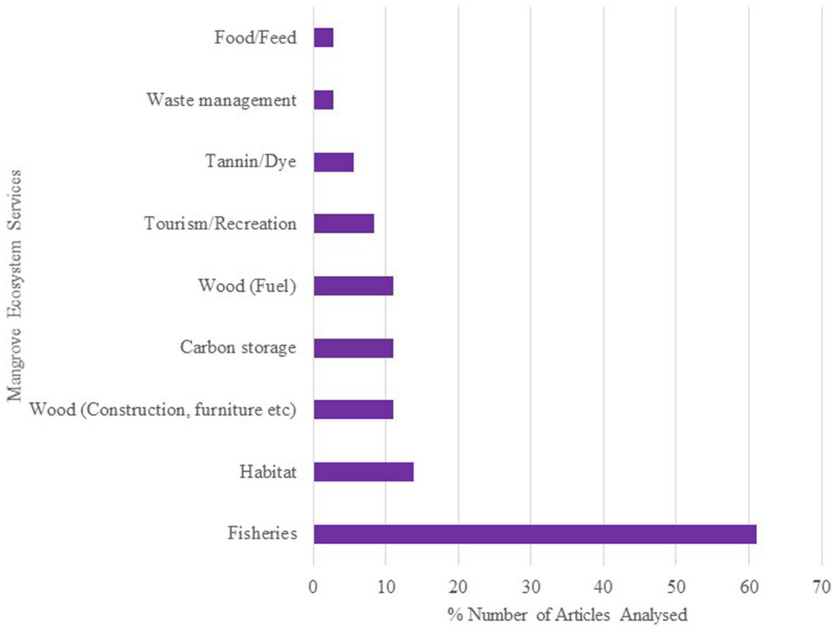

FIGURE 9
Distribution of mangrove ES mentioned in the articles covering studies in South America (n = 36).

of income to subsistence use and a decrease in domestic use of mangroves for fuelwood in Brazil (Moreira dos Santos and Lana, 2017). A lagging economy and lack of alternatives for construction materials have made mangrove harvesting inevitable in Western Venezuela adding pressure on mangrove forests (López-Hoffman et al., 2006).

3.2.5 Mangrove utilization in Oceania

Out of the 310 articles analyzed, only 9% (n = 27) were from Oceania of which 74% are from Australia. All the articles were on the regulatory and supporting services of mangroves. The contribution of mangroves to fisheries and habitat function was each covered by 44% of the articles. Carbon storage and coastal protection functions are covered by 11% of the articles each (Figure 10).

4 Discussion

A literature review produced by Friess (2016) showed that, between 1823 and 1883, studies focused on the export of mangrove products, although regulation services, such as erosion control and sediment accretion, were recognized as early as 1865. Studies on regulating and supporting services (e.g., fisheries, habitat, coastal protection and carbon sequestration) have dominated publications on mangrove ES since 2015, with peak number of articles in 2018 and 2019. Ongoing global attention on climate change and mitigation mechanisms in the Paris Agreement 2015 and the subsequent COP conferences have stimulated research on the contribution of blue carbon e.g., in carbon sequestration (e.g., Taillardat et al., 2018; Serrano et al., 2019; Were et al., 2019; Chatting et al., 2022) and natural coastal protection (Morris et al., 2018; Vanegas et al., 2019; Asari et al., 2021; Chang and Mori, 2021). Furthermore, regulating and supporting services have direct economic value (fisheries) or global significance (carbon storage, biodiversity), making them priorities for research funding and policy attention.

The review of 310 articles indicates that uses of mangrove resources are similar across continents, despite local variations in the dominant types and intensity of uses (e.g., Hamza et al., 2023; Reyes-Arroyo et al., 2021; Cornejo et al., 2005). Therefore, knowledge gained from research on ES/uses in one region can be replicable in another. It is unsurprising that the largest number of papers (43%) cover mangrove ES and use in Asia, where 39.2% of the global mangrove coverage is found. Indonesia alone has 19.7% of the world's mangrove cover (Jia et al., 2023) and was the country with the most literature on mangrove uses/ES in Asia (26% of the papers analyzed in Asia) and the world (11% of 310 papers). Despite the similarity of mangrove use across continents, the noted absence of published studies covering the ES of coastal protection in South America and waste management in Africa highlights regional disparities in mangrove ES research.

In 2020, Brazil and Australia ranked second and third in the world's mangrove coverage respectively (Jia et al., 2023) and this is reflected in the relative high number of papers on mangrove ES. Despite 20 papers found with information of mangrove ES in Australia, none covered direct use. This is surprising considering that traditional use of mangroves by indigenous people of Australia are wide and varied, including all the uses identified in this review (firewood and charcoal; construction of houses, furniture, boats and fishing gear; tannins for dyeing and leather production, food, medicine) and others, such as insecticide (Bandaranayake, 1998). Although information on uses of mangroves in Australia

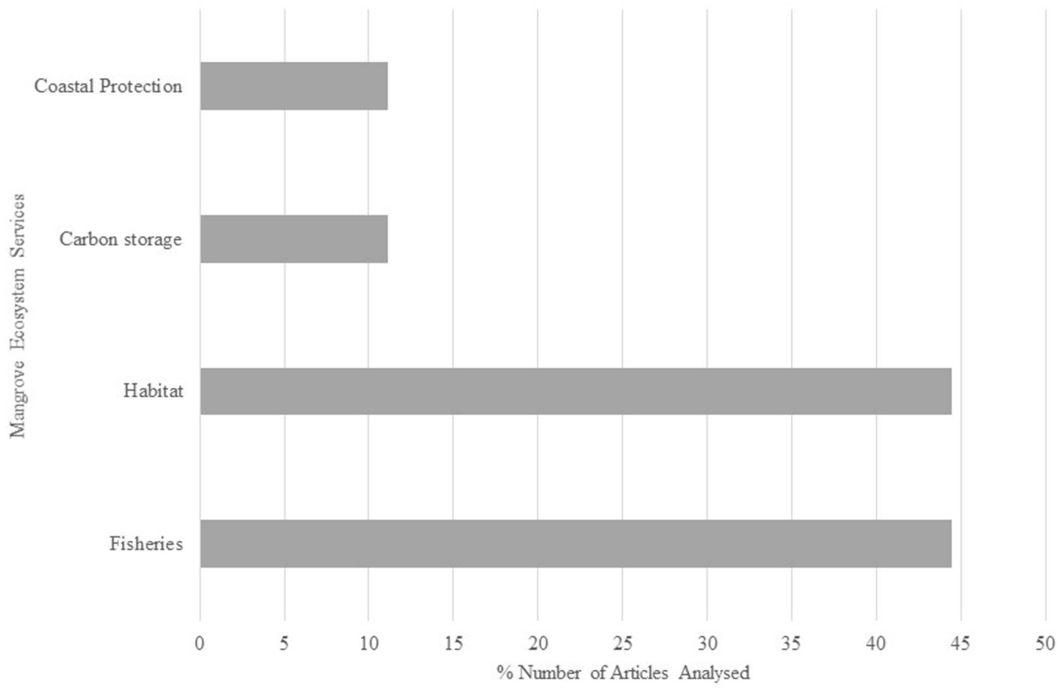

FIGURE 10
Distribution of mangrove ES mentioned in the articles covering studies in Oceania ($n = 27$).

can be found in online and gray literature, they are scarce in scientific publications. Perhaps there is less research interest because traditional uses of mangroves in Australia are no longer common practice and restricted to remote areas of low population, hence low environmental impact (Bird, 1986).

It is worth noting that the search did not capture all papers that might be considered relevant, such as the review of traditional and medicinal uses of mangroves written by Bandaranayake (1998) and Rasquinha and Mishra (2021). Bandaranayake (1998) cites Walsh (1977), who described the use of *Rhizophora sp.* seedlings to cure sore mouth and to produce wine that had aphrodisiac effect since the 13th century in Arabia as the earliest historical reference to the medicinal use of mangroves. It is important to recognize that a systematic search for scientific literature may miss some interesting publications and information, even when comprehensive databases such as the WoS are used. Use of different terms or phrases for the same concept or publishing in less prominent journals or gray literature that are not indexed are some of the reasons.

North America was the second most covered region having 16% of all the literature analyzed despite being third in terms of mangrove coverage (Spalding and Leal, 2021). Most of the literature on study areas in North America covered regulating and supporting services, while in Asia and Africa research on provisioning/direct uses of mangroves dominate the literature. Mangroves support the livelihoods of coastal communities in lower-income countries and their direct use is linked to mangrove loss and degradation, thus understanding their use is relevant to resource management (Feurer et al., 2018; Das et al., 2022). The proportion of literature covering the utilization of wood for fuel and construction was highest in Africa, depicting a greater dependence on mangrove wood products in this region compared to others (Spalding and Leal, 2021; Nunoo and Agyekumhene, 2022). The use of mangrove wood for domestic fuel is widespread across the continent, while commercial uses such as fish smoking in Cameroon and lime production in Madagascar are also notable. This heavy reliance on wood resources raises concerns about the sustainability of mangrove ecosystems, especially in West-Central African coastal states. The historical use of mangroves as a source of medicine, food and fodder was better represented in literature from Asia and Africa than in other regions.

This review identified 11 types of ES (Table 1) that were more often mentioned in the literature and should not be considered as the only uses and ES provided by mangroves. Other studies might have identified different number and types of mangrove ES depending on how the services are grouped, the terminology used and the geographic scale and focus of the research. For example, obtaining food for humans and feeds for animals were considered separate services in other studies (e.g., in Rönnbäck et al., 2007), while here they were counted together (e.g., Table 1, Figure 2). While genetic resources and maintenance of soil nutrients are more likely to be elicited by experts (e.g., Himes-Cornell et al., 2018), research focused on local community perceptions identify site-specific ES, such as space for the disposal of household waste, hunting, urban development (e.g., Jadin and Rousseau, 2022).

Communities living on tropical and subtropical coasts worldwide have used and relied on mangrove wood for their needs for thousands of years (e.g., Robinson and McKillop, 2013). Mangrove wood is appreciated due to high durability, resistance to salinity (Walters et al., 2008) and termite attacks (Conchedda et al., 2011). Due to the quality of the resource and its availability are an attraction, the risk of overexploitation is far greater in locations within few kilometers from settlements and of easier access, such as forest edges, around trails and roads or accessible by boat (Rasquinha and Mishra, 2021). While clearing mangroves for aquaculture continues, especially in Southeast Asia (Goldberg et al., 2020), harvesting pressures have decreased in some areas due to voluntary practice changes or enforced regulations. Examples are provided here; however, reports on changes in mangrove use over time are scarce in the scientific literature, and the underlying drivers are rarely discussed. It is apparent that the use of mangrove wood in construction of houses and boats is decreasing or no longer practiced by some communities in Madagascar (Scales and Friess, 2019), Brazil (Moreira dos Santos and Lana, 2017), India (Rasquinha and Mishra, 2021) and others. Rasquinha and Mishra (2021) report that communities living within the Bhitarkanika Wildlife Sanctuary on the east coast of India now use materials brought from nearby cities for their construction needs but they do not explain why mangrove wood is no longer used. They emphasize that local communities still depend on mangroves for fuelwood (cooking and heating), harvesting dry wood and cutting branches of preferred species while preserving larger trees. Legal protection of mangrove forests was a driver for the reduction in harvest and use of mangrove wood in southern Brazil, although illegal cutting is still practiced by locals who cannot afford alternative products (Moreira dos Santos and Lana, 2017). Legislation and regulations to halt mangrove loss and degradation were also implemented in other countries, such as the Philippines (Janssen and Padilla, 1999) and Kenya (GoK, 2017). However, illegal harvesting still occurs if suitable and sustainable alternative sources of income are not available to local communities (Hamza et al., 2023).

While in some places traditional uses of natural resources are gradually giving way to practices that use alternative products when they become affordable (Hamza, 2022), in other cases, increasing local needs for subsistence or income perpetuate the dependence on mangroves. Scales and Friess (2019) describe traditional and emerging uses of mangrove wood by communities in the Bay of Assassins in southwestern Madagascar for subsistence and commercial purposes that increase pressures on this natural resource. They report that houses and fences are almost exclusively built with mangrove wood, and more recently, mangrove poles are used for seaweed aquaculture and in the construction and operation of lime kilns. Paradoxically, the income from aquaculture (an activity that uses mangrove wood) has increased the demand for lime rendering, as it strengthens houses against the impacts of cyclones and is seen as an indicator of status (Scales and Friess, 2019). Contrasting with other locations in Africa, the Malagasy community in the Bay of Assassins prefer and mostly use wood from terrestrial forests as fuelwood for domestic cooking (Scales and Friess, 2019).

Thiagarajah et al. (2015) suggest that many communities in Asia had a closer connection with nature in the past and had a greater appreciation of the intrinsic value of mangroves before coastal areas became intensely developed. Although this might be common in other coastal areas worldwide, the intrinsic value of mangroves and how perceptions might have changed through time are not well described or assessed in the scientific literature available in English. Cultural ES associated with the intangible value of mangroves, such as sense of place, inspiration, and cultural heritage, are understudied in all regions and only covered in 9% of the literature analyzed. Similarly, a global review by Bimrah et al. (2022) mostly identified studies on regulatory services, such as carbon sequestration and disaster risk reduction, while cultural services were the least represented. Cultural services are more difficult to identify as they are innate to specific sites and individual experiences and, therefore, cannot be assessed through simple benefit transfer methods. Understanding the direct uses of mangrove resources by surrounding communities and their basic needs is essential for policy and management measures to be effective and sustainable. However, the management of natural resources will only be inclusive and equitable when their intangible cultural values are fully appreciated and considered.

5 Conclusion

A systematic review of 310 papers in the WoS focusing on mangrove uses has shown that mangrove ecosystems provide a wide range of ecosystem services globally, but their importance and utilization vary significantly across regions. While some services like fisheries support, carbon storage, and habitat provision are universally recognized, others show distinct regional patterns. The emphasis on certain ecosystem services in specific regions likely reflects local socio-economic dependencies and cultural values. Direct use of mangrove resources (e.g., wood for fuel and construction) are most often covered in less developed regions, such as Asia, Africa and South America. While the use of mangrove wood for fuel is still pervasive in less developed countries, the use in construction is reducing in some areas. The information presented also reveals a tension between the intensive use of mangrove resources (particularly for wood and charcoal) and the need for conservation. However, a shift is observed in the use of mangrove wood, transitioning from a primary source of income to subsistence use in Asia, Africa, and South America.

Beyond their ecological functions, mangroves provide significant value by supporting livelihoods, cultural practices, and traditional knowledge systems. Notably, mangroves possess medicinal properties, yet such uses remain underutilized globally. Furthermore, cultural services, which are essential for inclusive and equitable conservation, were found to be underrepresented in the literature. Therefore, it is crucial to emphasize these values in conservation efforts. The findings underscore the need for context-specific conservation and management approaches that consider both the ecological importance of mangroves and their socio-economic value to local communities, ensuring a more holistic and effective conservation strategy.

The literature coverage might not be a fair reflection of pressing issues as funding availability, distance from research centers and/or language barriers can create bias (in geography or topic coverage). This paper only reviewed literature from WoS and may have missed some relevant literature that might have been obtained if the search was extended to other databases. In addition, the review covers only scientific papers published in English, which tend to reflect wider/international interests, while gray literature in local language might offer different insights into local uses.

Author contributions

AH: Conceptualization, Formal analysis, Funding acquisition, Methodology, Writing – original draft, Writing – review & editing. LE: Conceptualization, Writing – review & editing. MC: Conceptualization, Writing – review & editing. JK: Conceptualization, Writing – review & editing.

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Conflict of interest

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsrma.2024.1395724/full#supplementary-material

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