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Review

The composition, distribution, and socio-economic dimensions of Ghana's mangrove ecosystems

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ABSTRACT

Mangrove ecosystems are recognised as one of the nature-based solutions to a changing climate. Notwithstanding the socio-ecological benefits of mangrove ecosystems, they are increasingly being destructed in some regions of the world. In Ghana, several studies have reported on the status, use, and management strategies of mangrove ecosystems in different sites of the country. However, these studies do not make it possible to appreciate the broader picture of Ghana's mangrove ecosystems since they are not synthesized into a single comprehensive report. This study uses the ROSES method for systematic reviews to report on Ghana's mangrove ecosystem distribution and species composition, as well as their socio-economic benefits, the anthropogenic and natural impacts on Ghana's mangrove ecosystems, and the management strategies and/or practices on Ghana's mangrove ecosystems. The study reveals there is no existing management strategy for Ghana's mangrove ecosystems, and therefore recommends the need to develop and implement policies and regulations that specifically target the protection and sustainable use of mangrove ecosystems in Ghana.

1. Introduction

Mangroves are forest ecosystems found in bays, estuaries, lagoons, and along the intertidal zones of coastal areas (Bunting et al., 2018; Mukherjee et al., 2014; Thomas et al., 2017). Present in the earth's tropical, subtropical, and warm temperate climate zones, and mostly consisting of woody vegetation, mangroves grow in over 120 countries and territories (Dahdouh-Guebas et al., 2021; Spalding, 2010). As of 2020, on a global coastline of 2,139,308.93 km, mangroves covered approximately 14.9% (i.e., 147,359 km^2) (Bunting et al., 2022a, 2022b), consisting of over 80 true species (Alappatt, 2008; Saenger et al., 2019; Spalding and Parrett, 2019). In 2016, it was estimated that about 40.5% of the global mangroves were deltaic, 27.5% were estuarine, 21.0% were open coast, and 11.0% were lagoonal (Worthington et al., 2020).

Mangrove ecosystems are identified as highly carbon-rich plant communities (Song et al., 2023) providing a large range of economic and socio-ecological services and benefits such as carbon storage and sequestration, coastal protection, food production, and tourism to surrounding coastal communities (Bunting et al., 2018, 2022a; Goldberg et al., 2020). The ecosystem services provided by mangroves globally are estimated to be over USD 1.6 billion per year. Also, mangroves serving as blue carbon systems sequester over 25.5 million tons of carbon per year while supplying about 10% of the global ocean's organic carbon (Bunting et al., 2022a; Daru et al., 2013; Polidoro et al., 2010).

Contrary to the above benefits, mangroves have experienced significant impacts of destruction and deforestation losing over 20–35%

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coverage in the last 50 years (Goldberg et al., 2020; Polidoro et al., 2010; Richards et al., 2020). More than 60% of this decline in global mangrove coverage has been associated with mangrove conversions into aquaculture, agriculture, and urban development (Bunting et al., 2018; Goldberg et al., 2020; Leal and Spalding, 2022). The intensification of mangrove restoration campaigns in the last couple of years has however slowed the annual rates of decline (Worthington et al., 2020), from 0.26% in 1996 to 0.13% in 2016 (Goldberg et al., 2020; Leal and Spalding, 2022), alongside expansion towards river-mouths and land by natural regeneration, mostly due to the rising sea level and temperature in areas where they occur (Leal and Spalding, 2022; Richards et al., 2020). Considering that there are limited global studies estimating the scale of impact of mangrove change on biodiversity puts mangrove ecosystems at a higher risk (UNEP, 2023).

While there have been several reports and studies conducted on mangrove ecosystems occurring at different sites in tropical countries, there is a high regional disproportionate distribution of these studies. Bimrah et al. (2022) in their research focusing on mangrove ecosystem services distribution point out that out of 76 papers, about 74% of the literature was found in Asia. Aside from this non-uniform distribution of mangrove reports and studies, there are also limited studies providing detailed reports on mangrove ecosystems at a national level. The compounding effects of this include a poor understanding of the global mangrove services, as well as a lack of integrated information to harness further research in mangrove science (Bimrah et al., 2022). For instance, in Africa, where the third largest mangrove extent in the world exists (UNEP, 2023), no detailed study has been undertaken at a national level to report on mangrove ecology and distribution, and its socio-economic dimensions (UNEP, 2023). The lack of detailed studies at national levels makes it difficult to comprehensively compare mangroves on country-by-country bases on the continent, and even compile mangrove information on a continental level. Moreover, in recent studies executed on a global scale such as Song et al. (2023), Goldberg et al. (2020), and Thomas et al. (2017), Africa, particularly West Africa, is often listed as a data-deficient spot on the planet compared to South-East Asia. Dahdouh-Guebas et al. (2022) pointed out avenues for further research, but above all a call for submitting questions on mangrove science and management to be answered with priority.

Through the present study, we seek to close this research gap by developing a comprehensive report on Ghana's mangroves and their socio-economic dimensions. Closing this gap serves as a roadmap for other African countries towards achieving a common goal of mangrove management on the continent. The use of systematic reviews has been demonstrated as a more valuable and informative form of gathering ecosystem information (Dahdouh-Guebas et al., 2021; Friess, 2016; Hagger et al., 2022; Poti et al., 2022), particularly for mangrove ecosystems at the national level in Africa, where information is scanty and scattered. Also, systematic reviews help to identify and mosaic the best available data or studies from multiple sources into a single synoptic but comprehensive study (Bimrah et al., 2022).

In Ghana, there are institutions like the Centre for African Wetlands (CAW), a member of the International Society for Mangrove Ecosystems (ISME) which have been involved in mangrove research and workshops (Baba et al., 2004; Macintosh and Ashton, 2003). There are also several studies (Aheto et al., 2014, 2016; Nortey et al., 2016; Ntyam et al., 2014; Obodai et al., 2019) conducted on Ghana's mangrove ecosystems in different sites which have reported on mangrove species composition, socio-economic benefits, anthropogenic and natural impacts on mangrove ecosystems, spatio-temporal changes of mangrove ecosystems, and management of mangrove ecosystems, among others. Recent studies in Ghana such as Asante et al. (2023), Sekey et al. (2023), and Peters and Kusimi (2023) have assessed the use of mangroves and their associated impacts, as well as some local mangrove restoration programmes. For instance, Sekey et al. (2023) make mention of how community participation is helping to restore the Keta Lagoon Complex Ramsar Site (KLCRS) while Asante et al. (2023) make mention that community-based mangrove management has been compromised to accommodate the needs of the local people. In as much as the findings of these studies and reports are relevant, they are locally restricted and hence do not provide a full appreciation of the state of Ghana's mangrove ecosystems. Also, individual local research and reports based on various independent objectives may not gain high recognition, though may carry quality information. Synthesising these individual studies together will help close this research gap and provide relevant information and data required to promote mangrove conservation and restoration in Ghana and beyond.

A study of this nature is important in Ghana considering the fact that the country serves as the regional centre (i.e., the CAW) for the Global Mangrove Database and Information System (GLOMIS) in Africa and the Middle East (Baba et al., 2004). It is also one of the countries with Ecuador and Guyana identified as having a good number of Ramsar Sites (protected areas), yet hotspots of mangrove loss (Hagger et al., 2022; Sekey et al., 2023). This study brings all these concepts of Ghana's mangroves together under one umbrella. We acknowledge the study of Nunoo and Agyekumhene (2022) which explored local utilization, threats, and existing conservation practices of Ghana's mangrove ecosystems. However, the study does not provide adequate information on Ghana's mangrove ecosystems since it is limited to a percentage of the total mangrove sites in Ghana with limited data provided.

An integrated study is therefore needed at national levels in Africa to help the continent gather most of its mangrove information, which will serve as a repository for mangrove ecosystem management and public education. This study evaluates Ghana's mangrove ecosystems and the socio-economic factors at play in their use and management by (i) assessing the current distribution and species composition of Ghana's mangrove ecosystems, (ii) identifying the natural and anthropogenic impacts on Ghana's mangrove ecosystems, (iii) determining and comparing the extent of mangrove ecosystem research conducted in Ghana's coastal regions, (iv) assembling and comparing the mangrove ecosystem goods and services in Ghana with other neighbouring countries, and (v) analysing the past and present management implications on Ghana's mangrove ecosystems.

This study will serve as a comprehensive national document on mangroves in Ghana. Serving also as a precedent for other nations to undertake similar studies, this study helps to understand mangrove dynamics on a country-wide scale, which will further help to compare mangroves on a country-by-country basis.

2. Methodology

2.1. Study area

Ghana is a West African country which is bordered by Burkina Faso on its north, Togo on its east, Cote D'Ivoire (indicated hereafter as Ivory Coast) on its west, and the Gulf of Guinea on its south. Ghana's geographical location lies between 07°56′47.5″ N and 001°1.392′ W and occupies a surface area of 238,533 km^2 (Ampim et al., 2021). The capital city of Ghana is Accra which is located in the Greater Accra region. Based on the climate, natural vegetation and soils of Ghana, there are seven agro-ecological zones which include Coastal Savannah, Wet Evergreen, Moist Evergreen, Deciduous Forest, Transition zone forest, Guinea Savannah, and Sudan Savannah zones. The average minimum and maximum temperatures of Ghana are 21 °C and 34.3 °C, respectively (Bessah et al., 2021).

Since mangroves are reported to occur in the coastal part of Ghana, the study was conducted in the coastal regions of Ghana which are located in the Wet-Evergreen and Coastal Savannah zones. The coastal regions include Volta, Greater Accra, Central, and Western Regions. These coastal regions experience bi-modal rainfall seasons with major rains occurring between March and July, and minor rainfall seasons occurring between September and November (Fig. 1). Over the last three decades, the mean annual total rainfall recorded for the Wet-Evergreen

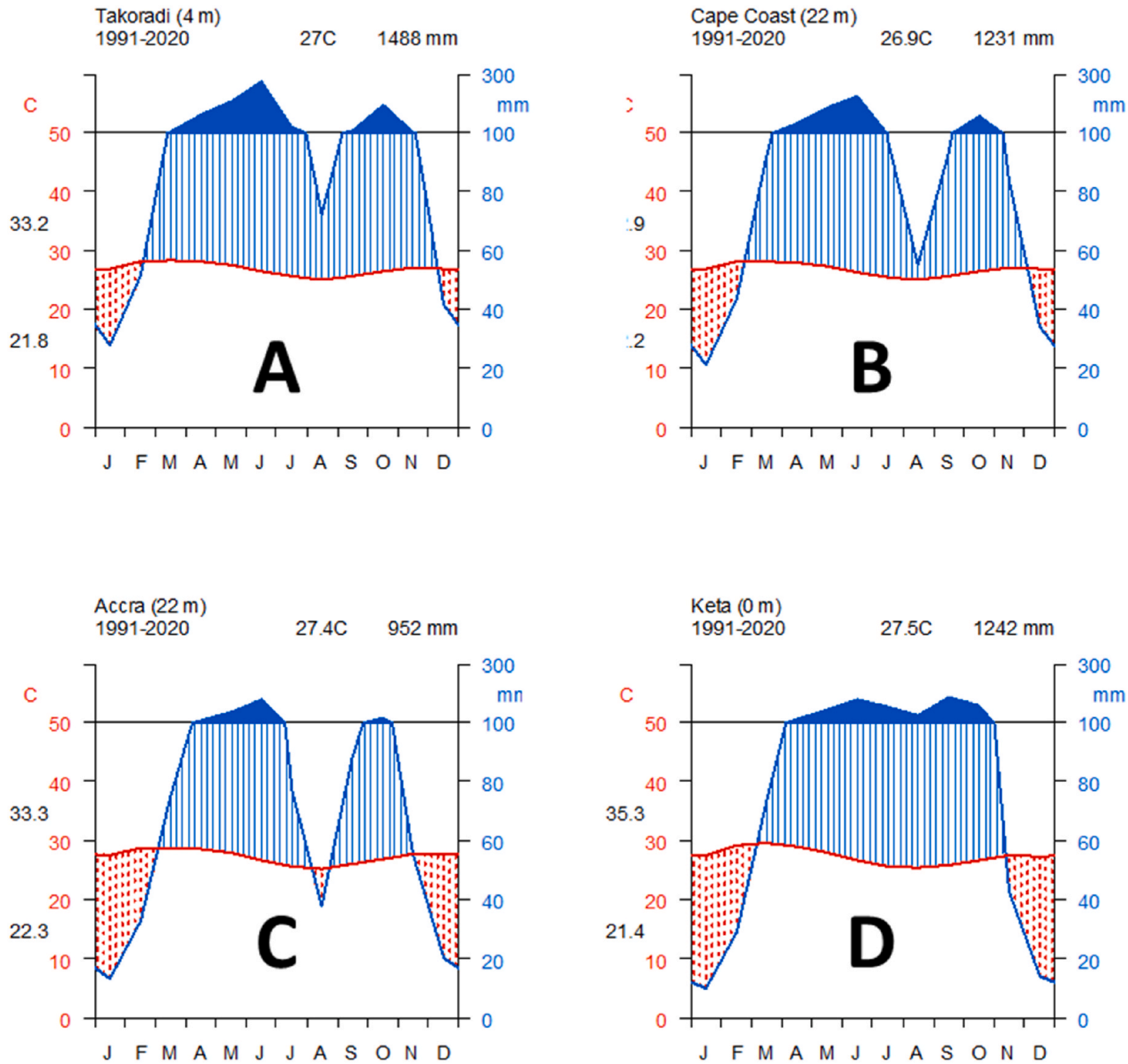

Fig. 1. Walter-Lieth climate charts showing the monthly mean air temperatures (red-coloured y-axis) and mean precipitation (blue-coloured y-axis) of the four coastal regions of Ghana (A = Western, B = Central, C = Greater Accra, D = Volta). Climate data were retrieved from https://climateknowledgeportal.worldbank.org/country/ghana. Topographic data of each monitoring stations was retrieved from "https://en-gb.topographic-map.com/". (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

and Coastal Savannah zones are 1850 mm and 700 mm, respectively (Bessah et al., 2021).

From the 10 m 2020 WorldCover map developed by the European Space Agency (ESA), a land-cover map of Ghana was developed to visualise the different land-covers present in Ghana (Fig. 2).

2.2. Search and selection of literature

In order to identify and select the available studies reporting on mangroves in Ghana, the RepOrting standards for systematic evidence syntheses (ROSES) method was used (Gatt et al., 2022; Haddaway et al., 2018). The search, screening and selection of studies took place in December 2022. The search databases that were used included Web of Science, Scopus, and Google Scholar. The search terms used in the search of studies in the databases are provided in Table 1. For all identified studies, the searches were limited to their titles/topics, abstracts, and keywords. All the searches were also limited to only English language studies and involved all available studies until December 2022. Unlike Scopus and Web of Science, the search strings for Google Scholar were less complex (Table 1).

In order to compare the ecosystem goods and services of Ghana's mangrove ecosystems with those of other West African neighbouring countries, we consulted literature, technical reports, the websites of international organisations and non-governmental organisations (NGOs), as well as the national websites of these neighbouring countries. All services were first gathered and grouped (see also Table S1), with the presence and absence of a service in a country denoted by 1 and 0, respectively. Hierarchical clustering analysis with Binomial dissimilarity index was used to establish how Ghana relates with its neighbouring West African countries in terms of mangrove ecosystem goods and services. It is worth noting that because mangrove ecosystem regulation and maintenance services are common ecological services provided by all mangrove ecosystems, they were not included in the analysis.

2.3. Screening

A total of 148 studies were identified from the databases using the search strings provided in Table 1. Out of the 148 identified studies, eight (8) duplicates were removed, and 70 studies were also removed

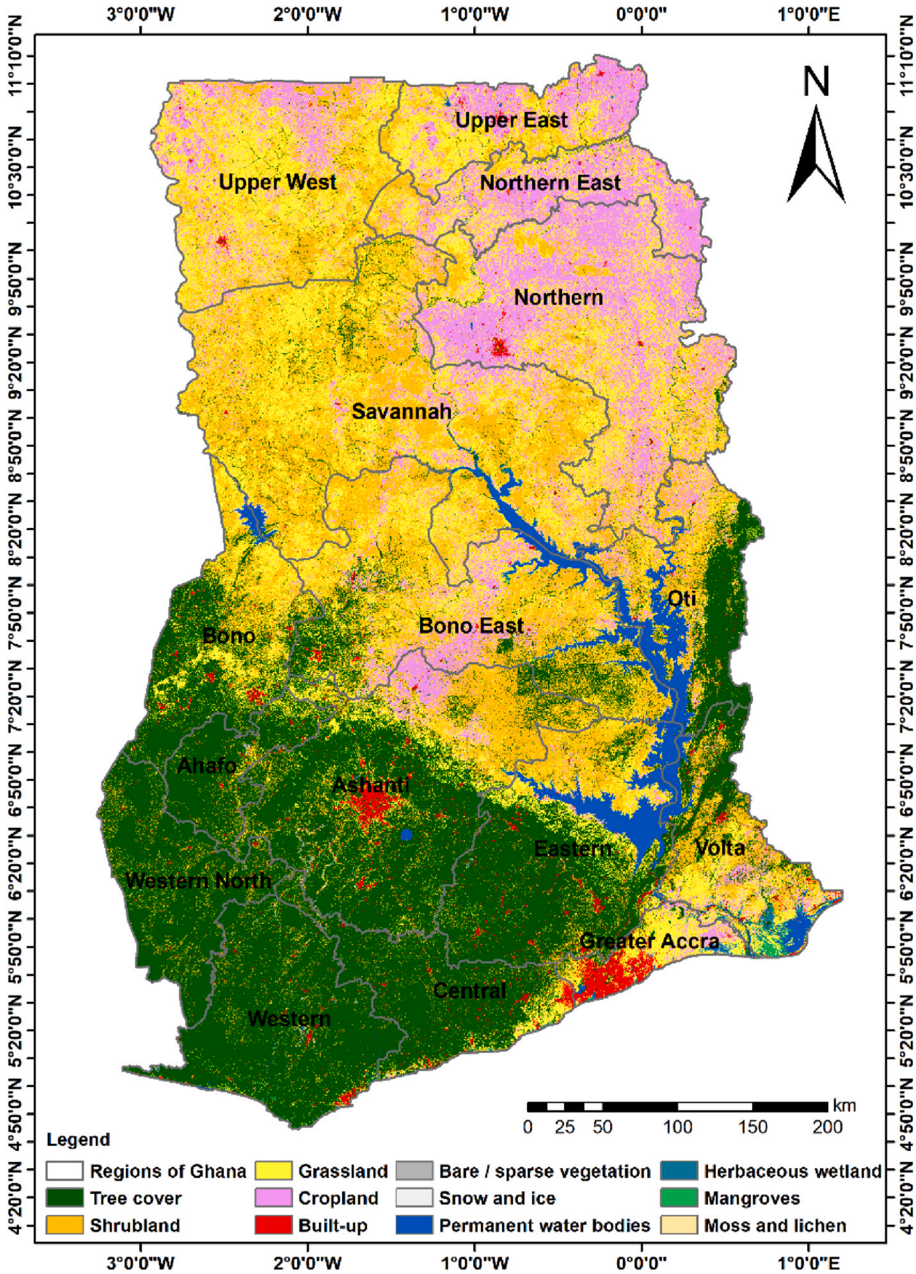

Fig. 2. A 2021 landcover map of Ghana. Map data was extracted from the 2021 WorldCover map developed and validated in near-real time based on Sentinel-1 and Sentinel-2 data (European Space Agency [https://esa-worldcover.org/en]; Zanaga et al., 2022), and United Nations Humanitarian Data Exchange (https://data.amerigeoss.org/dataset/ghana-administrative-boundaries).

after identifying that they did not directly report on Ghana mangroves. In total, 70 studies were found to be useful for the current study. It is worth noting that since the Scopus database was consulted first, all studies appearing in other databases but already downloaded from Scopus were ignored. Consequently, 36 studies in the Web of Science and 10 in Google Scholar were not downloaded to avoid repeated downloads of the same papers between databases.

The ROSES method has been identified as a more suitable method than the popular method PRISMA in conducting review studies in conservation and environmental management. Therefore, ROSES was used in conducting the screening and selection of relevant studies for this study. The entire screening and selection process is summarised in the ROSES flow diagram (Fig. 3).

2.4. Data extraction

From the selected studies, several relevant data were extracted, which included: mangrove ecosystem distribution in communities/districts/regions, geographical locations of identified mangrove ecosystems, mangrove extent, mangrove species, information on the management of mangrove ecosystems, anthropogenic and natural impacts on mangrove ecosystems. In cases where the geographical locations of identified mangrove ecosystems were not provided in the relevant literature, the respective coordinates in degrees and minutes (no seconds) were retrieved from Google Earth Pro (version 7.3.6.9326) based on the location information in the relevant literature and marked with an asterisk (Table S1). However, the geographical locations of some mangrove ecosystems were not available (NA) in the relevant literature and the Google Earth Pro software.

Table 1
Summary of literature search strategy for the current study indicating the databases, the search string, the total number of studies downloaded, and the number of selected relevant studies. The numbers in parenthesis are the number of duplicate studies.

Database	Search string	Total number of studies before screening	Number of selected studies
Scopus	TITLE-ABS-KEY (ghana* AND mangrove* AND ghana* OR mangrove* OR coast* OR manag* OR wetland* OR lagoon* OR estuar* OR service* OR function* OR good* OR implicat* OR importan* OR impact*)	48 (1)	37
Web of Science	Ghana* mangrove* (Topic) or ghana* mangrove* (Title) or ghana mangrove* (Abstract) and ghana* OR mangrove* OR coast* OR manag* OR wetland* OR lagoon* OR estuar* OR service* OR function* OR good* OR implicat* OR importan* OR impact* (Abstract)	40 (0)	7
Google Scholar	"ghana mangrove" & ghana* mangrove* ghana* OR ghana* OR coast* OR manag* OR wetland* OR lagoon* OR estuar* OR service* OR function* OR good* OR implicat* OR importan* "ghana* mangrove*"	60 (7)	26
Total		148 (8)	70

2.5. Field visits

Between March 2021 and December 2022, field visits were made to selected areas in Ghana possessing mangrove ecosystems: Ankobra river estuary in the Ellembelle District, Keta Lagoon Ramsar site in the Keta Municipal and Anloga Districts, Densu Delta in the Weija Gbawe Municipal District, and Amansuri lake (Nzulezu) in the Jomoro District. Engagements were held with residents living close to the Ankobra river estuary (Asante et al., 2023) and the site manager of the Keta Lagoon Ramsar site. Interview questions revolved around the management and use of mangroves on these sites. Observations and photographs of occurring mangrove species were taken.

3. Mangrove ecosystem distribution in Ghana

With Ghana being a coastal country along the Gulf of Guinea, a substantial number of mangrove-related studies (n = 70) have been conducted since the 1990s in different communities in the country's coastal regions (Tables 1 and S1). The distribution of mangrove ecosystems in Ghana extends from the western coast (bordering Ivory Coast) to the eastern coast (bordering Togo). The most developed stands of mangroves are situated on the western coast of the country between Ivory Coast and Cape Three Points (UNEP, 2007; Naidoo, 2023), the oil drilling spot of Ghana. However, mangroves are more abundant on the eastern coast, especially the Volta delta. Most of the mangrove stands in Ghana are found in estuaries and lagoons but there are few deltaic including the Densu Delta Ramsar Site (CBD-Ghana, 2010; Nunoo and Agyekumhene, 2022). In Nunoo and Agyekumhene (2022) they observed that mangrove species in Ghana are distributed by salinity. However, there are other physical factors like temperature, coastal typology, ocean currents and land barriers, wave action and sediment supply, river catchment discharge and sediment yield, and tidal range and inundation frequencies (Ellison, 2021).

The majority of studies in Ghana report mangroves occur in only four regions. However, few studies have reported the presence of mangroves in Digya National Park (07°31′28.80″ N and 000°13′28.08″ E) located in the Bono East Region (Osei et al., 2019; Twumasi et al., 2005). This area of the Digya National Park is reported to possess several patches of inland mangroves associated with the largest man-made freshwater reservoir, Lake Volta. Water from the tributaries of Lake Volta is said to inundate the mangrove patches throughout the year (Osei et al., 2019). The mention of mangroves occurring in Digya National Park however remains questionable since the existing global mangrove maps (Bunting et al., 2022b) which span from 1996 to 2020 as well as local studies (such as Nortey et al., 2016; Nunoo and Agyekumhene, 2022) do not capture mangroves in this area. This implies that the mangroves which were once reported to exist in Digya National Park in 1991 (Twumasi et al., 2005) might have been degraded by the late 1990s or the mapping did not consider the area to be possessing mangroves since the Lake Volta is a freshwater lake which is about 150 km away from Ghana's coast.

4. Mangrove species composition in Ghana

According to the UNEP (2007), there are 17 true mangrove species occurring in Africa, and eight of them are located in 19 West African countries. Nigeria is reported to possess all eight mangrove species present in West Africa (UNEP, 2007). Togo, an east-neighbouring country of Ghana is reported to possess three mangrove species, namely *Rhizophora racemosa* G. Mey (Red mangrove), *Avicennia germinans* (L.). Stearn. (Black mangrove) and *Conocarpus erectus* L. (Button mangrove), while Ivory Coast, a neighbouring country to the west of Ghana possesses five mangrove species, namely, *Laguncularia racemosa* Gaertn. (White mangrove), *A. germinans*, *R. racemosa*, *Acrostichum aureum* L. (Golden leather fern), and *C. erectus* (Naidoo, 2023; UNEP, 2007). Compared to other countries on the Atlantic coast of Africa, Ghana shares the same species composition with Senegal, The Gambia, Guinea Bissau, Sierra Leone, Guinea, Nigeria, Cameroon, and Gabon (Naidoo, 2023).

Several studies conducted on Ghana's mangroves have reported the number of mangrove species to be ranging from five to seven species (Armah et al., 2005; Asare and Javier, 2022; Darkwa and Smardon, 2010; Gordon et al., 2009; Nortey et al., 2016; UNEP, 2007). The mangrove species reported to be in Ghana include all the five species found in Ghana's neighbouring countries in addition to *Rhizophora mangle* Guppy. (Red mangrove) and *Rhizphophora harisonii* Leechman. (Nortey et al., 2016; UNEP, 2007). *Avicennia germinans* is known to be a common species found on the higher ground and in the closed lagoons (Armah et al., 2005) while the open lagoons tend to be dominated by *R. racemosa* (Gordon et al., 2009). In contrast to multiple studies which indicate which state five-seven mangrove species in Ghana, Nunoo and Agyekumhene (2022) consider only three mangrove species, associating *A. aureum* and *C. erectus* as non-mangrove species.

In Ghana and other West African countries, studies that mention mangrove species do not classify them as either true or associate mangroves as compared to mangrove ecology studies conducted in other tropical and sub-tropical countries like Sri Lanka, India, Thailand, and Australia, among others (Duke and Allen, 2006; Giesen et al., 2007; Jayatissa et al., 2002; Wang et al., 2011). For instance, to several mangrove ecologists, *Acrostichum* spp. is not a true mangrove species but rather a mangrove associate (Chang, 1997; IUCN, 1983; Jayatissa et al., 2002; Kathiresan and Bingham, 2001; Mu et al., 2007; Tansley and Fritsch, 1905). Other studies conducted at different sites, however, consider *Acrostichum* spp. as true mangroves (Duke, 1993; Giesen et al., 2007; Lin, 1999; Tomlinson, 2016). Dahdouh-Guebas et al. (2005a, 2005b) demonstrated however that this can be detrimental when considering the functionality of the forest, which may be jeopardised because of the presence of associate species (cf. Dahdouh-Guebas and Cannicci, 2021).

From our field visits to the Keta Lagoon Ramsar site, the Amansuri

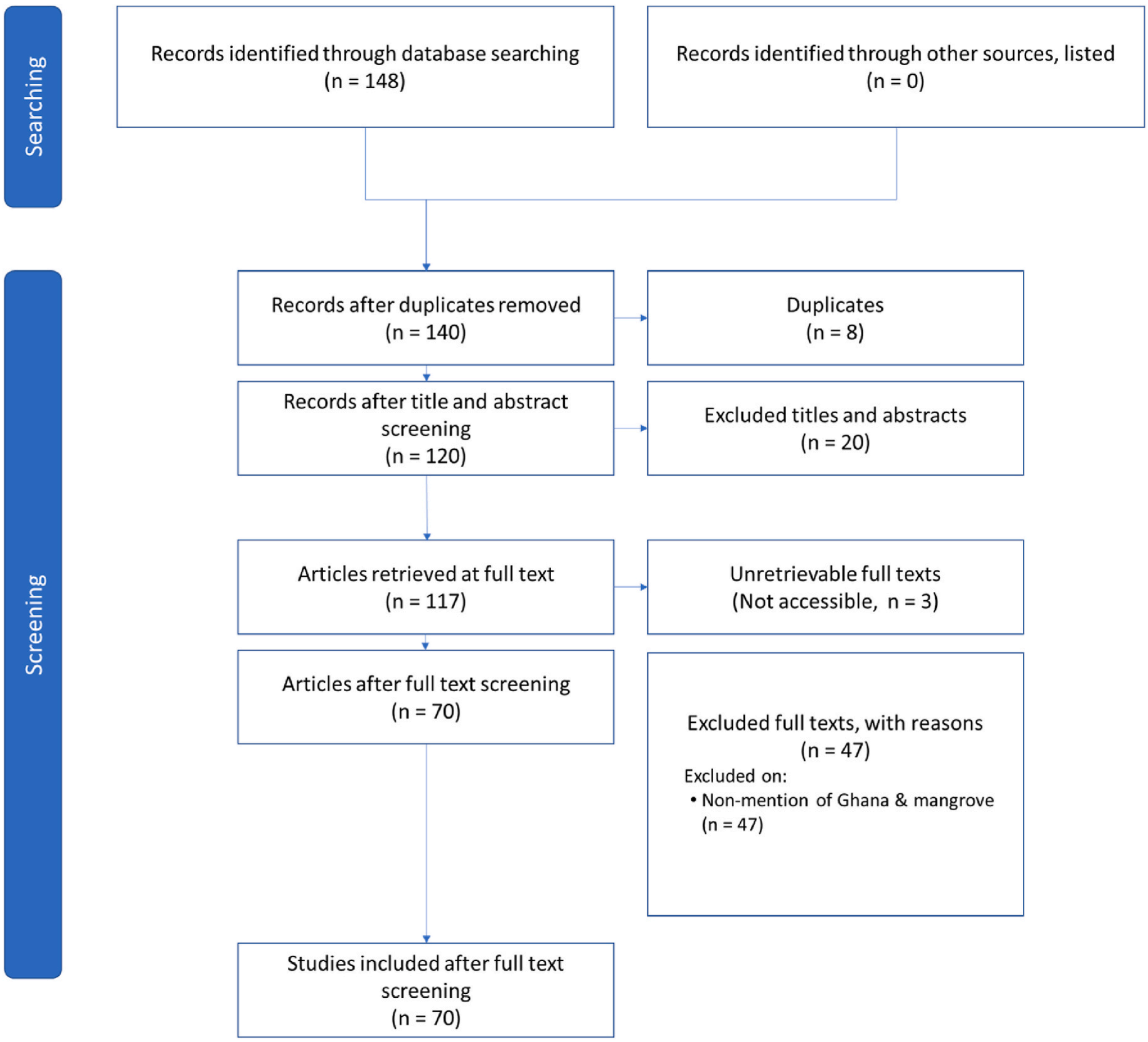

Fig. 3. ROSES flow diagram summarising the screening and selection of literature for data extraction.

lake, and the Ankobra river estuary, we identified four out of the seven species: *Laguncularia racemosa*, *Avicennia germinans*, *Acrostichum aureum, Rhizophora racemosa* and *Conocarpus erectus* (Fig. 4). *Laguncularia racemosa* was observed along the edges of the Meandah trail, which is flooded with the freshwater lake, Amansuri lake. The species was also observed at inland sites of the Keta Lagoon Ramsar site. These observations indicate the species' adaptation to freshwater and low-saline conditions.

5. Anthropogenic and natural impacts on Ghana's mangrove

5.1. Anthropogenic impacts

Along a total coastline of about 636.24 km, mangrove ecosystems in Ghana are identified to cover less than 1% (104.36 km^2) of Ghana's total land area of 238,533 km^2 (Bunting et al., 2022b). This narrow strip of mangrove forests along with other coastal ecosystems is surrounded by over 25% of the nation's population (Amlalo, 2006; Attuquayefio and Gbogbo, 2001; Fianko and Dodd, 2019).

Despite its relatively small size compared to other forest ecosystems in Ghana, mangrove ecosystems face severe pressures from both direct and indirect sources ranging from direct cutting to pollution. Wood et al. (2019) in their preliminary survey of forests in Benin and Ghana observed that mining is one of the causes of mangrove degradation in these two countries. The destruction by mining goes from the felling of mangroves to give space for mineral exploitation to the discharge of mined turbid water full of chemicals and mud that are harmful to organisms present in the mangrove ecosystem. The issue of mangrove destruction caused by mining activities is also pronounced in other African countries such as Togo, Senegal, Kenya, and Gabon (Naidoo, 2023). Oil mining has also been identified as a potential threat to mangroves in the Western region of Ghana (Asante et al., 2023). In Nigeria, oil spills and crude oil exploratory activities have been identified as major contributors to mangrove destruction in the Niger Delta (Onyena and Sam, 2020).

A number of studies including Coleman et al. (2004, 2008), Fianko and Dodd (2019), and Peters and Kusimi (2023) have attributed the destruction of Ghana's mangroves to the lack of law enforcement and inadequate public education on the impact of environmental degradation on Ghana, and its neighbouring countries. It is therefore not surprising that mangrove degradation due to human activities is seen even in the Ramsar Sites of Ghana despite the efforts by civil society organisations and governments to restore and conserve mangrove ecosystems (Asante et al., 2017; Fianko and Dodd, 2019; Sekey et al., 2023). For example, factors such as indiscriminate waste disposal, poor attitude of residents toward environmental conservation, wildfires, and shoreline recession through sand winning, fishing, and farming activities; overgrazing, over-exploitation of mangroves, uncontrolled sand, and

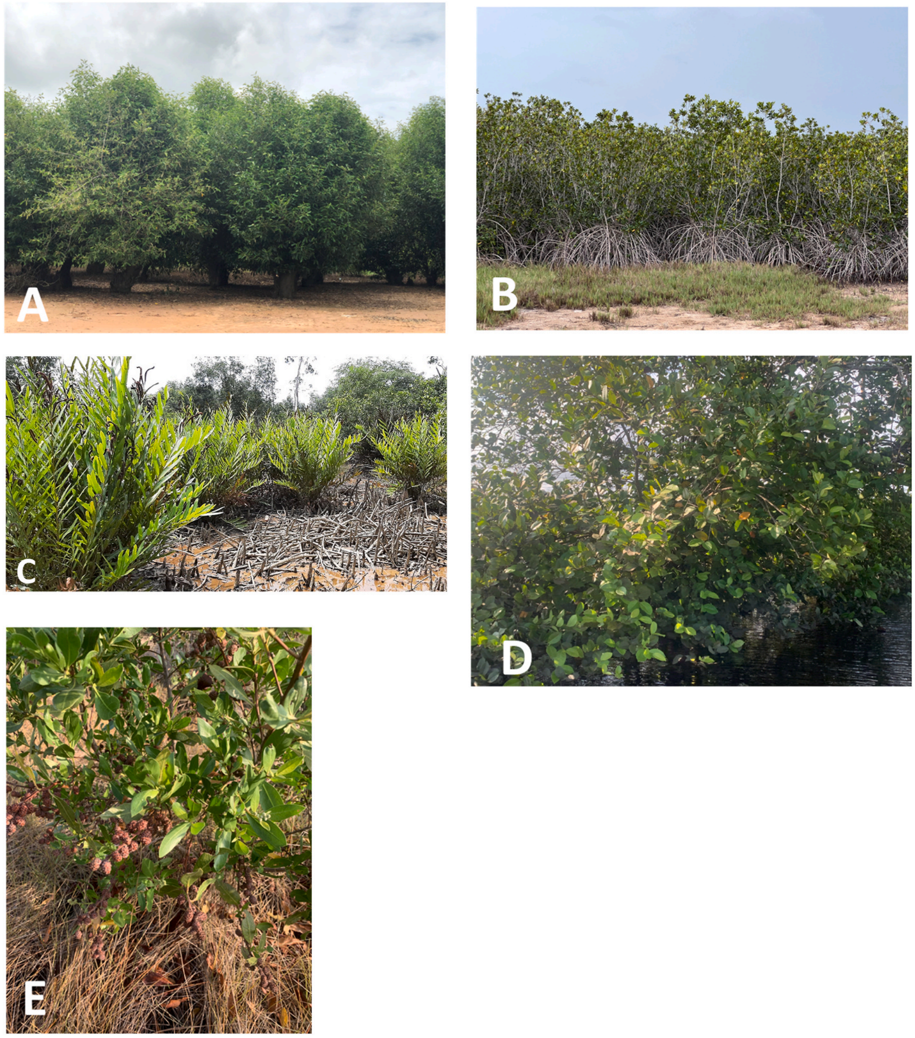

Fig. 4. Mangrove species observed in Ghana's mangrove ecosystems. Panels A, B, C, D, and E are field photographs of *A. germinans, R. racemosa*, *A. aureum, L. racemosa, and C. erectus,* respectively.

salt mining have been identified as the main causes of mangrove degradation in the Songhor Ramsar Site (Fianko and Dodd, 2019).

Overexploitation of mangroves for instance is a major issue reported across all mangrove-possessing nations including Kenya (Dahdouh-Guebas et al., 2021; Kairo et al., 2002; Kairu et al., 2021), India (Dahdouh-Guebas et al., 2006, 2021), and the whole of West Africa and South-East Asia (Friess et al., 2020). Salt and sand winning and their impairment on mangrove conservation and restoration were also reported in Ghana by Coleman et al. (2008) and Coleman et al. (2004). In the Densu Delta Ramsar site, it is reported that more than 50% of the land area, is currently owned by Panbros Salt Industries, a salt mining company (Key Biodiversity Areas Partnership, 2022), and the remaining mangrove areas are being degraded for residential and commercial development and heavily exploited by local people for producing firewood and fish traps (Fig. 5). The impact of large-scale salt production on mangroves is also prevalent in other African countries such as Ivory Coast, Benin, the Republic of Guinea, Tanzania, Kenya, Mozambique, Mauritania, and Sierra Leone (Naidoo, 2023). Also, sand mining has been reported as a threat to mangroves in Cameroon (Nfotabong-Atheull et al., 2009, 2011).

Aside from the above human-related issues, mangrove governance issues including ownership and land tenure have been identified as a key cause of mangrove degradation in Ghana. A typical example of land tenure and mangrove ownership where families or people claim ownership of mangroves either by land inheritance or cultivation has been reported by Asante et al. (2017). These issues of governance are impairing the mangrove restoration efforts in the Songhor Ramsar and the Keta Lagoon Ramsar sites (Asante et al., 2017). Similar cases of land tenure and mangrove ownership and their impacts on mangrove conservation and restoration (Lovelock and Brown, 2019) have been reported in different countries including Sri Lanka (Dahdouh-Guebas et al., 2021; IUCN, 2011), and Tanzania (Mshale et al., 2017). In Guyana, land tenure and ownership have been reported to have negative impacts on mangrove conservation, however, their impacts differ by the type of tenure system whether public (state-owned), indigenous people or private ownership (Johnson-Bhola, 2020).

Mangrove ecosystems in Ghana have received and absorbed myriads of pollutants from point and non-point sources for decades. The sinking of these pollutants has been reported to have had a very significant impact on the growth of mangroves in Ghana. Essumang et al. (2012) have reported high quantities of trace metals including mercury, nickel, cadmium, and arsenic in lagoons and estuaries in Ghana. It was reported that these metals cause a reduction in mangrove species abundance, hence are major causes of mangrove decline in Ghana. Similar cases of heavy metal pollution including lead, zinc, copper, and chromium from industrial processes on mangroves and other halophytic plants have been observed in India (Agoramoorthy et al., 2008) and Asia (Sandilyan and Kathiresan, 2014). Sandilyan and Kathiresan (2014) explained that

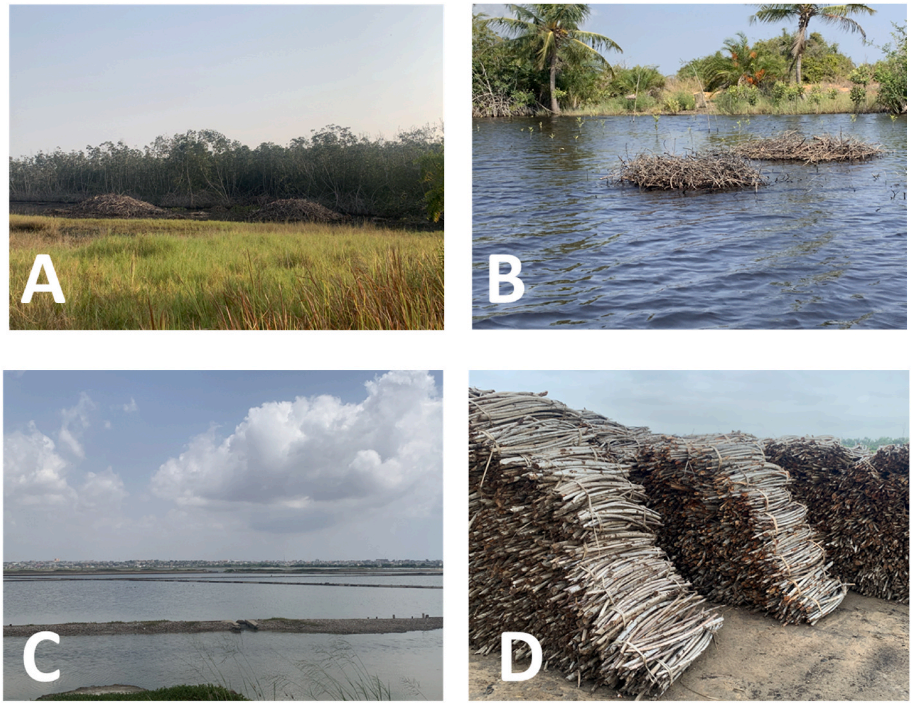

Fig. 5. Pictures showing some anthropogenic impacts on Ghana's mangrove ecosystems. Panel A shows freshly cut *R. racemosa* trees to be transported by local people in Salo community, Panel B shows mangrove sticks used as traps for blue crabs (Callinectes sp.) in Galo community, Panel C shows salt pans and residential area (behind the salt pans) in the Densu Delta Ramsar Site, and Panel D shows harvested bundles of fuelwood from R. *racemosa* trees ready for sale in Salo mangrove market. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

the metals get accumulated in the mangrove flora and therefore impede mangrove growth and abundance. There is however a trade-off in the presence of heavy metals in mangrove ecosystems. Mangroves are one of the best blue carbon storage systems relevant for climate change mitigation. Hence, the presence of heavy metals in mangrove ecosystems supports the climate mitigation function of mangroves since the heavy metals are able to inhibit microbial decomposition in mangrove soils. This reduces the CO_2 emissions which would occur in mangroves through the methanogenic activities of microbes (Ma et al., 2021).

According to the 2021 Population and Housing Census, the population of the four coastal regions of Ghana has increased, representing about 39% of the total 30.1 million population of Ghana (Ghana Statistical Service, 2021). This increase exerts excessive pressure on coastal zones through the reclaiming of land for agriculture and settlements. These two factors (agriculture and settlements) are noted to have impacted mangrove ecosystems in Ghana for decades. Coleman et al. (2008), who focused on the west coast of Ghana observed a significant increase in settlements between 1990 and 2000 from 11.72 to 17.92 km^2 while agriculture activities increased from 153.63 to 204.50 km^2 during the same period. The increase in both factors (i.e., settlement, and agriculture) paralleled a decline in mangrove cover from 260.5 km^2 in 1990 to 190.5 km^2 in 2000. The impacts of the development of settlements in mangrove areas in Ghana have also been reported by Attuquayefio and Gbogbo (2001).

In Ghana, mangrove destruction occurring in each of the four coastal regions may be driven by a socio-economic activity that is particular in that coastal region. For instance, in the Volta region where one can find the largest mangrove market, the increase in firewood production has significantly contributed to the increased loss of mangroves in Ghana. In the Central and Greater Accra region, the developments of settlements, ports and harbours, large-scale commercial salt extraction, and resorts, among other infrastructure and superstructure have also significantly contributed to the loss of Ghana's mangroves over the past decades. In the Western region, agricultural activities involving coconut plantations have majorly contributed to the loss of mangroves in Ghana.

In Ghana, aquaculture is not identified as a key threat to mangroves as compared to other countries in the Atlantic and Indian Oceans. For instance, countries like Nigeria, Madagascar, Mozambique (Naidoo, 2023), Sri Lanka, India, Bangladesh, Indonesia, Vietnam, the Philippines and Thailand (Ofori et al., 2022) have had studies reported significant losses of mangroves caused by aquaculture.

5.2. Natural impacts

Despite the growing concerns about anthropogenic pressures that are leading to mangrove depletion in Ghana, there are natural factors contributing to the depletion of mangroves in the country (Gordon et al., 2009). It is estimated that natural or indirect human impacts have contributed to about 40% loss in the extent of global mangroves (Goldberg et al., 2020; Naidoo, 2023). Sea level change on the global front is noted as a major threat to coastal habitats (Boatemaa et al., 2013) and mangroves in Ghana are no exceptions to the threats. Thus, mangroves get inundated by rising sea levels which create physiological stresses on both propagules and mature mangroves. Similarly, Ward et al. (2016) indicated an existing link between low accretion rates, sea level rise and mangrove loss in Cameroon, where a long-term sediment deficit coincided with a period of mangrove retreat in the Cameroon Estuary. Moreover, it is reported that sea level rise has been a major driver causing the Sundarbans in India and Bangladesh to lose 17,000 ha of its mangrove extent since the 1970s (Ward et al., 2016).

Shoreline changes such as recession have been recognised as a combined factor with sea level changes destroying mangroves in Ghana. Boatemaa et al. (2013) noted that there have been threats of shoreline recessions occurring on the eastern coast of Ghana, along the Volta River estuary in the Keta municipality, where a major cover of Ghana's mangroves is found. The eastern coastline experienced an average erosion rate of 4–8 m yr^{-1} before the construction of the nation's main source of hydroelectric power (the Akosombo Dam) between 1961 and 1965 but has reduced to less than between 2 and 4 m yr^{-1} after the Keta Sea defence project (Boatemaa et al., 2013; Boateng, 2018; Jayson-Quashigah et al., 2013; Ly, 1980). The frequency of flooding has therefore reduced since the late 90s along the eastern coast, but its effects are significant on mangroves (Rubin et al., 1999).

6. Mangrove ecosystem research in Ghana

Mangrove ecosystem research is very important to enhance the development of an effective management plan. Without mangrove ecosystem research in Ghana, it is impossible to evaluate Ghana's mangrove species composition and their socio-economic benefits, anthropogenic and natural impacts, spatio-temporal changes, and management strategies, among others. The evaluation of the number of mangrove-related studies conducted per coastal region of Ghana provides information on where mangrove research is paramount and where it is lacking. Among the four coastal regions in Ghana, the Western region recorded the highest number of mangrove-studied areas, followed by the Volta region, the Central region, and the Greater Accra region, in that order (Fig. 6). The implication is that there is less research conducted in the Central region and the Greater Accra region as compared to the Western region. This could be explained by the fact that the Central region and the Greater Accra region possess the least mangrove extent in Ghana with most of these mangrove forests degraded for infrastructural developments.

7. Goods and services derived from Ghana's mangroves

Mangrove ecosystem services identified in Ghana are notable in other mangrove-possessing countries present in the Atlantic and Indian Oceans (Mitra, 2020). The mangrove ecosystem services in Ghana include direct and indirect use values and non-use values. There are also optional values which serve as premium benefits (Aheto et al., 2014, 2016; Takyi et al., 2022). The different services are explained below following the ecosystem services classification by the Common International Classification of Ecosystem Services (CICES), a scheme developed by the European Environment Agency (EEA). The CICES standardises ecosystem services descriptions for comparison. Using this classification scheme, this study acknowledges supporting ecosystem services as intrinsic properties of ecosystems that support other ecosystem services. Therefore, supporting services are not described here. A full list of mangrove ecosystem goods and services, and areas in which a particular mangrove ecosystem service was mentioned in Ghana are summarised in Table S2.

7.1. Provisioning services

Mangroves in Ghana serve as an important source of fish protein for most rural communities who cannot afford expensive fleets to go for sea fishing (Asare and Javier, 2022). In mangroves, fishers only need to employ a few inputs such as canoes, handpicking, hook and line, etc. (Asante et al., 2023) to harvest fish such as tilapia, crustaceans, gastropods, bivalves, and catfish (Agbekpornu et al., 2016, 2021; Asare et al., 2019; Chuku et al., 2020). Taking a critical look at some global and regional mangrove research including Hamilton and Snedaker. (1984), Mitra (2020), Bimrah et al. (2022) and Naidoo (2023), fisheries stand out as an ancient and the commonest human activity in mangroves supporting community livelihoods. In Ghana, fish harvests in mangroves have been reported in coastal lagoons and estuaries fringing rural populations including the Volta River estuary (Dankwa and Gordon, 2002); Kakum mangrove river estuary (Aheto et al., 2014; Asare and Javier, 2022), and Muni Pomadzi Ramsar site in the Central region (Koranteng et al., 2000); Amanzule mangrove forest (Ajonina et al., 2014) and Nyan estuary (Dzakpasu and Yankson, 2015) in the Western region; and the Songhor and Keta lagoons (Agbekpornu et al., 2016). This ecosystem service of mangroves has been identified to boost the economy of local communities (Aheto et al., 2016; Asare et al., 2019).

Mangroves are also used in Ghana for healing ailments (Asante et al., 2023). For example, in Ankobra, the bark, roots and leaves of mangroves *Rhizophora* spp. and *Avicennia* spp. are used for treating wounds, ulcers, malaria, hypertension, rheumatism, measles, sexual dysfunction, and many other diseases. Mangroves are also used for raising one's appetite when mixed with local gin called "*akpeteshie*" (the mixture of the plant parts, mostly the roots of the mangroves and the gin yields the drink called 'bitters') (Asante et al., 2023). Also, the mangroves species *Conocarpus erectus*, *Laguncularia racemosa* and *Rhizophora racemosa* in Ghana have been identified to contain strains of endophytic microbes including *Penicillium herquei* strain BRS2A-AR, *Cladosporium oxysporum* strain BRS2A-AR2F, and *Mycobacterium* sp. BRS2A-AR2 that have shown antiparasitic activity against tropical parasites *Trypanosoma brucei* subsp. *brucei strain* 927/4 GUTat10.1, *Leishmania donovani* (Laveran and Mesnil) Ross, *Leishmania major* (Yakimoff and Schokhor), *Schistosoma mansoni* (Sambon) and *Trichomonas mobilensis* (U.S.A.: M776 [M776]). The *Mycobacterium* sp. BRS2A-AR2 for instance is extracted from the aerial roots of *Rhizophora racemosa*, and it is effective against *Trypanosoma brucei* subsp. *brucei.* These are samples from the Western, Volta and unexplored Bono East region by Kyeremeh et al. (2019). Moreover, Kwain et al. (2019) with mangrove rhizosphere extracts *Paenibacillus* sp. DE2SH (GenBank Accession Number: MH091697) from Digya National Park, Bono East, reports its ability against the *Trypanosoma brucei* subsp. *brucei.* Similar medicinal benefits of mangroves have also been reported in India and other Indian Ocean countries, where species of *Xylocarpus*,

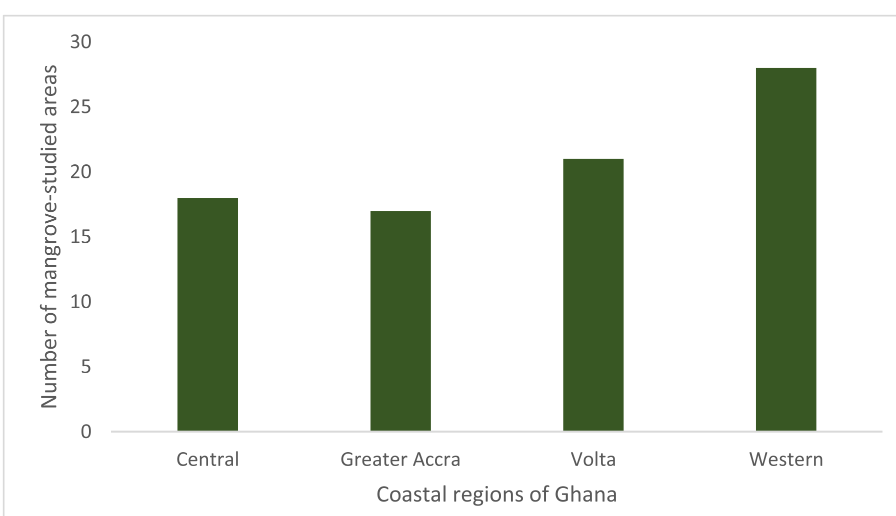

Fig. 6. Number of mangrove-studied areas per coastal region in Ghana as evidenced by peer-reviewed studies and organisational reports published between 1990 and 2022.

Avicennia, and *Bruguiera* are used for local medicine due to their antibacterial properties (Dahdouh-Guebas et al., 2000, 2006; Satyanarayana et al., 2012; Saranraj and Sujitha, 2015; Mitra, 2023).

The biomass stored as aboveground carbon by mangroves is harvested by rural populations for fuelwood, charcoal, and construction purposes. In the western region, Ajonina et al. (2014) estimated the total value of mangroves for fuelwood to be USD 2765 ha^{-1}. On the eastern coast of Ghana, mangroves as fuelwood and constructions are exploited on commercial bases for export to countries like Benin and Cameroon (Aheto et al., 2016) which generates a return of about USD 383.12 ha^{-1}yr^{-1} to mangrove planters in Anyanui, Volta region, Ghana. Fuelwood or firewood produced from mangroves is mostly preferred by fish smokers because of the ability to give good taste and colour to the fish while mangroves for building are based on durability (Asante et al., 2023). Moreover, the fish smokers believe that firewood from *Rhizophora racemosa* stems and roots (Fig. 3) are more favourable because they are able to last longer in the fire and do not produce too much smoke, thereby increasing the shelf life of the smoked fish.

Red mangroves are also used for reddening fishing nets with the idea of increasing the durability of the nets as well as increasing fish catch through fish blinding (Aheto et al., 2016; Nortey et al., 2016). The most important part of the mangrove for net tanning is the bark (Takyi et al., 2022). The use of red mangroves as dyes for tanning and dyeing materials such as leather products and fishing nets (FAO, 2007) is also recognised in countries like Kenya (Dahdouh-Guebas et al., 2000), and India (Dahdouh-Guebas et al., 2006).

Moreso, mangroves in Ghana provide space and support for salt mining, aquaculture, and agriculture. Farming and aquaculture have become common in some mangrove areas of Ghana because of the ready accessibility to water which has been prominent in Narkwa, Keta, Fosu, Songhor, Muni-Pomadze, Benya lagoons, and Densu Delta (Chuku et al., 2020; Osei et al., 2021; Takyi et al., 2022). The ecosystem also serves as a space available for salt mining in Ghana. These activities are prominent in the Benya, Keta, Sakumo and Kpeshie lagoons (Takyi et al., 2022), the Densu Delta (Key Biodiversity Areas Partnership, 2022), as well as the Kakum mangrove estuarine system (Asare et al., 2015; Asare and Javier, 2022).

7.2. Regulation and maintenance services

As documented in other mangrove-possessing nations, mangrove ecosystems in Ghana are also important for water purification (Aheto et al., 2016; Darkwa and Smardon, 2010). Particularly, mangrove oysters (*Crassostrea tulipa* Lamarck, 1819) identified in Ghana have been identified as good water quality assays because of their ability to filter out pollutants in huge volumes of water (Chuku et al., 2020; Obodai et al., 2010). Also, the Nyan estuary in the Western region of Ghana is noted to have relatively better water quality due to the limited disturbance of its surrounding mangrove ecosystems (Dzakpasu and Yankson, 2015; Nortey et al., 2016). However, lagoons such as the Benya in the Western region (Obodai et al., 2010) and the Fosu (Darkwa and Smardon, 2010) in the Central region have been described to have dead zones harbouring high quantities of heavy metals and nutrients due to the destruction of their mangrove ecosystems. Thus, the indiscriminate cutting of mangroves without control and replacement renders the remaining mangroves low ability to control and transform nutrients such as nitrogen, and chemicals such as pesticides, causing human and ecological health risks.

As the world seeks different ways to mitigate climate change, the carbon-sequestrating ability of mangroves as a service for climate regulation is also reported in Ghana. This involves the capacity of mangroves to store carbon as biomass. To understand this, studies have weighed the storage capacity of degraded and less degraded mangrove forests in Ghana. For example, Adotey et al. (2022) compared the Amanzule and the Kakum/Iture mangrove forests and report that the Amanzule which is less degraded stored about 34-fold higher above-and-below-ground carbon than the Kakum mangrove forests. The same report recorded about 5-fold more soil carbon in the Amanzule than in the Kakum forest. A similar study by Ajonina et al. (2014) comparing two sites (degraded and less degraded forests) in the Amanzule mangrove forests estimated about 78% more aboveground carbon in the less degraded site than the degraded portion of the forest representing about 185 tC ha^{-1} (ranging between 65 and 422 tC ha^{-1}). In the Songhor Ramsar site, Ntyam et al. (2014) recorded a total of 9, 0443.17 gm^{-2} litters in the litterfall of *Avicennia* spp. and *Rhizophora* spp.

Again, most coastlines of Ghana are eroding due to rising sea levels (Boatemaa et al., 2013); (Appeaning Addo, 2014; Evadzi et al., 2017, 2018). Mangrove ecosystems have therefore been identified as a good system to minimise the effects of the constant sea level rise, hence the recommendations to improve the management of mangroves in Ghana, especially along the coast of Keta (Boatemaa et al., 2013). For example, a case by Darko et al. (2022) in Ningo-Prampram in the Greater Accra region indicates that about 1–2 km of land have been taken over by the sea due to sea level rise. The growing of mangroves and coconut trees has been initiated as defence mechanisms (Darko et al., 2022). Also, sea encroachment of about 2.32 myr^{-1} of the Keta coastline has prompted effective measures to expand mangrove ecosystems (Boatemaa et al., 2013).

Mangroves in Ghana serve as habitats for spawning, nursery, and feeding by fish stock populations. A typical example is the Songhor Ramsar site which because of its high mangroves' value holds the highest population of birds (tern count) on the Ghanaian coasts. This is more than 10% of the overall coastal count (and $\geq$23 species of water birds) (Fianko and Dodd, 2019; Piersma and Ntiamoa-Baidu, 1995). Furthermore, mangroves as habitats for fish stock protection have been recognised to be more important to the protection of fish. Koranteng et al. (2000) reported the fish stock of the Muni Pomadzi Ramsar Site has declined in association with the degradation of mangroves and recommended reafforestation could help revamp the fisheries. Other areas in Ghana where mangroves have been cited as important sites include the Volta River estuary (Aheto et al., 2016), Songhor and Keta lagoons (Asante et al., 2017), and Fosu Lagoon (Darkwa and Smardon, 2010).

7.3. Cultural services

Lagoons and mangroves in Ghana have received some recognition as providing support for spiritual and cultural well-being. Communities use this spiritual significance to set local laws that help to protect the mangrove and lagoon resources. For example, the Fosu lagoon which is called "baka" in the Ghanaian "*Fante*" language, is seen as a god and therefore a shrine has been built in the narrow strip of mangrove forest where traditional authorities perform rituals every year during the "*Bakatue*" festival (*Baka* i.e., the lagoon and … *tue* means removal; so, removal of the lagoonal sand bar for the sea to 'cleanse' the lagoon) (Apter, 2017; Korsah and Kuwornu-Adjaottor, 2019; Takyi et al., 2022). Also, in Winneba where the Muni-Pomadzi lagoon is located, there is a belief that the lagoon is a god, and the fishes are believed to be its children. Therefore, on non-fishing days, these children (the fishes) come out freely to play, any interference by fishers on such set days is forbidden (Takyi et al., 2022). The lagoon is also seen as security to the community against enemies during conflicts (Apter, 2017).

In Ankobra, the entire estuary is seen as a goddess who comes out over the night to perform her rituals and sleep in a small house built for her in the mangrove forest. The whole community believes that the goddess, i.e., the estuary, preserves their lives. These livelihoods include the provision of food, water, and fuelwood. It is also believed that the goddess protects them against enemies, in that no murderer goes free after crossing the estuary or river. The traditional authorities of Ankobra revere this most and hence perform annual rituals in the house as well as forbid the entire community from rearing goats, as the goddess dislikes it (Asante et al., 2023). In the same estuary are two big and tall stones, which are believed to be a couple (the god and the goddess). According to the communities around the mangrove forest, there is evidence that anyone who takes a picture of this couple (the god and the goddess) dies (Asante et al., 2023).

Another cultural service contributed by mangroves in Ghana is the potential to serve as a nature-based system for gaining knowledge for formal and informal environmental education. This service is crucial for changing the mental states of people towards ecosystems, particularly for those who see wetlands and other ecosystems as wastelands. Mangrove research in Ghana has increased the knowledge about nature where the public gets to know the importance of mangroves (Aheto et al., 2016; Nortey et al., 2016), and how a change in mangroves impacts the well-being of mangrove dependents (Asare and Javier, 2022; Chuku et al., 2020). In mangrove restoration programmes organised by NGOs such as A ROCHA Ghana in Muni-Pomadze, communities are involved in the programme as a means to educate the public on mangrove ecosystem conservation. Different school clubs are also established coupled with various community and traditional engagements.

7.4. Ghana's relationship with other West African countries in terms of mangrove ecosystem goods and services

The importance of mangroves in Africa, particularly west Africa, allows a look into how Ghana is related to its neighbouring countries in terms of the mangrove ecosystem goods and services derived in the country. This improves our knowledge of how mangroves connect coastal communities in the region. Mangrove ecosystem goods and services derived by Ghana are not much distinguishable from those of its neighbouring West African countries. For example, fuelwood, charcoal production, construction wood, fencing, furniture, fish traps, space for urban development, agriculture, aquaculture, salt production, dyes for tanning fishing nets, fishing, fish traps, medicine, spiritual well-being, tourism and recreation, and environmental education are similar services derived in the majority of coastal countries in West Africa (Fig. 7). The only distinct service of mangroves in Ghana was the use of mangroves (new roots of *Rhizophora* spp.) as food (Asante et al., 2023). On the other hand, while mangroves are used for spiritual benefits, their uses in some West African countries differ from Ghana. For example, the inhabitants of Ehotilé, a village in the N'Ganda N'Ganda (Ramsar Site) of Ivory Coast, believe they are the descendants of the lagoon, living at the bottom and having ephemerally been sent to explore the terrestrial world (Forest Carbon Markets and Communities (FCMC), undated), which is quite different from the way mangroves benefit people spiritually in Ghana as described above. While fisheries as a service connect Ghana to all the countries, Sierra Leone, Guinea, Guinea Bissau, and Mauritania were more related by wildlife hunting in mangroves.

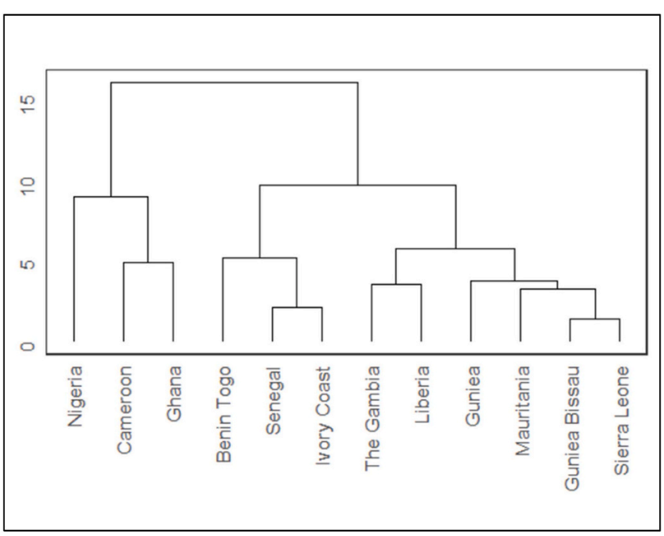

Fig. 7. A Hierarchical clustering analysis of how Ghana relates with its neighbouring West African countries in terms of mangrove ecosystem goods and services. The figure only shows a relationship regarding cultural and provisioning services of mangroves (See Table S2 for more details of the goods and services of mangroves by the countries.

Other services of the West African mangroves include mangroves for joinery wood and fodder (feed for livestock) exclusively in Togo-Benin (Adite et al., 2013; Ahouangan et al., 2022); beverage/alcohol and honey in Senegal and Nigeria (Abere and Ekeke, 2011; Cormier-Salem and Panfili, 2016); thatching and boat carving in Nigeria and Cameroon (Feka and Manzano, 2008). Additionally, mangroves are used for building oyster racks in Sierra Leone (Kamara, 1982); rest beds and fish-smoke rafts in Cameroon (Feka and Manzano, 2008); fish drying wood and livestock farming in Guinea (Forest Carbon Markets and Communities (FCMC)); and the hunting of crocodiles and other wild animals (bushmeat) in most of the countries. However, these services are not yet identified in Ghana.

8. Past and present management strategies of Ghana's mangrove ecosystems

Following the reports of anthropogenic impacts on Ghana's mangrove ecosystems, it is important to identify the existing mangrove ecosystem management systems and strategies in the country, and how effective they have been in the past years compared to the present. In Ghana, it has been reported that mangrove ecosystems are usually under the management of government institutions, NGOs, and local groups and communities (Ajonina, 2011; Asante et al., 2017). In the past years, commitments have been shown by the government (*i.e.,* the Wildlife Division of the Forestry Commission) and other stakeholders such as the Lands Commission and the Department of Town and Country Planning towards the management of coastal ecosystems including mangroves. This resulted in drafting of various strategic documents such as the Coastal Zone Management Indicative Plan, Integrated Coastal Zone Plan, National Wetlands Conservation Strategy and Action Plan (Asante et al., 2017). Efforts have also been made by local communities in restoring and managing degrading mangrove ecosystems with the support of both governmental and non-governmental organisations (Aheto et al., 2016).

Field visits to the Ankobra river estuary and the Keta Lagoon Ramsar site revealed the condition of their existing mangroves and the available management plans. Recognising the sensitivity and delicate nature of the Ankobra river estuary and its mangroves sheltering over 27 and 21 fish species and families, respectively (Ghana Ministry of Fisheries and Aquaculture Development and Fisheries Commission (GMFADFC), 2020), major management measures spanning from national to the local level have taken place to halt the negative repercussions associated with the socioeconomic pressures. However, the problems identified by the various management initiatives have remained unsolved (Donkor and Agyemang, 2015). For example, at the national level, the Environmental Protection Agency (EPA) enacted regulations to protect the Ankobra river estuary from mining activities, but low enforcement led to increased pollution affecting the marine ecosystem downstream with mangroves inclusive. The Water Resources Commission (WRC) participatory management plan for the Ankobra river estuary which was to ensure sustainable measures to improve land use practices and management of liquid and solid wastes into the Ankobra river estuary largely neglects the southern part where the estuary and its mangroves are found (Donkor and Agyemang, 2015; Water Resources Commission Ghana, 2009).

The bordering administrative district and municipal assemblies instituted Spatial Development Framework in 2012 which designated a 50-m buffer from the river estuarine as a conservation area. However, monitoring and evaluation of this initiative collapsed years before 2015 due to a lack of logistics such as boats and funds (Donkor and Agyemang, 2015).

Moreover, the United States Agency for International Development (USAID) sponsored a project named the Integrated Coastal and Fisheries Governance (ICFG), which is locally known as "Hen Mpoano" (Akan-Fanti language for "Our Coast") in the Western Region of Ghana, from 2009 to 2013. The project area included the Ankobra river estuary and its estuary as a subsidiary to the Greater Amanzule Mangrove Forest in its plan. The main aim of the project was to acknowledge the ecosystem benefits provided by coastal ecosystems in the region and how coastal communities can sustainably use these socioeconomic benefits (Coastal Resource Centre, 2012). However, after the end of the project, much attention was given to the Greater Amanzule which is potentially suited to be a Ramsar Site. Therefore, the problems that existed before the project regarding social and economic pressures reverted with uncontrolled cutting and degradation of the Ankobra river estuary and its resources (Donkor and Agyemang, 2015; Nortey, 2018).

The reversion of the problems resulted in forming the premise of the most recent management initiative which began in October 2014 and ended in October 2019. This was a project spearheaded by the Sustainable Fisheries Management Project (SFMP) and the Hen Mpoano (HM) funded by the USAID with a collaboration of the University of Rhode Island Coastal Resource Centre aimed at revamping the Ankobra river estuary to contribute to replenishing the general fish stock in the country – which was the general principle of the SFMP. The objectives of the project included the identification of the different land uses within the estuary, the threatening land uses to the estuary and its mangroves, and local community education on the potential dangers posed by human activities to the ecosystem (Donkor and Agyemang, 2015). This brought together five main mangrove communities namely Sanwoma, Eziome, Eshiem, Kukuaville and Adelekezo (Asante et al., 2023) who were taken through training aimed at promoting sustainable use of mangrove resources, initiating and adopting best management practices through cutting and replanting of mangrove seedlings, protecting valuable mangrove resources, and the creation of navigational access through mangroves to farms (Nortey, 2018).

The initiative was based on the Community-Based Fisheries Management Area (CBFMA) instituted by the Ministry and Fisheries and Aquaculture Development (Donkor and Agyemang, 2015; GMFADFC, 2020; Nortey, 2018). The project yielded the Village Saving and Loans Association (VSLA) established to support the communities, and the community-based management plan (GMFADFC, 2020; Nortey, 2018). Mostly in Ghana, when projects end, monitoring mostly ceases. In Ankobra, the SFMP and the HM since the end of the project have now become passive monitors due to the lack of adequate funds to support surveillance. Even though the communities recall the lessons from the training given to them by the SFMP and HM and the repercussions that may arise if the mitigations measures are not undertaken, the issue of mangrove destruction does persist due to high economic problems in the communities and a lack of flourishing and alternative jobs (Asante et al., 2023).

According to the Site Manager of the Keta Lagoon Complex Ramsar Site, since there is no active management plan for mangroves in the area, the local people are not restricted from cutting them. Moreover, the only contribution from the Forestry Commission of Ghana in managing the Keta Lagoon Ramsar site's mangroves is to educate the local communities on the socio-ecological benefits of mangroves and to also support mangrove restoration projects. Currently, mangrove restoration projects are ongoing in the Keta Lagoon Ramsar site with support from NGOs like A Rocha Ghana, Seawater Solutions and Friends of the Earth-Ghana where over 150 ha of degraded mangrove areas are being restored. In some areas, mangroves are planted by individuals for firewood production which is sold locally and internationally for various purposes. This is supported by Sekey et al. (2023) who indicated that communities in and around the Keta Lagoon Complex Ramsar Site now assume mangrove plantation as a farming system to cater for their future economic and domestic needs.

As stated earlier that mangrove land ownership by individuals remains one of the crucial issues for mangroves in Ghana, the government has in recent times reclaimed ownerships of these lands through the payment of financial compensation to individual landowners. A typical example is the Obane restored mangrove project site (Awuku-Sowah et al., 2023). Few studies have been conducted in some of the local communities near mangrove ecosystems to understand their perceptions and efforts toward the management of mangrove ecosystems and their implications (Aheto et al., 2016; Derkyi et al., 2009). For instance, a study conducted by Derkyi et al. (2009) on the indigenous practices of managing mangroves in the Amanzule River and the Ama Emissa River reported the existence of some local beliefs such as the recognition of the Amanzule River as a deity, the observation of certain local customs before harvesting of mangroves, traditional bans and fines restricting the harvesting of fresh mangroves, setting aside of taboo days where the river and its resources cannot be exploited, among others. It is further noted that these indigenous practices have proved effective only in some communities and they are likely to fade away with time (Derkyi et al., 2009).

Another study by Aheto et al. (2016) revealed that since the establishment of the Mangrove Planters and Fishmongers Association in the Anyanui area of Ghana in 1991, the members of the association have been motivated by the monetary benefits that arise from the harvesting and sale of mangrove wood and their access to credit, loans and investment opportunities, and not necessarily ecological interests. This notwithstanding has significantly contributed to the conservation of mangrove ecosystems in the Anyanui community (Aheto et al., 2016) Ajonina (2011) categorises the institutions and stakeholders involved in managing Ghana's mangrove ecosystems into two levels and provides the roles of each institution under each category (Tables 2 and 3).

9. Limitation of study

A review study of this nature majorly relied on previously published local and international studies and the availability of these studies using a search and selection methodology. Using robust selection criteria, only 70 out of the 148 downloaded studies were selected and their findings included in the current study. The selection of only 50% of the downloaded studies indicates the limited nature of mangrove ecosystem research in Ghana. Moreover, although field visits were made to selected mangrove areas in Ghana, the number of visited sites was limited due to time and financial constraints. We hold that having sufficient published studies on Ghana's mangroves and undertaking more field visits to other mangrove sites will improve the database capacity of local and international research of this kind.

10. Conclusion

The study has assessed and reported on the distribution of mangrove

Table 2
First-level institutions/stakeholders and their roles in managing Ghana's mangrove ecosystems (adapted from Ajonina, 2011; Feka, 2015)

Institutions	Roles
Central Government	Development of policies, treaties, and laws (forestry & wildlife policy 1994, Ramsar treaty 1971, wildlife Act, etc.)
Departments/Ministries/Agencies	Charged with the elaboration, implementation, enforcement, compliance, monitoring, and evaluation of policies of the Government in the domain of forest and wildlife.
Regional administration	Complementary and supervisory
Academic and research institutions	They are to provide research information on the state of wetlands and conditions of mangroves
Local Government	Regulation, enforcement, and implementation
Donor/Funding agencies	Provision of funds and technical advice

Table 3
Second-level institutions/stakeholders and their roles in managing Ghana's mangrove ecosystems (adapted from Ajonina, 2011).

Institutions	Roles
District assemblies	Regulation, permitting, enforcement (agencies like town and country planning are supposed to regulate developments in the districts.)
Traditional authorities	They are the custodians of the land and are supposed to regulate its usage through the granting of tenurial rights etc
Local communities	They in most cases depend directly on the resource and are to help manage it
NGOs and other civil society groups	Inform and educate local communities on sustainable management of mangroves

ecosystems and their species composition in Ghana, the existing mangrove research in Ghana, the goods and services of Ghana's mangrove ecosystems, the anthropogenic and natural impacts on Ghana's mangrove ecosystems, and the past and present strategies in managing Ghana's mangroves.

Using a Systematic Evidence Syntheses method, ROSES, the study has provided a comprehensive database of the several communities or sites in Ghana where mangroves can be located. The distribution of mangrove ecosystems in Ghana extends from coastal communities located on the western coast (bordering Ivory Coast) to the eastern coast (bordering Togo). The communities (villages/towns/sites) hosting these mangroves can be identified with the help of additional information such as their geographical locations, districts/municipality, and regions, which are also provided in this study. The study has also presented the mangrove species (in pictures taken from the field) which are identified in Ghana, *i.e., Laguncularia racemosa*, *Avicennia germinans*, *Rhizophora harrisonii*, *Rhizophora racemosa*, *Rhizophora mangle*, *Acrostichum aureum,* and *Conocarpus erectus*.

An appraisal was also undertaken on the goods and services mangrove ecosystems in Ghana present to the people, revealing that local people derive several benefits from mangrove ecosystems, where some individuals go further to plant mangroves (mainly *Rhizophora racemosa*) for fuelwood production. A further assessment of the past and existing mangrove management strategies in Ghana uncovered that there are several policies and regulations available as well as institutions/organisations involved in protecting and restoring Ghana's coastal ecosystems. However, there are no specific policies and regulations that focus on mangrove ecosystem conservation and management. While some of these tools for managing Ghana's coastal ecosystems have been effective over the past years, some have failed and others, especially traditional beliefs, are expected to fail if adequate measures to revive them are not undertaken immediately.

The current study serves as a precedent for other African countries possessing mangrove ecosystems to undertake similar studies to understand the mangrove dynamics from a country-wide scale. Having such a scale of studies across mangrove nations on the continent is an opportunity to have coherent and standard comparative assessment of mangrove management. This will go a long way to promote effective decision-making processes concerning the management of coastal ecosystems on the continent. In Ghana, we recommend that further studies should be conducted to estimate the carbon sequestration and coastal defence potential of Ghana's mangroves toward climate change mitigation and adaptation. Findings will help contribute to developing effective policies required for managing and protecting Ghana's mangrove ecosystems (Dahdouh-Guebas et al., 2022). Moreover, the monetary value of these goods and services of Ghana's mangroves also needs to be estimated at the regional and national levels. We further recommend that the institutions responsible for protecting and regulating the use of mangroves in Ghana should revise their laws and policies, and broadly promote sustainable mangrove restoration projects in Ghana's coastal regions. In effect, there is a need to develop and implement policies that specifically target the protection and sustainable use of mangrove ecosystems in Ghana.

CRediT authorship contribution statement

Samuel A. Ofori: Conceptualization, Methodology, Supervision, Writing – original draft, Writing – review & editing, Investigation. **Frederick Asante:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Investigation. **Tessia Ama Boatemaa Boateng:** Writing – original draft, Investigation. **Farid Dahdouh-Guebas:** Conceptualization, Supervision, Writing – review & editing.

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.jenvman.2023.118622.

References

Abere, S., Ekeke, B., 2011. The Nigerian mangrove and wildlife development. Mediterr. J. Soc. Sci. 2, 107-107.

Adite, A., ImorouToko, I., Gbankoto, A., 2013. Fish assemblages in the degraded mangrove ecosystems of the coastal zone, Benin, West Africa: implications for ecosystem restoration and resources conservation. J. Environ. Protect. 4 (12), 15. https://doi.org/10.4236/jep.2013.412168.

Adotey, J., Acheampong, E., Aheto, D.W., Blay, J., 2022. Carbon stocks assessment in a disturbed and undisturbed mangrove forest in Ghana. Sustainability 14. https://doi.org/10.3390/su141912782.

Agbekpornu, H., Yeboah, D., Quaatey, S., Pappoe, A., Ennin, J.E., 2016. Value chain analysis of captured shrimp and Tilapia from Keta lagoon in Ghana. Asian Journal of Agricultural Extension, Economics & Sociology 14, 1–11. https://doi.org/10.9734/AJAEES/2016/30829.

Agbekpornu, H., Ennin, E.J., Issah, F., Pappoe, A., Yeboah, R., 2021. Women in West African mangrove oyster (Crassostrea tulipa) harvesting, contribution to food security and nutrition in Ghana. Oceanogr Fish Open Access J 14. https://doi.org/10.19080/OFOAJ.2021.14.555878.

Agoramoorthy, G., Chen, F.-A., Hsu, M.J., 2008. Threat of heavy metal pollution in halophytic and mangrove plants of Tamil Nadu, India. Environ. Pollut. 155, 320–326. https://doi.org/10.1016/j.envpol.2007.11.011.

Aheto, D.W., Okyere, I., Asare, N.K., Dzakpasu, M.F., Wemegah, Y., Tawiah, P., Dotsey-Brown, J., Longdon-Sagoe, M., 2014. A survey of the benthic macrofauna and fish species assemblages in a mangrove habitat in Ghana. West African Journal of Applied Ecology 22, 1–15-11–15.

Aheto, D.W., Kankam, S., Okyere, I., Mensah, E., Osman, A., Jonah, F.E., Mensah, J.C., 2016. Community-based mangrove forest management: implications for local livelihoods and coastal resource conservation along the Volta estuary catchment area of Ghana. Ocean Coast Manag. 127, 43–54. https://doi.org/10.1016/j.ocecoaman.2016.04.006.

Ahouangan, B.S.C.M., Koura, B.I., Sèwadé, C., Toyi, M.S., Lesse, A.D.P., Houinato, M.R. B., 2022. Ruminant keeping around mangrove forests in Benin (West Africa):

herders' perceptions of threats and opportunities for conservation of mangroves. Discover Sustainability 3, 13. https://doi.org/10.1007/s43621-022-00082-x.
Ajonina, G., 2011. Rapid Assessment of Mangrove Status to Assess Potential for Payment for Ecosystem Services in Amanzule in the Western Region of Ghana, USAID Integrated Coastal and Fisheries Governance Program for the Western Region of Ghana. Narragansett, RI. Coastal Resources Center, Graduate School of Oceanography, University of Rhode Island, Ghana, p. 36. http://www.crc.uri.edu/.
Ajonina, G.N., Agardy, T., Lau, W., Agbogah, K., Gormey, B., 2014. Mangrove conditions as indicator for potential payment for ecosystem services in some estuaries of western region of Ghana, West Africa. In: Diop, S., Barusseau, J.-P., Descamps, C. (Eds.), The Land/Ocean Interactions in the Coastal Zone of West and Central Africa. Springer International Publishing, Cham, pp. 151–166. https://doi.org/10.1007/978-3-319-06388-1_13.
Alappatt, J.P., 2008. Chapter 5 - structure and species diversity of mangrove ecosystem. In: Sivaperuman, C., Velmurugan, A., Singh, A.K., Jaisankar, I. (Eds.), Biodiversity and Climate Change Adaptation in Tropical Islands. Academic Press, pp. 127–144. https://doi.org/10.1016/B978-0-12-813064-3.00005-3.
Amlalo, D.S., 2006. The protection, management and development of the marine and coastal environment of Ghana. Administering Marine Spaces: International Issues 148.
Ampim, P.A.Y., Ogbe, M., Obeng, E., Akley, E.K., MacCarthy, D.S., 2021. Land cover changes in Ghana over the past 24 years. Sustainability 13, 4951. https://www.mdpi.com/2071-1050/13/9/4951.
Appeaning Addo, K., 2014. Coastal vulnerability index to sea level rise in Ghana. Coastal and Marine Research 2, 1. https://doi.org/10.12966/cmr.01.01.201.
Apter, A., 2017. History in the dungeon: atlantic slavery and the spirit of capitalism in Cape coast castle, Ghana. Am. Hist. Rev. 122, 23–54.
Armah, A.K., Wiafe, G., Kpelle, D.G., 2005. Sea-level rise and coastal biodiversity in West Africa: a case study from Ghana. Climate change and Africa 204–217.
Asante, W.A., Acheampong, E., Boateng, K., Adda, J., 2017. The implications of land tenure and ownership regimes on sustainable mangrove management and conservation in two Ramsar sites in Ghana. For. Pol. Econ. 85, 65–75. https://doi.org/10.1016/j.forpol.2017.08.018.
Asante, F., Hugé, J., Asare, N.K., Dahdouh-Guebas, F., 2023. Does mangrove vegetation structure reflect human utilization of ecosystem goods and services? iScience 26 (6), 106858. https://doi.org/10.1016/j.isci.2023.106858.
Asare, N.K., Javier, J.L., 2022. Tidal influence on fish faunal occurrence and distribution in an estuarine mangrove system in Ghana. Afr. J. Aquat. Sci. 47, 88–99. https://doi.org/10.2989/16085914.2021.1978380.
Asare, C., Owusu, A., Kankam, S., Nortey, D., 2015. Small Pelagic Fisheries Data Collection: Orientation Training Report, the USAID/Ghana Sustainable Fisheries Management Project (SFMP). Narragansett, RI. Coastal Resources Center. Graduate School of Oceanography, University of Rhode Island and Hen Mpoano. GH2014_ACT049_HM, Ghana. http://www.crc.uri.edu/projects_page/ghanasfmp/.
Asare, B., Obodai, E.A., Acheampong, E., 2019. Mangrove oyster farming: prospects as supplementary livelihood for a Ghanaian fishing community. Journal of Fisheries and Coastal Management 1, 7–14. https://doi.org/10.5455/jfcom.20190311090846.
Attuquayefio, D., Gbogbo, F., 2001. Prospects of conserving wetlands along the mukwe lagoon at nungua in the greater Accra region of Ghana. West African Journal of Applied Ecology 2.
Awuku-Sowah, E.M., Graham, N.A.J., Watson, N.M., 2023. The contributions of mangroves to physiological health in Ghana: insights from a qualitative study of key informants. Wellbeing, Space and Society 4, 100137. https://doi.org/10.1016/j.wss.2023.100137.
Baba, S., Gordon, C., Kainuma, M., Ayivor, J.S., Dahdouh-Guebas, F., 2004. The global mangrove database and information system (GLOMIS): present status and future trends. In: Berghe, E.V., Brown, M., Costello, M.J., Heip, C., Levitus, S., Pissierssens, P. (Eds.), Proceedings Colour of the Ocean Data. International Symposium on Oceanographic Data and Information Management with Special Attention to Biological Data. UNESCO (France) & VLIZ (Belgium), France, pp. 3–14.
Bessah, E., Boakye, E.A., Agodzo, S.K., Nyadzi, E., Larbi, I., Awotwi, A., 2021. Increased seasonal rainfall in the twenty-first century over Ghana and its potential implications for agriculture productivity. Environ. Dev. Sustain. 23, 12342–12365. https://doi.org/10.1007/s10668-020-01171-5.
Bimrah, K., Dasgupta, R., Hashimoto, S., Saizen, I., Dhyani, S., 2022. Ecosystem services of mangroves: a systematic review and synthesis of contemporary scientific literature. Sustainability 14 (19), 12051. https://doi.org/10.3390/su141912051.
Boatemaa, M.A.A., Kwasi, A.A., Mensah, A., 2013. Impacts of shoreline morphological change and sea level rise on mangroves: the case of the Keta coastal zone. Journal of Environmental Research and Management 4, 359–367. http://www.e3journals.org.
Boateng, I., 2018. An Assessment of Vulnerability and Adaptation of Coastal Mangroves of West Africa in the Face of Climate Change. Springer International Publishing, pp. 141–154. https://doi.org/10.1007/978-3-319-73016-5_7.
Bunting, P., Rosenqvist, A., Lucas, R., Rebelo, L.-M., Hilarides, L., Thomas, N., Hardy, A., Itoh, T., Shimada, M., Finlayson, C., 2018. The global mangrove watch—a new 2010 global baseline of mangrove extent. Rem. Sens. 10, 1669. https://doi.org/10.3390/rs10101669.
Bunting, P., Rosenqvist, A., Hilarides, L., Lucas, R.M., Thomas, N., 2022a. Global mangrove watch: updated 2010 mangrove forest extent (v2.5). Rem. Sens. 14, 1034. https://doi.org/10.3390/rs14041034.
Bunting, P., Rosenqvist, A., Hilarides, L., Lucas, R.M., Thomas, N., Tadono, T., Worthington, T.A., Spalding, M., Murray, N.J., Rebelo, L.-M., 2022b. Global mangrove extent change 1996–2020: global mangrove watch version 3.0. Rem. Sens. 14 https://doi.org/10.3390/rs14153657.
Chang, W., 1997. Pen culture of mud crabs in the mangrove ecosystems in Sarawak (East Malaysia). Aqua. Asia 3–5.
Chuku, E.O., Yankson, K., Obodai, E.A., Acheampong, E., Boahemaa-Kobil, E.E., 2020. Effectiveness of different substrates for collecting wild spat of the oyster Crassostrea tulipa along the coast of Ghana. Aquaculture Reports 18, 100493. https://doi.org/10.1016/j.aqrep.2020.100493.
Coastal Resource Centre, 2012. Semi-Annual Report Oct-March (2012). Coastal Resources Center, University of Rhode Island. USAID Integrated Coastal and Fisheries Governance Initiative for the Western Region, p. 82. Ghana. https://pdf.usaid.gov/pdf_docs/PA00HSHG.pdf.
Coleman, T.L., Manu, A., Twumasi, Y.A., 2004. Application of Landsat Data to the Study of Mangrove Ecologies along the Coast of Ghana. Center for Hydrology, Soil Climatology, and Remote Sensing Alabama A&M University, Alabama.
Coleman, T., Twumasi, Y., Manu, A., 2008. Spatio-temporal Analysis of Migration Patterns in Ghana from 1970-2000 Using GIS. Proceedings of the 5th Afri can Association of Remote Sensing of the Environment (AARSE) Conference, pp. 18–21.
Cormier-Salem, M.C., Panfili, J., 2016. Mangrove reforestation: greening or grabbing coastal zones and deltas? Case studies in Senegal. Afr. J. Aquat. Sci. 41, 89–98. https://doi.org/10.2989/16085914.2016.1146122.
Dahdouh-Guebas, F., Cannicci, S., 2021. Mangrove restoration under shifted baselines and future uncertainty. Front. Mar. Sci. 8, 799543 https://doi.org/10.3389/fmars.2021.799543.
Dahdouh-Guebas, F., Mathenge, C., Kairo, J.G., Koedam, N., 2000. Utilization of mangrove wood products around mida creek (Kenya) amongst subsistence and commercial users. Econ. Bot. 54 (4), 513–527. https://doi.org/10.1007/BF02866549.
Dahdouh-Guebas, F., Hettiarachchi, S., Sooriyarachchi, S., Lo Seen, D., Batelaan, O., Jayatissa, L.P., Koedam, N., 2005a. Transitions in ancient inland freshwater resource management in Sri Lanka affect biota and human populations in and around coastal lagoons. Curr. Biol. 15 (6), 579–586.
Dahdouh-Guebas, F., Jayatissa, L.P., Di Nitto, D., Bosire, J.O., Lo Seen, D., Koedam, N., 2005b. How effective were mangroves as a defence against the recent tsunami? Curr. Biol. 15 (12), R443–R447. https://doi.org/10.1016/j.cub.2005.07.025.
Dahdouh-Guebas, F., Collin, S., Lo Seen, D., Rönnbäck, P., Depommier, D., Ravishankar, T., Koedam, N., 2006. Analysing ethnobotanical and fishery-related importance of mangroves of the East-Godavari Delta (Andhra Pradesh, India) for conservation and management purposes. J. Ethnobiol. Ethnomed. 2, 24. https://doi.org/10.1186/1746-4269-2-24.
Dahdouh-Guebas, F., Hugé, J., Abuchahla, G.M.O., Cannicci, S., Jayatissa, L.P., Kairo, J. G., Kodikara Arachchilage, S., Koedam, N., Mafaziya Nijamdeen, T.W.G.F., Mukherjee, N., Poti, M., Prabakaran, N., Ratsimbazafy, H.A., Satyanarayana, B., Thavanayagam, M., Vande Velde, K., Wodehouse, D., 2021. Reconciling nature, people and policy in the mangrove social-ecological system through the adaptive cycle heuristic. Estuar. Coast Shelf Sci. 248, 106942 https://doi.org/10.1016/j.ecss.2020.106942.
Dahdouh-Guebas, F., Friess, D.A., Lovelock, C.E., Connolly, R.M., Feller, I.C., Rogers, K., Cannicci, S., 2022. Cross-cutting research themes for future mangrove forest research. Nature Plants 8, 1131–1135. https://doi.org/10.1038/s41477-022-01245-4.
Dankwa, H.R., Gordon, C., 2002. The fish and fisheries of the lower Volta mangrove swamps in Ghana. In: African Journal of Science and Technology (Science and Engineering Series), vol. 3. http://hdl.handle.net/1834/636.
Darko, G., Bi, S., Sarfo, I., Amankwah, S.O.Y., Azeez, F.E., Yeboah, E., Oduro, C., Kedjanyi, E.A.G., Archer, B., Awuah, A., 2022. Impacts of climate hazards on coastal livelihoods in Ghana: the case of Ningo-Prampram in the Greater Accra region. Environ. Dev. Sustain. 24, 1445–1474. https://doi.org/10.1007/s10668-021-01492-z.
Darkwa, S., Smardon, R., 2010. Ecosystem restoration: evaluating local knowledge and management systems of fishermen in Fosu lagoon, Ghana. Environ. Pract. 12, 202–213. https://doi.org/10.1371/journal.pone.0066686.
Daru, B.H., Yessoufou, K., Mankga, L.T., Davies, T.J., 2013. A global trend towards the loss of evolutionarily unique species in mangrove ecosystems. PLoS One 8, e66686. https://doi.org/10.1371/journal.pone.0066686.
Derkyi, M.A.A., Boateng, K., Owusu, B., 2009. Local communities' traditional knowledge of the mangrove forest ecosystem in Nzema East and Mfantseman Districts in Ghana. Traditional forest-related knowledge and sustainable forest management in Africa. IUFRO world series 23, 137–147.
Donkor, P., Agyemang, F., 2015. Analysis of Spatial Planning Options: Ankobra, the USAID/Ghana Sustainable Fisheries Management Project (SFMP), Narragansett, RI. Coastal Resources Center. Graduate School of Oceanography, University of Rhode Island and Spatial Dimensions. GH2014_ACT046_SpS. https://www.crc.uri.edu/download/GH2014_ACT046_SpS_FIN508.pdf.
Duke, N.C., 1993. Mangrove floristics and biogeography. In: Alista, I.R., Daniel, M.A. (Eds.), Tropical Mangrove Ecosystems. American Geographical Union, Washington, DC, pp. 63–100. https://doi.org/10.1029/CE041.
Duke, N.C., Allen, J.A., 2006. Rhizophora mangle, R. samoensis, R. racemosa, R.× harrisonii (Atlantic–East Pacific red mangrove). Species profiles for pacific island agroforestry 10, 1–18.
Dzakpasu, M.F., Yankson, K., 2015. Hydrographic characteristics of two estuaries on the south western coast of Ghana. New York Science Journal 8, 60–69. http://www.sciencepub.net/newyork.
Ellison, J.C., 2021. Factors influencing mangrove ecosystems. In: Rastogi, R.P., Phulwaria, M., Gupta, D.K. (Eds.), Mangroves: Ecology, Biodiversity and Management. Springer Singapore, pp. 97–115. https://doi.org/10.1007/978-981-16-2494-0_4.

Essumang, D.K., Boamponsem, L.K., Adokoh, C.K., Bentum, J.K., Owusu, C., Adu-Boakye, M.E., Afrifa, J., 2012. Evaluation of the levels of selected heavy metals in mangrove ecosystem and roadside topsoil in Ghana. Environ. Pract. 14, 173–183. https://doi.org/10.1017/S1466046612000191.

Evadzi, P.I., Zorita, E., Hünicke, B., 2017. Quantifying and predicting the contribution of sea-level rise to shoreline change in Ghana: information for coastal adaptation strategies. J. Coast Res. 33, 1283–1291. https://doi.org/10.2112/JCOASTRES-D-16-00119.1.

Evadzi, P.I.K., Scheffran, J., Zorita, E., Hünicke, B., 2018. Awareness of sea-level response under climate change on the coast of Ghana. J. Coast Conserv. 22, 183–197. https://doi.org/10.1007/s11852-017-0569-6.

Feka, N.Z., Manzano, M.G., 2008. The implications of wood exploitation for fish smoking on mangrove ecosystem conservation in the South West Province, Cameroon. Trop. Conserv. Sci. 1, 222–241. https://doi.org/10.1177/194008290800100303.

Fianko, J.R., Dodd, H.S., 2019. Sustainable management of wetlands: a case study of the Songor Ramsar and Unesco man and biosphere reserve in Ghana. Journal of Wetlands Environmental Management 6, 45–53. https://doi.org/10.20527/jwem.v6i1.173.

FCMC. Forest Carbon Markets and communities (FCMC), mangrove reserves in five West African countries. https://www.climatelinks.org/sites/default/files/asset/document/Mangrove_Reserves_Brief.pdf.

Friess, D.A., Yando, E.S., Abuchahla, G.M.O., Adams, J.B., Cannicci, S., Canty, S.W.J., Cavanaugh, K.C., Connolly, R.M., Cormier, N., Dahdouh-Guebas, F., Diele, K., Feller, I.C., Fratini, S., Jennerjahn, T.C., Lee, S.Y., Ogurcak, D.E., Ouyang, X., Rogers, K., Rowntree, J.K., Sharma, S., Sloey, T.M., Wee, A.K.S., 2020. Mangroves give cause for conservation optimism, for now. Curr. Biol. 30, R153–R154. https://doi.org/10.1016/j.cub.2019.12.054.

Gatt, Y.M., Andradi-Brown, D.A., Ahmadia, G.N., Martin, P.A., Sutherland, W.J., Spalding, M.D., Donnison, A., Worthington, T.A., 2022. Quantifying the Reporting, Coverage and Consistency of Key Indicators in Mangrove Restoration Projects. https://doi.org/10.3389/ffgc.2022.720394.

Ghana Ministry of Fisheries, Aquaculture Development, Fisheries Commission (GMFADFC), 2020. Ankobra estuary community-based fisheries management plan, western region, Ghana. In: Commission, F. (Ed.), Ministry of Fisheries and Aquaculture Development. Accra. https://www.crc.uri.edu/download/GH2014_ACT084_MOFAD_FC_FIN508.pdf.

Ghana Statistical Service, 2021. Ghana 2021 Population and Housing Census: Preliminary Report. https://census2021.statsghana.gov.gh/gssmain.

Giesen, W., Wulffraat, S., Zieren, M., Scholten, L., 2007. Mangrove Guide Book for Southeast Asia. FAO Regional Office for Asia and the Pacific, Bangkok, Thailand.

Goldberg, L., Lagomasino, D., Thomas, N., Fatoyinbo, T., 2020. Global declines in human-driven mangrove loss. Global Change Biol. 26, 5844–5855. https://doi.org/10.1111/gcb.15275.

Gordon, C., Tweneboah, E., Mensah, A., Ayivor, J., 2009. The application of the ecosystem approach to mangrove management: lessons for Ghana. Nature & Faune 24, 30–41.

Haddaway, N.R., Macura, B., Whaley, P., Pullin, A.S., 2018. ROSES RepOrting standards for Systematic Evidence Syntheses: pro forma, flow-diagram and descriptive summary of the plan and conduct of environmental systematic reviews and systematic maps. Environ. Evid. 7, 7. https://doi.org/10.1186/s13750-018-0121-7.

Hagger, V., Worthington, T.A., Lovelock, C.E., Adame, M.F., Amano, T., Brown, B.M., Friess, D.A., Landis, E., Mumby, P.J., Morrison, T.H., O'Brien, K.R., Wilson, K.A., Zganjar, C., Saunders, M.I., 2022. Drivers of global mangrove loss and gain in social-ecological systems. Nat. Commun. 13 (1), 6373. https://doi.org/10.1038/s41467-022-33962-x.

Hamilton, L.S., Snedaker, S.C., 1984. In: Honolulu, Hawaii (Ed.), East-West Environment and Policy Institute, Handbook for Mangrove Area Management. The Institute.

IUCN, 1983. Global Status of Mangrove Ecosystems. IUCN Commission on Ecology, the Netherlands.

IUCN, 2011. An Appraisal of Mangrove Management in Micro-tidal Estuaries and Lagoons in Sri Lanka, Colombo, Sri Lanka. https://portals.iucn.org/library/efiles/documents/2011-112.pdf.

Jayatissa, L.P., Dahdouh-Guebas, F., Koedam, N., 2002. A review of the floral composition and distribution of mangroves in Sri Lanka. Bot. J. Linn. Soc. 138, 29–43. https://doi.org/10.1046/j.1095-8339.2002.00002.x.

Jayson-Quashigah, P.-N., Addo, K.A., Kodzo, K.S., 2013. Medium resolution satellite imagery as a tool for monitoring shoreline change. Case study of the Eastern coast of Ghana. J. Coast Res. 511–516. https://doi.org/10.2112/SI65-087.1.

Johnson-Bhola, L., 2020. Effects of Rural Land Tenure System on Mangroves Management in Corentyne, Guyana, Land Use Change and Sustainability. IntechOpen. https://doi.org/10.1016/j.sciaf.2022.e01420.

Kairo, J.G., Dahdouh-Guebas, F., Gwada, P.O., Ochieng, C., Koedam, N., 2002. Regeneration status of mangrove forests in Mida Creek, Kenya: a compromised or secured future? Ambio 562–568.

Kairu, A., Kotut, K., Mbeche, R., Kairo, J., 2021. Participatory forestry improves mangrove forest management in Kenya. Int. For. Rev. 23, 41–54. https://doi.org/10.21203/rs.3.rs-44725/v1.

Kamara, A.B., 1982. Preliminary studies to culture mangrove oysters, Crassostrea tulipa, in Sierra Leone. Aquaculture 27, 285–294. https://doi.org/10.1016/0044-8486(82)90063-1.

Kathiresan, K., Bingham, B.L., 2001. Biology of Mangroves and Mangrove Ecosystems, Advances in Marine Biology. Academic Press, pp. 81–251. https://doi.org/10.1016/S0065-2881(01)40003-4.

Key Biodiversity Areas Partnership, 2022. Key Biodiversity Areas Factsheet: Densu Delta Ramsar Site and Vicinity. Extracted from the World Database of Key Biodiversity Areas. Developed by the Key Biodiversity Areas Partnership: BirdLife International, IUCN, American Bird Conservancy, Amphibian Survival Alliance, Conservation International, Critical Ecosystem Partnership Fund, Global Environment Facility, Re: wild, NatureServe, Rainforest Trust. Royal Society for the Protection of Birds, World Wildlife Fund and Wildlife Conservation Society. Key Biodiversity Areas. http://www.keybiodiversityareas.org/.

Koranteng, K.A., Ofori-Danson, P.K., Entsua-Mensah, M., 2000. Fish and fisheries of the Muni lagoon in Ghana, West Africa. Biodivers. Conserv. 9, 487–499. https://doi.org/10.1023/A:1008903813222.

Korsah, L.A., Kuwornu-Adjaottor, J.E., 2019. The Akan experience of god through the eyes of the fante from oguaa. Art Human Open Acc J 3, 280–283. https://doi.org/10.15406/ahoaj.2019.03.0014.

Kwain, S., Tetevi, G.M., Mensah, T., Camas, A.S., Camas, M., Dofuor, A.K., Azerigyik, F. A., Deng, H., Jaspars, M., Kyeremeh, K., 2019. Digyaindoleacid A: 2-(1-(4-Hydroxyphenyl)-3-oxobut-1-en-2-yloxy)-3-(1H-indol-3-yl) propanoic acid, a novel indole alkaloid. Molbank. https://doi.org/10.3390/M1080, 2019, M1080.

Kyeremeh, K., Kwain, S., Tetevi, G.M., Camas, A.S., Camas, M., Dofuor, A.K., Deng, H., Jaspars, M., 2019. α-d-Glucopyranosyl-(1→2)-[6-O-(l-tryptophanyl)-β-d-fructofuranoside]. Molbank. https://doi.org/10.3390/M1066, 2019.

Leal, M., Spalding, M.D., 2022. The State of the World's Mangrove. Gloabal, Mangrove Alliance, pp. 1–92.

Lin, P., 1999. Mangrove Ecosystem in China. Science Press, Beijing, China, Beijing, China.

Lovelock, C.E., Brown, B.M., 2019. Land tenure considerations are key to successful mangrove restoration. Nature Ecology & Evolution 3 (8). https://doi.org/10.1038/s41559-019-0942-y, 1135–1135.

Ly, C.K., 1980. The role of the Akosombo Dam on the Volta river in causing coastal erosion in central and eastern Ghana (West Africa). Mar. Geol. 37, 323–332. https://doi.org/10.1016/0025-3227(80)90108-5.

Ma, J., Ullah, S., Niu, A., Liao, Z., Qin, Q., Xu, S., Lin, C., 2021. Heavy metal pollution increases CH4 and decreases CO2 emissions due to soil microbial changes in a mangrove wetland: microcosm experiment and field examination. Chemosphere 269, 128735. https://doi.org/10.1016/j.chemosphere.2020.128735.

Macintosh, D.J., Ashton, E.C., 2003. Report on the Africa Regional Workshop on the Sustainable Management of Mangrove Forest Ecosystems. ISME/cenTER/CAW.

Mitra, A., 2020. Ecosystem services of mangroves: an overview. In: Mitra, A. (Ed.), Mangrove Forests in India. Springer International Publishing, pp. 1–32. https://doi.org/10.1007/978-3-030-20595-9_1.

Mshale, B., Senga, M., Mwangi, E., 2017. Governing Mangroves: Unique Challenges for Managing Tanzania's Coastal Forests.

Mu, M.-R., Jiang, Q.-L., Wang, W.-Q., 2007. Comparison of leaf chloride content and leaf traits between true mangrove plants and semi-mangrove plants. Chinese Journal of Plant Ecology 31, 497.

Mukherjee, N., Sutherland, W.J., Dicks, L., Hugé, J., Koedam, N., Dahdouh-Guebas, F., 2014. Ecosystem service valuations of mangrove ecosystems to inform decision making and future valuation exercises. PLoS One 9, e107706. https://doi.org/10.1371/journal.pone.0107706.

Naidoo, G., 2023. The mangroves of Africa: a review. Mar. Pollut. Bull. 190, 114859 https://doi.org/10.1016/j.marpolbul.2023.114859.

Nfotabong-Atheull, A., Din, N., Longonje, S.N., Koedam, N., Dahdouh-Guebas, F., 2009. Commercial activities and subsistence utilization of mangrove forests around the Wouri estuary and the Douala-Edea reserve (Cameroon). J. Ethnobiol. Ethnomed. 5, 35. https://doi.org/10.1186/1746-4269-5-35.

Nfotabong-Atheull, A., Din, N., Essomè Koum, L.G., Satyanarayana, B., Koedam, N., Dahdouh-Guebas, F., 2011. Assessing forest products usage and local residents' perception of environmental changes in peri-urban and rural mangroves of Cameroon, Central Africa. J. Ethnobiol. Ethnomed. 7, 41. https://doi.org/10.1186/1746-4269-7-41.

Nortey, D.D.N., 2018. Sustainable Mangrove Harvesting and Management. Training for Mangrove Harvesters: A Summary Report, the USAID/Ghana Sustainable Fisheries Management Project (SFMP). Coastal Resources Center. Graduate School of Oceanography, University of Rhode Island and Hen Mpoano, Narragansett, RI. GH2014_ACT25 _HM. 15 pp, Ghana. http://www.crc.uri.edu/projects_page/ghanasfmp/.

Nortey, D.D.N., Aheto, D.W., Blay, J., Jonah, F.E., Asare, N.K., 2016. Comparative assessment of mangrove biomass and fish assemblages in an urban and rural mangrove wetlands in Ghana. Wetlands 36, 717–730. https://doi.org/10.1007/s13157-016-0783-2.

Ntyam, S.C.O., Kojo Armah, A., Ajonina, G.N., George, W., Adomako, J., Elvis, N., Obiang, B.O., 2014. Importance of Mangrove Litter Production in the Protection of Atlantic Coastal Forest of Cameroon and Ghana, the Land/Ocean Interactions in the Coastal Zone of West and Central Africa. Springer, pp. 123–137. https://doi.org/10.1007/978-3-319-06388-1_11.

Nunoo, F.K., Agyekumhene, A., 2022. Mangrove degradation and management practices along the coast of Ghana. Agric. Sci. 13, 1057–1079. https://doi.org/10.4236/as.2022.1310065.

Obodai, E., Nyarko, H., Amponsah, S., 2010. Effect of depuration on microbial content of mangrove oyster (crassostr ea tulipa) from Benya lagoon, Ghana. Ethiopian Journal of Environmental Studies and Management 3.

Obodai, J., Adjei, K.A., Odai, S.N., Lumor, M., 2019. Land use/land cover dynamics using landsat data in a gold mining basin-the Ankobra, Ghana. Remote Sens. Appl.: Society and Environment 13, 247–256. https://doi.org/10.1016/j.rsase.2018.10.007.

Onyena, A.P., Sam, K., 2020. A review of the threat of oil exploitation to mangrove ecosystem: insights from Niger Delta, Nigeria. Global Ecology and Conservation 22, e00961. https://doi.org/10.1016/j.gecco.2020.e00961.

Osei, E., Kwain, S., Mawuli, G.T., Anang, A.K., Owusu, K.B.-A., Camas, M., Camas, A.S., Ohashi, M., Alexandru-Crivac, C.-N., Deng, H., 2019. Paenidigyamycin A, potent

antiparasitic imidazole alkaloid from the Ghanaian Paenibacillus sp. DE2SH. Mar. Drugs 17, 9.
Osei, I.K., Yankson, K., Obodai, E.A., 2021. Effect of sedentary biofoulers on the growth and survival of cultured oysters (Crassostrea tulipa) towards its mass culture in the Densu Delta, Ghana. Aquacult. Int. 29, 813–826. https://doi.org/10.1007/s10499-021-00659-9.
Peters, M.K., Kusimi, J.M., 2023. Changes in wetland and other landscape elements of the Keta Municipal area of Ghana. J. Coast Conserv. 27 (1), 1. https://doi.org/10.1007/s11852-022-00928-6.
Piersma, T., Ntiamoa-Baidu, Y., 1995. Waterbird Ecology and the Management of Coastal Wetlands in Ghana. https://www.vliz.be/imisdocs/publications/72/314272.pdf.
Polidoro, B.A., Carpenter, K.E., Collins, L., Duke, N.C., Ellison, A.M., Ellison, J.C., Farnsworth, E.J., Fernando, E.S., Kathiresan, K., Koedam, N.E., Livingstone, S.R., Miyagi, T., Moore, G.E., Ngoc Nam, V., Ong, J.E., Primavera, J.H., Salmo III, S.G., Sanciangco, J.C., Sukardjo, S., Wang, Y., Yong, J.W.H., 2010. The loss of species: mangrove extinction risk and geographic areas of global concern. PLoS One 5, e10095. https://doi.org/10.1371/journal.pone.0010095.
Poti, M., Hugé, J., Shanker, K., Koedam, N., Dahdouh-Guebas, F., 2022. Learning from small islands in the Western Indian Ocean (WIO): a systematic review of responses to environmental change. Ocean Coast Manag. 227, 106268 https://doi.org/10.1016/j.ocecoaman.2022.106268.
Richards, D.R., Thompson, B.S., Wijedasa, L., 2020. Quantifying net loss of global mangrove carbon stocks from 20 years of land cover change. Nat. Commun. 11, 4260. https://doi.org/10.1038/s41467-020-18118-z.
Rubin, J.A., Gordon, C., Amatekpor, J.K., 1999. Causes and consequences of mangrove deforestation in the Volta estuary, Ghana: some recommendations for ecosystem rehabilitation. Mar. Pollut. Bull. 37, 441–449. https://doi.org/10.1016/S0025-326X(99)00073-9.
Saenger, P., Ragavan, P., Sheue, C.R., López-Portillo, J., Yong, J.W.H., Mageswaran, T., 2019. Mangrove biogeography of the indo-pacific. In: Gul, B., Böer, B., Khan, M.A., Clüsener-Godt, M., Hameed, A. (Eds.), Sabkha Ecosystems: Volume VI: Asia/Pacific. Springer International Publishing, Cham, pp. 379–400. https://doi.org/10.1007/978-3-030-04417-6_23.
Sandilyan, S., Kathiresan, K., 2014. Decline of mangroves – a threat of heavy metal poisoning in Asia. Ocean Coast Manag. 102, 161–168. https://doi.org/10.1016/j.ocecoaman.2014.09.025.
Saranraj, P., Sujitha, D., 2015. Mangrove medicinal plants: a review. Am.-Eurasian J. Toxicol. Sci. 7 (3), 146–156. https://doi.org/10.5829/idosi.aejts.2015.7.3.94150.
Satyanarayana, B., Bhanderi, P., Debry, M., Maniatis, D., Foré, F., Badgie, D., Jammeh, K., Vanwing, T., Farcy, C., Koedam, N., Dahdouh-Guebas, F., 2012. A socio-ecological assessment aiming at improved forest resource management and sustainable ecotourism development in the mangroves of tanbi wetland national Park, the Gambia, West Africa. AMBIO 41 (5), 513–526. https://doi.org/10.1007/s13280-012-0248-7.
Sekey, W., Obirikorang, K.A., Boadu, K.B., Gyampoh, B.A., Nantwi-Mensah, A., Israel, E. Y., Asare-Ansah, O., Ashiagbor, G., Adjei-Boateng, D., 2023. Mangrove plantation and fuelwood supply chain dynamics in the Keta lagoon complex ramsar site, Ghana. Wetl. Ecol. Manag. 31 (1), 143–157. https://doi.org/10.1007/s11273-022-09906-z.
Song, S., Ding, Y., Li, W., Meng, Y., Zhou, J., Gou, R., Zhang, C., Ye, S., Saintilan, N., Krauss, K.W., Crooks, S., Lv, S., Lin, G., 2023. Mangrove reforestation provides greater blue carbon benefit than afforestation for mitigating global climate change. Nat. Commun. 14 (1), 756. https://doi.org/10.1038/s41467-023-36477-1.
Spalding, M., 2010. World Atlas of Mangroves, first ed. Routledge, London. https://doi.org/10.4324/9781849776608.
Spalding, M., Parrett, C.L., 2019. Global patterns in mangrove recreation and tourism. Mar. Pol. 110, 103540 https://doi.org/10.1016/j.marpol.2019.103540.
Takyi, R., El Mahrad, B., Nunoo, F.K.E., Adade, R., ElHadary, M., Essandoh, J., 2022. Adaptive management of environmental challenges in West African coastal lagoons. Sci. Total Environ. 838, 156234 https://doi.org/10.1016/j.scitotenv.2022.156234.
Tansley, A.G., Fritsch, F.E., 1905. Sketches of vegetation at home and abroad. I. The flora of the ceylon littoral. New Phytol. 4, 1–17. http://www.jstor.org/stable/2427526.
Thomas, N., Lucas, R., Bunting, P., Hardy, A., Rosenqvist, A., Simard, M., 2017. Distribution and drivers of global mangrove forest change, 1996–2010. PLoS One 12, e0179302. https://doi.org/10.1371/journal.pone.0179302.
Tomlinson, P.B., 2016. The Botany of Mangroves. Cambridge University Press.
Twumasi, Y.A., Coleman, T.L., Manu, A., 2005. Biodiversity management using remotely sensed data and GIS technologies: the case of Digya National Park, Ghana. In: Proceedings of the 31st International Symposium on Remote Sensing of Environment (ISRSE): Global Monitoring for Sustainability and Security. Saint Petersburg, Russia, 20-24 June 2005. CD-ROM. The International Society of Photogrammetry and Remote Sensing (ISPRS).
UNEP, 2007. Mangroves of Western and Central Africa (978-92-807-2792-0), p. 2022 [Retrieved Novemeber 20. http://www.unep-wcmc.org/resources/publications/UNEP_WCMC_bio_series/26.htm.
UNEP, 2023. Decades of Mangrove Forest Change: what Does it Mean for Nature, People and the Climate? https://wedocs.unep.org/20.500.11822/42254.
Wang, W., Yan, Z., You, S., Zhang, Y., Chen, L., Lin, G., 2011. Mangroves: obligate or facultative halophytes? A review. Trees (Berl.) 25, 953–963. https://doi.org/10.1007/s00468-011-0570-x.
Ward, R.D., Friess, D.A., Day, R.H., Mackenzie, R.A., 2016. Impacts of climate change on mangrove ecosystems: a region by region overview. Ecosys. Health Sustain. 2 (4), e01211 https://doi.org/10.1002/ehs2.1211.
Water Resources Commission Ghana, 2009. In: Commission, W.R. (Ed.), Ankobra River Basin- Integrated Water Resources Management Plan. http://www.wrc-gh.org/basins/ankobra/.
Wood, D., Fatoyinbo, T., Lagomasino, D., Reid, J., Seidu, O., Pigott, H., Asare, K., Adam, A., Payton, A., Yedu Aidoo, K., 2019. Earth Observation Systems to Promote Public Sector Monitoring of Mangroves and Terrestrial Forests in Benin and Ghana in Support of SDG15. AGU Fall Meeting Abstracts, pp. B21A–B25A.
Worthington, T.A., zu Ermgassen, P.S.E., Friess, D.A., Krauss, K.W., Lovelock, C.E., Thorley, J., Tingey, R., Woodroffe, C.D., Bunting, P., Cormier, N., Lagomasino, D., Lucas, R., Murray, N.J., Sutherland, W.J., Spalding, M., 2020. A global biophysical typology of mangroves and its relevance for ecosystem structure and deforestation. Sci. Rep. 10, 14652 https://doi.org/10.1038/s41598-020-71194-5.