Marine Pollution Bulletin 197 (2023) 115735

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Review

Assessment of coastal and marine ecosystems in West Africa: The case of Ghana

Richard Takyi [a,b,*], Badr El Mahrad [c,d,e], Cynthia Addo [f], John Essandoh [g], Mohamed ElHadary [e,h,i], Richard Adade [j], Eddiebright Joseph Buadi [g], Benjamin Osei Botwe [b], Francis Kofi Ewusie Nunoo [b]

[a] Blue Resources Research and Policy Institute, Box L534 Mallam, Greater Accra, Ghana
[b] Department of Marine and Fisheries Sciences, University of Ghana, Legon, Ghana
[c] Murray Foundation, Brabners LLP, Horton House, Exchange Street, Liverpool L2 3YL, UK
[d] Laboratory of Geoscience, Water and Environment, (LG2E-CERNE2D), Department of Earth Sciences, Faculty of Sciences, Mohammed V University of Rabat, Rabat 10000, Morocco
[e] CIMA, FCT-Gambelas Campus, University of Algarve, 8005-139 Faro, Portugal
[f] Fisheries Committee for the West-Central Gulf of Guinea, Tema, Ghana
[g] Department of Conservation Biology and Entomology, University of Cape Coast, Ghana
[h] Department of Biological, Geological and Environmental Sciences, University of Bologna, 48123 Ravenna, Italy
[i] Department of Environmental Engineering, University of Science and Technology, Zewail City of Science and Technology, Giza 12578, Egypt
[j] Centre for Coastal Management-African Centre of Excellence in Coastal Resilience, University of Cape Coast, Ghana

ARTICLE INFO

Keywords:
Coastal and marine ecosystems
Socio-ecological framework
Anthropogenic drivers
Environmental pollution
Ecosystem management

ABSTRACT

Coastal and marine ecosystems, as integral component of social, ecological, and economic systems, are critical in providing essential ecosystem services that underpin human activities, including fishing and mining. Effective management of these ecosystems is paramount to safeguarding their vital contributions. This study adopts a socio-ecological framework, "Drivers (D) of human activities (A), associated Pressures (P), State change in coastal and marine environments, Impact (I) on human welfare (W) and Response (R) as measures (M) of management, (DAPSI(W)R(M))," to analyse the complexities of coastal and marine ecosystems in the Ghanaian context. The study identifies various drivers of anthropogenic activities, such as fishing, oil and gas production, and waste disposal. These anthropogenic activities create significant pressures, including selective extraction of living and non-living resources, as well as habitat degradation through substratum loss and pollution. Consequently, these pressures have led to changes in fish biomass and habitat quality, among other ecological shifts.

1. Introduction

Coastal and marine environments provide enormous ecosystem services (e.g., food, shelter, employment, security, transportation, and scientific research, among others), which contribute to shaping the progress of human culture and economic development, as well as defining how humans connect to the rest of the world (Bowen et al., 2006; Clark and Johnston, 2016).

Globally, >3 billion people depend on coastal and marine ecosystems due to their substantial social and economic benefits such as fishing and tourism. With an estimated value of US$ 4.6 trillion, marine tourism constitutes about 50 % of the global total revenue from tourism and has the potential to employ nearly 8.5 million individuals by 2030. Shipping (including freights transportation) accounts for about 80 % of the world trade, with an estimated 11 billion tonnes in 2021, while mining was valued at US$ 35 billion (Löf et al., 2022; Northrop et al., 2022; UNCTAD, 2022).

Coastal and marine environments host diverse habitats (e.g., estuaries and reefs) and a wealth of biodiversity, essential for sustaining life (e.g., nesting and spawning), and climate regulations (Schumm et al., 2021; United Nations, 2017). The ocean, for instance, hosts approximately 10 million of the world's species, with diverse essential genetic resources (UN, 2017). Furthermore, it produces about 50 % of the world's oxygen, while absorbing about 30 % of carbon dioxide.

* Corresponding author at: Blue Resources Research and Policy Institute, Box L534 Mallam, Greater Accra, Ghana.
E-mail address: richardktakyi@gmail.com (R. Takyi).

https://doi.org/10.1016/j.marpolbul.2023.115735
Received 5 September 2023; Received in revised form 26 October 2023; Accepted 27 October 2023
Available online 3 November 2023

Mangroves alone storing up to five times more carbon dioxide (Chatting et al., 2022; Rabone et al., 2019; UN, 2017).

Although coastal and marine environments have been integral to the development of human civilisation and linking cultures, they have also been a subject of deleterious human activities (FAO, 2022; Quimbayo et al., 2022). These activities include illegal, unreported, and unregulated (IUU) fishing, coastal deforestation, sand mining, and pollution (e.g., by macro- and micro- plastics, organic waste, hydrocarbons) from industrial and domestic sources, with areas, including marine protected areas not being spared these detrimental effects (Agyeman et al., 2021; Faseyi et al., 2022; Nunoo and Agyekumhene, 2022). This situation has led to the development of several international conventions (e.g., the 15th Convention of Parties on Biological Diversity (COP15)) and agreements (e.g., the FAO Code of Conduct for Responsible Fisheries) aimed at protecting and conserving coastal and marine resources (Hofmann, 2022; UNESCO-IOC, 2021; UNESCO, 2020). Several other ocean management tools (e.g., marine protected areas and spatial planning) have been proposed and implemented in some areas (e.g., Great Barrier Marine Parks, Galapagos Marin Reserves) across the globe to reduce or eliminate pressures, change in the state or impact of these ecosystems caused by several human activities (Masud et al., 2022; Trouillet and Jay, 2021). Due to the socio-ecological nature of coastal and marine ecosystems, the integration of social and ecological priorities in decision-making to curb degradation and ensure resilience and sustainability has also been proposed (Abelson et al., 2020; Schratzberger et al., 2019).

There is an urgent call for enhanced conservation and sustainable utilisation of coastal and marine resources, which face considerable pressure and state change owing to human activities (OECD, 2022; United Nations, 2017). This requires that policymakers and managers of coastal and marine resources in coastal countries adopt integrated adaptive management strategies. The broadly and previously used approach known as Drivers (D), Activities (A), Pressures (P), State changes (S), Impacts (I) on human welfare (W) and the Response (R) as Measures (M) (DAPSI(*W*)R(M)), is crucial for facilitating efficient and effective decision making processes (El Mahrad et al., 2020; Nicholls and Hanson, 2007). The DAPSI(*W*)R(M) framework, which is an expanded scope of the DPSIR framework, is an integrated and interdisciplinary approach that bridges the gap between the environment and society. It provides a distinctive holistic structure to problems and can identify management approaches capable of addressing the myriad of linkages between environmental challenges and their drivers, activities, and pressures (Elliott et al., 2017; Gari et al., 2015). Despite its capability, there is little work that fully articulates this tool in the decision-making of coastal and marine resources globally, especially in the West African region.

Therefore, our study aims to apply the DAPSI(*W*)R(M) framework to the coastal and marine environment of Ghana (West Africa) as the case study and propose some recommendations for sustainable management.

2. Materials and methods

2.1. Study area

Ghana is located in West Africa and has a coastline (Fig. 1) of approximately 550 km, with an exclusive economic zone (EEZ) area of 225,000 km^2 (Armah and Amlalo, 1998; Nunoo et al., 2014; Wiafe, 2010). The coastal and marine environment has diverse resources, including fisheries, nesting and feeding grounds for birds and turtles, oil and gas reserves, sand and gravels, salt, lagoons, estuaries, beautiful

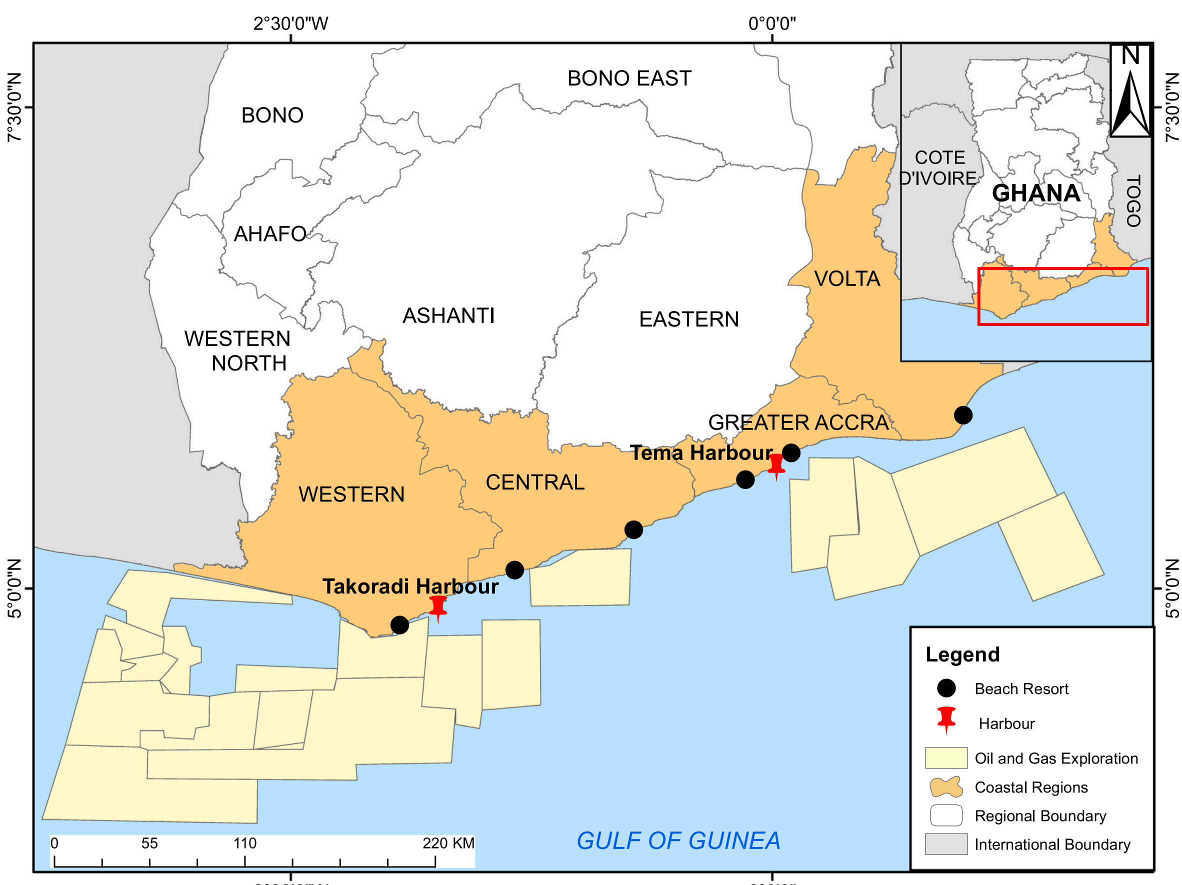

Fig. 1. The coastal regions and marine environment of Ghana with some human activities, such as infrastructure construction, oil and gas mining and exploratory activities.

beaches (sandy and rocky), etc. (Environmental Protection Agency of Ghana, 2020; MoFAD, 2019; Skaten, 2018).

There are four coastal administrative regions along the 550 km coastline, namely:

Western Region – The region borders Cote d'Ivoire on the west, Central Region on the east, and the Atlantic Ocean on the south, with about 192 km coastline (Boye et al., 2018). Sekondi-Takoradi is its administrative capital. Ghana's second largest marine shipping port, the Takoradi Port, is on the coast of the Western Region. There are offshore crude oil and gas extraction activities in the Western Region, with the majority of petrochemical industries and thermal plants located along its coast. The region has several heritage and tourist sites, including forts and castles (Gbeckor-Kove et al., 2021a).

Central Region – It has a coastline length of about 168 km (Ghana Statistical Service, 2013). The region is bordered by Greater Accra Region, Western North and Western regions, Eastern and Ashanti regions, and the Atlantic Ocean to the east, west, north, and south, respectively. The administrative capital for the region is Cape Coast. The region hosts essential fishing ports (e.g., the Elmina Fishing Harbour) and numerous tourist sites (i.e., colonial forts, castles, beaches) along its coast.

Greater Accra Region – It is home to the national capital (i.e., Accra) with a coastline that extends from Krokrobite in the west to Ada in the east (Greater Accra Regional Co-ordinating Council, 2016). It is the hotspot for economic activities, shipping (i.e., Tema shipping port) and fishing facilities (e.g., Tema, and Jamestown fishing harbours), and enormous urban growth at the expense of vegetative cover and coastal habitats (Addae and Oppelt, 2019).

Volta Region – It is located at the easternmost part of the coastline of Ghana and shares boundary with the Volta Lake. The region has the shortest coastline with important fisheries and beaches, which supports essential livelihoods and generates revenue.

2.2. Methods

2.2.1. Data source, collection, and analysis

Data were systematically collected (spanning a 20-year period) by using predefined keywords and search phrases, including "*the importance of the coastal and marine environment in Ghana,*" "*human activities in and along coastal area of Ghana,*" "*human activities in the marine environment of Ghana,*" "*pressure from fishing activities,*" "*pollution of coastal wetlands,*" "*climate change and coastal zone of Ghana,*" among others, as a guide to search for data from online scholarly portals (i.e., ScienceDirect, Google Scholar, Frontiers, Nature Journal, etc.), government institutions' portals (e.g., Ghana Maritime Authority (GMA), Ghana Ports and Harbours Authority (GPHA), Ministry of Finance (MoF), Ministry of Fisheries and Aquaculture Development (MoFAD), etc.), academic and research institution portals in Ghana, and other sources (Abalansa et al., 2021; El Mahrad et al., 2020).

The present study draws on an extensive collection of literature, totalling 162 publications (Fig. 2), comprising 77 peer-reviewed journal articles, 46 reports, 6 theses, and 33 other relevant sources. This selection encompasses materials published between 2004 and 2023 chosen based on their relevance to the research theme (El Mahrad et al., 2020; Takyi et al., 2021, 2022). Additionally, field observations were conducted in Greater Accra and Volta regions to assess the spectrum of anthropogenic activities occurring in the coastal and marine environments. These observations were conducted using a comprehensive checklist.

The relevant information in the data gathered was analysed, collated, and tabulated (Table 1) into Drivers, Activities, Pressure, State Change, Impact on *Welfare*, and Response as *Measures* of the framework herein referred to as (DAPSI(*W*)R(M)).

3. Results and discussion

3.1. Drivers

3.1.1. Biological and physiological needs

The quest to fulfil fundamental biological and physiological needs, such as drink (water) and food (Fig. 3), becomes significant in a country grappling with water scarcity of about 12.3 % and with over 11 % of the population experiencing food insecurity (with 6 % severely food insecure) cannot be overemphasised (Addo, 2023; Ghana Statistical Service, 2022; MoFA et al., 2020). For instance, seawater provides desalinated potable water to over 500,000 people within the Greater Accra Region (Ghana Water Company Limited, 2019; Ngnenbe, 2020). Coastal and marine environments provide diverse fish species (e.g., *Sarotherodon melanotheron*, *Katsuwonus pelamis*, *Dentex* spp., and *Carcharhinus leucas*), marine mammals (e.g., *Peponocephalas electra*), salt, and other animals that serve as a food source to individuals and communities (Sagoe et al.,

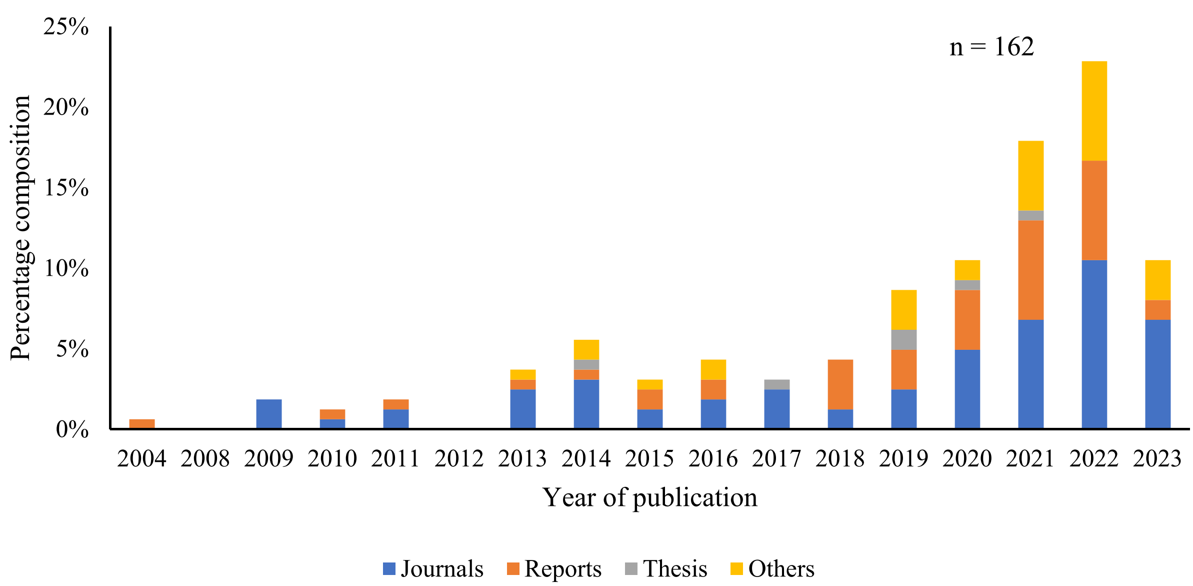

Fig. 2. Percentage composition of literature used for the study, with most of the data sourced from publications between 2019 and 2023, and peer review dominating the literary work.

Table 1
Analysis of data on coastal and marine environments with the DAPSI(*W*)R(*M*) framework.

Drivers	The basic human needs based on Maslow's proposed theory relating to the needs for an individual's survival, i.e., the biological and physiological needs (e.g., food, water, shelter), psychological (e.g., esteem) and self-fulfilment needs which influence human activities.
Activities	These are the fishing, mining (e.g., salt, oil, and gas mining), shipping, and construction of infrastructure activities, including water desalination facilities, ports, sea defence, oil and gas pipelines (Fig. 3), etc. that are undertaken within the coastal and marine areas due to the need to meet the drivers.
Pressure	Reflects the rate and mechanism of change resulting from exogenic pressure (i.e., climate change) and the human activities (endogenic pressure) taking place within the coastal and marine environment. e.g., rate of abrasion, smothering, desiccation, and introduction of compounds (Fig. 3).
State Change	Refers to the change in the state of species diversity and distribution, genetic resources, marine and fresh water supply to lagoons, among others due to the pressure generated by activities of humans in the coastal and marine environment.
Impact on *Welfare*	Refers to the effect of the state in the change in the environment on the ecosystem services that the coastal and marine environment provide to humans, i.e., availability of food (e.g., fish), safety concerns, impact on leisure, etc.
Response as *Measures*	This is the management measures, i.e., convention, laws, regulations, institutions, and traditional norms that has been applied or currently in place to curb or reduce or eliminate the drivers, activities, pressures, and state changes. e.g., Wild Animal Preservation (Amendment) Law of 1983, Coastal Development Act of 2017, and taboos on killing sea turtles.

Adapted from Elliott et al. (2017).

2021; Seidu et al., 2022). Furthermore, the need for shelter due to the availability of land and building materials (e.g., sand (Plate A), stones, wood, thatch, etc.) for the construction of homes and other buildings is an essential driver (Asante et al., 2023; Ghana Statistical Service, 2022). For instance, due to the availability of land and building materials, about a quarter of the population of Ghana lives in the coastal zone (Adu-Gyamfi et al., 2020).

3.1.2. Safety needs

The need to be secured and safe for freedom from fear of natural physical phenomena (e.g., tidal waves, etc.) and external aggression, including piracy, human trafficking, and terrorism, are essential drivers. For example, coastal and marine environments serve as avenues for policing (e.g., IUU fishing) and safeguarding installations, communities, and the country within the EEZ (Bell et al., 2021; Pichon and Pietsch, 2020).

3.1.3. Revenue

The need of an individual or a country to raise revenue (Fig. 3) from salaries and taxes for the provision of goods and services at the personal or national levels in a country where multidimensional poverty is over 46 % is a driver (Ghana Statistical Service, 2022). For instance, the Government of Ghana (GoG) generates about 65 % of domestic revenue from the ports and about US$ 12 million, US$ 152 million, and US$ 26 million from salt, canned tuna, and chilled fish exports in 2021, respectively (Adams, 2021; Ghana Export Promotion Authority, 2022a, 2022b; Koranteng, 2022; Ocloo, 2022a). Furthermore, offshore crude oil production has yielded an average total revenue of approximately US$ 525.52 million per year between 2018 and 2021 (MoF, 2018a, 2019, 2020, 2021a).

Individuals could earn revenues (between US$ 55 and US$ 184 per month from Keta Lagoon or US$ 1000 and US$ 1730 annually from mangrove fuelwood harvest) due to the rich biodiversity and the aesthetic value in a country with an annual household income of about US$2900 (Dali et al., 2023; Ghana Statistical Service, 2019; Sagoe et al., 2021; Sekey et al., 2023).

3.1.4. Livelihood

The aspiration of an individual to be employed or a country to create employment (e.g., fishers, freight forwarders, offshore drilling engineers, hoteliers, traders, etc.) for its citizens to reduce the rate of unemployment and poverty in a country where the unemployment rate is about 13.9 % is a driver (Adams, 2021; Ghana Statistical Service, 2022; Sekey et al., 2022).

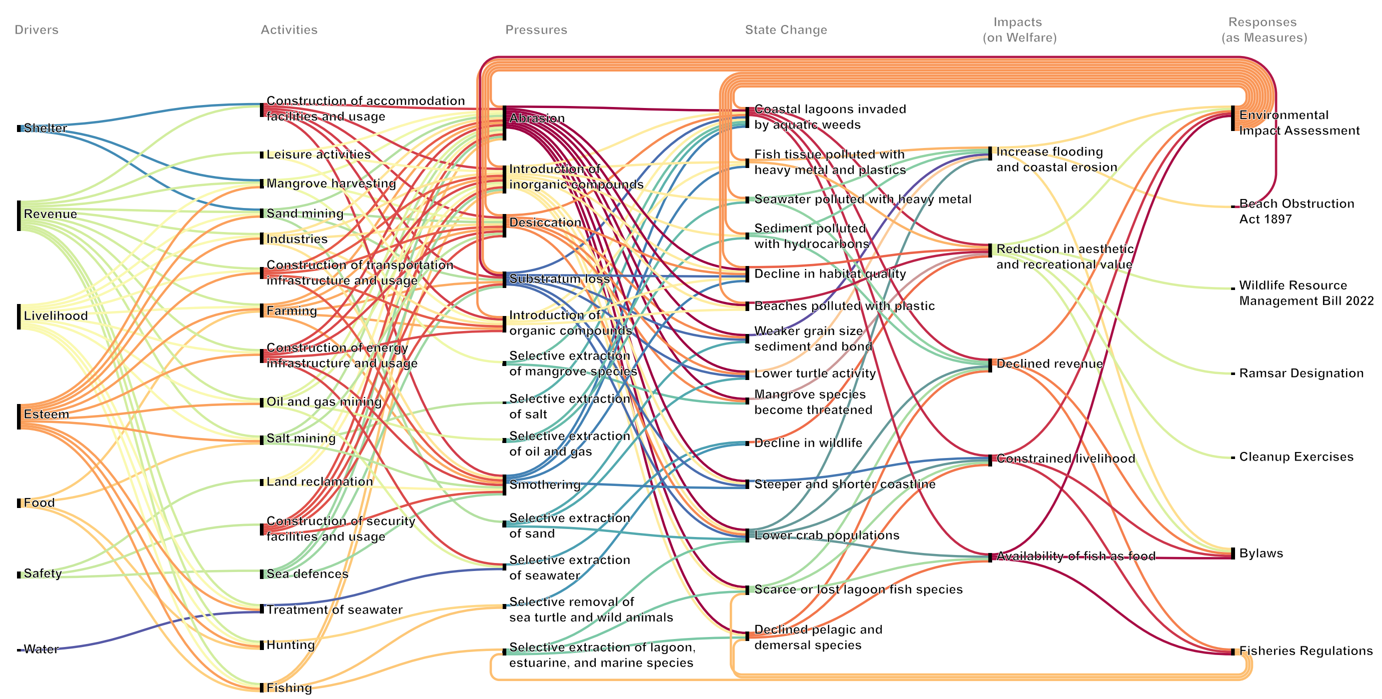

Fig. 3. The linkage between drivers (D) of human activities (A), their associated pressure (P), and the state change (S) in coastal and marine environments of Ghana, with impact (I) (on welfare (W)) and some management responses (R) (as measures (M)) (adapted from Takyi et al. (2023)).

Plate A. An example of an onsite arrest of a pick-up load of beach sand by security personnel at Keta in the Volta Region of Ghana. *Photo credit: Cynthia Addo.*

3.1.5. Esteem needs

The needs to be independent and self-reliant (i.e., achieving sound economic dominance, with receive respect from others) is a motivator. For instance, Ghana wants to continue to enjoy independence and respect from the comity of nations because of its role as an essential fishing, shipping port, and energy hub in West Africa.

3.2. Activities

Considering the drivers described earlier, several human activities (Fig. 3) take place within Ghana's coastal and marine environments, which include the following:

3.2.1. Fishing and farming

Fishing activities (Table 2) include artisanal, semi-industrial, and industrial fishing that target different species of fish. These fishing activities employ fishing gears of varying sizes and types and methods (e.g., trawling, seining, and traps) to meet the desire for food, livelihood, esteem, and revenue generation (MoFAD, 2021; Nunoo et al., 2014; Nunoo and Azumah, 2015).

Coastal crop farming of plants (e.g., coconut, rubber, cabbage, chilli), forestry (e.g., mangrove afforestation), and the rearing of animals (e.g., shrimps) on small to large scales are prevalent in the coastal zone due to the need for food, drink, revenue, livelihood and the availability of land (Darko et al., 2022; Maya, 2020; Nkansah-Poku et al., 2009).

3.2.2. Treatment of seawater for use

This activity involves seawater desalination (because of the need for water) to supply potable water (40,000 m^3/day) to communities within the Greater Accra Region for domestic and other uses (Table 2) (Ngnenbe, 2020).

3.2.3. Harvesting and hunting

Mangroves and other plants are harvested as building materials, fuelwood, and for distillation of local gin '*Akpeteshie*' due to the need for shelter, drink, livelihood, and revenue (Dali et al., 2023; Nunoo and Agyekumhene, 2022). Additionally, because of the need for food and revenue, the coastal forest of wetlands is used as hunting grounds for wildlife (Atubiga and Donkor, 2022).

3.2.4. Mining

Mining activities include offshore oil and gas drilling and coastal area sand, stones, and salt mining due to the need for revenue, shelter, food, livelihood, and esteem. Oil and gas are mined in the Jubilee (i.e., 60 km off the coast, with a 110 km^2 area and a total water depth between 3500 and 4200 m), *Twenneboa, Enyenra,* and *Ntomme* (TEN) (i.e., up to 24 wells), and the *Sankofa Gye Nyame* fields, off the coast of the Western Region of Ghana (Kastning, 2011; MoF, 2020, 2021a; Skaten, 2018). These activities make use of Floating Production Storage and Offloading vessels (FPSOs) installed in about 1100 m depth offshore for the processing of 80,000 to 120,000 barrels of crude oil per day (MoF, 2018b).

Sand mining involves uncontrolled clearing of vegetation, scooping of sand with shovels, and head pans. The sand is carted with pick-up vehicles (Plate A), and mechanised dump (tipper) trucks (Anim et al., 2013; Jonah et al., 2015a). Salt mining (i.e., on large and small scales) activities involve the construction of saltpans in coastal wetlands and pumping of seawater (Atta-Quayson, 2018; Mensah, 2021; The Business and Financial Times, 2022).

3.2.5. Construction of infrastructure and use of coastal and marine ecosystems

These activities (Table 2) include the construction and operation of infrastructures for the transport (e.g., roads, railways, shipping (Plate B) and fishing ports, and container terminals (Plate C)), and the energy (e.g., rigs, oil and gas pipelines, refineries, thermal plants, and fuel storage tanks) sectors, as well as industries (e.g., for tuna, steel, and cement) (Akwetteh et al., 2021; Ghana National Gas Company, 2022; GPHA, 2021; Gyan et al., 2020; Volta River Authority, 2021). This is to meet the esteem, safety, revenue, and livelihood needs.

Additionally, the construction and utilisation of several types of residential, commercial (e.g., health centres, markets, beach resorts (Fig. 4), entertainment centres, and schools), security (e.g., forward operating bases), and sanitation facilities (e.g., landfill, and sewage treatment plants) are present to meet shelter, revenue, livelihood and esteem needs (Ahmed et al., 2018; Ghana Investment Promotion Council, 2022; Graphic.com.gh, 2019; Ministry of Tourism Arts and Culture, 2020; Salifu, 2019). The construction of coastal protective structures, i.e., 110 km of grey infrastructure (Plate D), reclamation of beaches, and dredging of wetlands and nearshore waters are rife due to safety needs (Agyeman, 2022; Angnuureng and Appeaning Addo, 2013; Asiedu-Addo, 2021; Charuka et al., 2023; Ghana Business News, 2019).

Other human activities, including research, military activities (e.g., patrols and surveillance by the Ghana Navy), leisure (i.e., swimming, horse riding, and quad biking), and waste (e.g., plastic and organic) discharge from residential, commercial, and health facilities into wetlands, beaches, and marine waters are rife along the Ghana coast (Kortei and Quansah, 2016; Lazar et al., 2020; Ocloo, 2022b).

Table 2
Human activities/sectors in the coastal and marine environment of Ghana, West Africa.

Sector/Activity	Regional Coastal and Marine Area				Reference
	Western	Central	Greater Accra	Volta	
Fishing	x	x	x	x	Nunoo and Asiedu (2013)
Farming					Darko et al. (2022); Maya (2020)
– Crops and animal rearing	x	x	x	x	
– Aquaculture			x		
Harvesting and hunting	x	x	x	x	Nunoo and Agyekumhene (2022)
Treatment of seawater			x		Ngnenbe (2020)
Mining					Kastning (2011); Jonah et al. (2015a); Atta-Quayson (2018)
– *Oil and gas*	x				
– *Sand and stone*		x	x	x	
– *Salt*		x	x	x	
Transportation infrastructure					Ghana Ports and Harbours Authority (GPHA) (2021); Akwetteh et al. (2021); Field observation
– *Shipping ports with container terminals* (i.e., *Tema and Takoradi)*	x		x		
– *Fishing port* (e.g., *Elmina, Dixcove, Tema,* etc.*)*	x	x	x		
– *Drydocks*	x		x		
– *Roads*	x	x	x		
Energy infrastructure					Adjimah and Luki (2017); Ghana National Gas Company (2022)
– *FPSOs*	x				
– *Refinery (Oil and Gas)*	x		x		
– *Gas pipelines*	x				
– *Thermal plants*	x		x		
Coastal protection, land reclamation and dredging	x	x	x	x	RSIM Directorate (2022)
Tourism and leisure					Ghana Investment Promotion Council (2022); Field observation
– *Hotels, beach resorts, monuments* (e.g., *castles, forts,* etc.*)*	x	x	x	x	
– *Public beach use*	x	x	x	x	
Residential, education and sanitation infrastructure					Ahmed et al. (2018); Salifu (2019); Field observation
– *Housing*	x	x	x	x	
– *Health facilities*	x	x	x		
– *Educational facilities Schools*	x	x	x		
– *Commercial centres* (e.g., *pubs, markets, banks,* etc.*)*	x	x	x	x	
Industrial use					Field observation
– *Large scale* (e.g., *tuna processing, cement manufacturing,* etc.*)*	x	x	x		
– *Small scale*	x	x	x	x	
Waste disposal					Kortei and Quansah (2016); Field observations
– *Domestic*	x	x	x	x	
– *Industrial*	x	x	x		
Security and defence (Forward operating base and patrols)	x	x	x	x	Ocloo (2022b)
Research, survey, and educational activities	x	x	x	x	Lazar et al. (2020); Teye et al. (2020)

Legend: x- present; List of activities adapted from Takyi et al. (2022).

3.3. *Pressure*

Single or multiple pressures (Fig. 3, Table 3) are the mechanisms of change created by one or more of the aforementioned human activities, which can affect the characteristics of the environments.

3.3.1. *Extraction of living resources*

The pressure from fishing activities includes the selective removal (i.e., high fishing mortality) of adult and juvenile fish species in coastal lagoons (e.g., *Sarotherodon melanotheron*), estuaries (e.g., *Tympanotonus fuscatus*), marine (e.g., *Caranx hippos*, *Katsuwonus pelamis*, *Thunnus obesus*, *Sardinella* spp., *Pseudotholithus*), and shrimps at a catch per unit efforts ranging between about 0.03 (artisanal), 0.14 (semi-industrial) and 3.4 (industrial) mt/fleet/day (MoFAD, 2022). Adult and juvenile cetaceans also face pressure from selective capture. For example, *Stenella clymene, Peponocephalas electra, Steno* sp., and *Tursiops* sp. were being captured at a rate of 0.7 and 3 individuals/day at Dixcove in the Western Region of Ghana due to fishing activities (de Boer et al., 2016; van Waerebeek et al., 2009; Van Waerebeek et al., 2014). The pressure from the selective capture of sharks is currently at a rate of 7 to 10 and 1 to 5 individuals by specialised shark and bycatch fishers, respectively, per fishing trip (Sekey et al., 2022). In the case of *Lepidochelys olivacea* and *Dermochelys coriacea*, pressure from the selective capture was rated between 14 and 8 individuals/year, respectively, at Dzita (Volta Region) along the coast of Ghana due to fishing and hunting (Agyekumhene et al., 2021; Dzita Turtle Protection, 2021). Mangroves have also not been spared. The selective harvesting of mangrove species, including *Rhizophora mangle* and *Avicennia germinans*, among others, as fuelwood (e.g., 93 kg of mangrove trees/day in the Keta Lagoon), building materials, and the creation of land space for construction activities constitutes pressure on the mangrove resources (Nunoo and Agyekumhene, 2022; Sekey et al., 2023; Takyi et al., 2022).

3.3.2. *Extraction of non-living resources*

There is pressure from the selective extraction of non-living resources such as beach sediments (e.g., at a rate of 47,562.7 m^3/year along the coastline of the Central Region), salt, oil (over 100,000 barrels/day) and gas (over 211 $\times$ 10^6 standard cubic feet/day) due to mining activities (Ghana News Agency, 2023; Jonah et al., 2015a, 2015b; MoF, 2021b; Ofori-Atta, 2023). Another important pressure comes from the extraction of seawater for desalination, cooling of steam condensers, and the discharge of hot water from the several thermal plants along the coastal area of Ghana due to the operations of energy infrastructure (Roy et al., 2022).

3.3.3. *Abrasion*

Pressure from the high physical and mechanical interaction with flora and fauna is a function of the frequency and scale of activities. Activities such as fishing, dredging, mining of e.g., salt, over 2917 dump (tipper) trucks of sand/site/year, extraction of oil and gas, and construction of infrastructure such as refineries (Table 3) are present (Jonah et al., 2015a).

Plates B and C. New port terminal at Tema Port, and a container terminal infrastructure along the coast of Ghana. *Photo credit: Richard Takyi.*

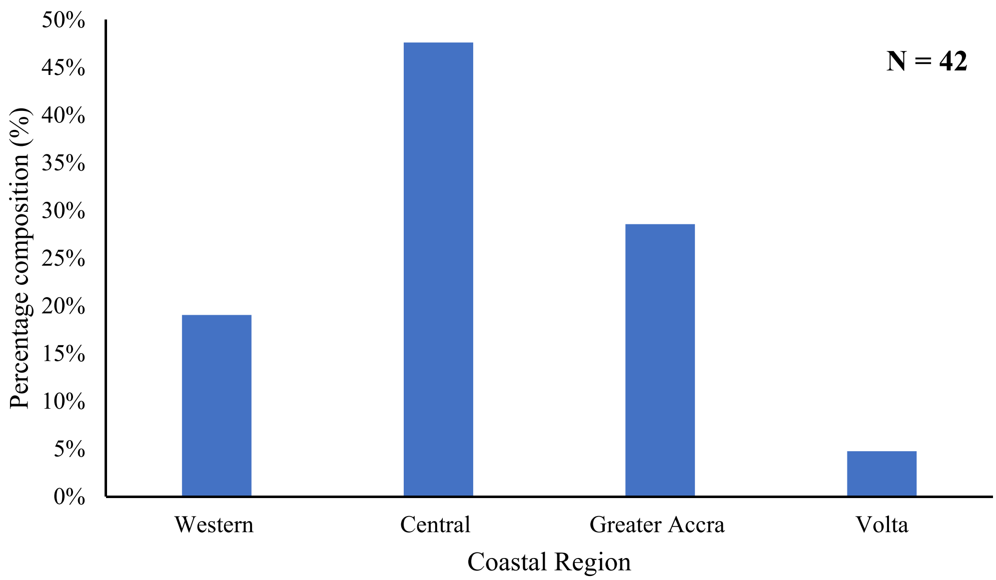

Fig. 4. Percentage composition of beach resorts along the coastal regions of Ghana, with the Central Region accounting for most beach resorts (Source: *Google Map and field observation*).

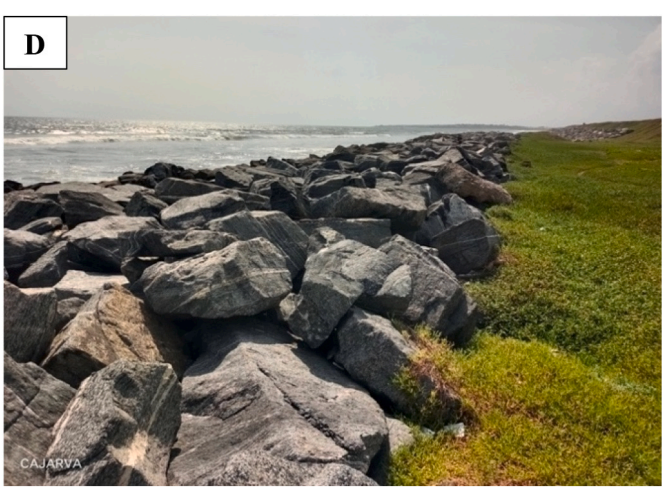

Plate D. Example of coastal defence structure along the Sakumono – Tema beach road in the Greater Accra Region of Ghana. *Photo credit: Richard Takyi.*

Table 3
Pressures generated from the human activities in coastal and marine environment of Ghana.

Pressure	Lagoons	Estuaries	Beaches	Marine
Selective extraction of living resources				
– *Fish species*	x			x
– *Mangroves*	x	x		
– *Turtles and crabs*	x	x	x	x
– *Dolphins and whales*				x
Selective extraction of non-living resources				
– *Salt*	x			x
– *Oil and gas*				x
– *Sand*	x		x	
Abrasion				
– *Physical and mechanical interaction*	x	x	x	x
Desiccation	x		x	
Smothering	x		x	x
Substratum loss	x		x	x
Introduction of materials and chemical compounds				
– *Inorganic*	x	x	x	x
– *Organic*	x	x	x	x
Underwater noise				x

Legend: x- present; List of pressure adapted from El Mahrad et al. (2020).

Additionally, leisure activities (e.g., walking, horse riding, and quad biking) on the sandy and rocky beaches by revellers and tourists constitute physical and mechanical pressure on sea turtles and shorebirds nesting on the sandy beaches and benthic species.

3.3.4. Desiccation, smothering and substratum loss

Desiccation, smothering (e.g., due to sediment influx and deposition), substratum loss (about 2 m/year along the coastline) and built-up (e.g., 0.05 km^2 along the Kokrobite-Bortianor coast) are pressures that emanate from human activities such as construction of infrastructure, mining and farming (Appeaning Addo et al., 2020; Atayi et al., 2022; Boafo et al., 2014; Ekumah et al., 2020). Increase in the rate of exposure to the sun and substratum loss to crabs (*Ocypode* spp.), and sea turtles (e.g., *L. olivacea, D. coriacea,* and *Chelonia mydas*) that use the littoral zone as habitats or nursery grounds attributed to coastal deforestation and sand mining activities constitute additional pressure (Agyekumhene et al., 2021; Jonah et al., 2015b; Tanner, 2013).

3.3.5. Underwater noise

Pressure from the underwater noise (i.e., localised noise) generated from shipping intensity of 1394–1593 vessels/year and construction of subsea infrastructure is also a source of pressure on marine organisms such as *Peponocephala electra* (GPHA, 2023; Ofori-Danson et al., 2022).

3.3.6. Introduction of chemical compounds and materials

There is pressure from the release of inorganic (e.g., macro- and microplastics, sediments, heavy metals) and organic compounds and materials into coastal and marine environments due to fishing and farming, mining, construction of infrastructure, shipping, leisure, and waste discharge activities (Badu et al., 2019; Takyi et al., 2022). For instance, the accumulation of litter on beaches and in coastal lagoons (at a rate of 0.028 items/m^2/month) and the monthly localised oil spill (at least 10 km^2 of the sea surface) in extraction areas constitute pressure (Marine and Coastal Resources (esa), 2021; Nukpezah et al., 2021; Van Dyck et al., 2016).

3.3.7. Exogenic pressures

There are exogenic pressures from the changes in thermal regime, sea level rise (i.e., about 0.3 cm/year in over 21 years and is projected to increase nationwide to 39 cm by 2080), and wave exposure due to climate change exacerbated by human activities such as coastal deforestation, mining (e.g., sand and oil and gas), and construction of energy infrastructure (Elliott et al., 2017; EPA, 2021; GoG, 2021; Ministry of Foreign Affairs, 2018).

3.4. State change

This relates to the change in the state of coastal and marine environments due to single or multiple pressures resulting from the myriad of human activities (Fig. 3)

3.4.1. Stock of flora and fauna

The stock of small pelagic fisheries, i.e., *Sardinella* sp., *Engraulis encrasicolus* and *Scomber colias*, has declined, with some demersal and pelagic species either endangered or critically endangered due to the pressure of selective extraction and the effect of climate change (EPA, 2021; Takyi et al., 2023). For instance, the biomass of seabreams and snappers has declined between 2016 and 2019 by over 1300 t and 420 tonnes, respectively, due to fishing activities and the pressure of selective extraction (MoFAD, 2022). Some fauna in coastal lagoons have been lost (e.g., *Lutjanus goreensis*, grey mullet, shrimp, and crabs in the Fosu Lagoon), become scarce (e.g., *Mugil cephalus* in the Mukwe and Keta lagoons), or has declined (e.g., important international waterbirds) due to the pressure of selective extraction (Takyi et al., 2022). The species richness, evenness, and diversity of benthic macroinvertebrates in some coastal lagoons such as the Keta Lagoon, have decreased by 2.4, 1.2, and 4.1, respectively, due to pressure generated by anthropogenic activities (Addo et al., 2014; Mahu et al., 2023).

Crab populations that characterised the coastline of Cape Coast have declined due to pressure from human activities (Aheto et al., 2011; Jonah et al., 2015b). The nursery activities of sea turtles, including *L. olivacea., D. coriacea,* and *C. mydas,* are declining at the rate of 60, 17, and 2 nests/year along the coast due to the pressures generated from sand mining, fishing, and hunting (poaching and egg collection) activities (Agyekumhene et al., 2021). The vegetation (e.g., coconut and thick trees) that characterised the coastline of Ghana have drastically reduced. The mangrove forest is declining at a rate of 8.1 km^2/year due to human activities and pressure from selective extraction (Anim et al., 2013; Johnson, 2020; Nunoo and Agyekumhene, 2022). Mangrove species such as the *Laguncularia* sp. are the most threatened species in coastal lagoons due to the pressure from mangrove harvesting (Ministry of Environment Science Technology and Innovation, 2016; Takyi et al., 2022).

Coastal wetlands and marine environments have been invaded by aquatic weeds and marine algae (e.g., *Enteromorpha flexuosa*), respectively, due to pressure from human activities and thermal regime change (Dzakpasu, 2019; EPA, 2021). The population of invasive species (e.g., *Viossa cusbidata, Salvinia molesta, Eichhornia crassipes, Pistia stratiotes*) is increasing along the western coast (EPA, 2021; Ministry of Environment Science Technology and Innovation, 2016).

3.4.2. Pollution of flora and fauna

The tissues of some aquatic organisms (*Crassostrea tulipa, S. maderensis* and *Ilisha africana*) have become polluted with microplastics fibre and pellets due to pressure generated by human activities such as waste disposal (Addo et al., 2022; Nuamah et al., 2023). Additionally, fish species, including *S. melanotheron*, have become polluted with heavy metal such as cadmium and arsenic (Takyi et al., 2022). There is bioaccumulation of manganese, molybdenum, zinc, and iron in marine microplankton and mesoplankton with potential for biomagnification along the food chain due to pressure from the release of chemical compounds and other materials (Chevrollier et al., 2022).

3.4.3. Habitats quality

The quality of coastal (e.g., Benya, Fosu, Korle, and Sakumo lagoons) and marine habitats have either declined or are declining due to pressures generated by several human activities (Amponsah et al., 2023; EPA, 2021). Coastal forests in wetlands, which serve as sanctuaries and breeding grounds, have become bare lands due to built-ups, waste disposal, and deforestation (e.g., about 13 % and 43 % of vegetation in Ankobra and Volta estuaries, respectively) (Kutir et al., 2022; Ministry of Environment Science Technology and Innovation, 2022). The carbon stock in trees and soil in the Kakum mangrove forest has declined by 0.9 and 2382 trees/ha, respectively (Adotey et al., 2022).

Some coastal lagoons (e.g., Benya, Korle, Mukwe, and Sakumo II) have become dissolved oxygen stressed, while others are severely stressed (e.g., Laloi Lagoon), and moderately polluted (e.g., Brenu Lagoon) with a dominance of stress-tolerant species (*Capitella capitata* and *Ampithoe* sp.), due to waste disposal and agricultural activities (Akwetey et al., 2021; Badu et al., 2019; Takyi et al., 2022). The nearshore waters at e.g., Sakumono, Korle Gonno and estuaries such as the Ankobra (pollution index of 1.9) and Pra (pollution index of 2.7 and turbidity >500 ppm) are polluted with high coliforms (*Escherichia coli*) and plastics due to the several human activities (Amponsah and Amarquaye, 2021; Faseyi et al., 2022; Okyere, 2019; Van Dyck et al., 2016). The water of coastal lagoons (e.g., Benya, Fosu, Narkwa, Korle, and Kpeshie) has acquired high faecal coliforms (*E. coli*) and heavy metal concentrations due to pressure generated by human activities such as waste discharge (Adinortey, 2014; Mensah, 2019; Takyi et al., 2022).

Additionally, the sediments of estuaries (e.g., Densu) and coastal lagoons (e.g., Korle and Kpeshie) have acquired high lead (Pb) concentrations (Akita et al., 2020; Clottey et al., 2022). Sediments of lagoons, including the Mukwe and Kpeshie lagoons, have become polluted with microplastics due to pressure from human activities such as waste disposal (Chico-Ortiz et al., 2020; Clottey et al., 2022). The concentrations of arsenic (As), nickel (Ni), and copper (Cu) in seawater along offshore oil and gas pipelines have exceeded recommended levels by NOAA, while the offshore sediments have high total petroleum hydrocarbon for the pipeline route (about 72 mg/kg) and drill-field (about 1165 mg/kg) due to pressure from oil and gas activities (Sackitey, 2019). Pressure from ports activities have resulted in widespread dichlorodiphenyltrichloroethane (DDT), hexachlorocyclohexane (HCH), and polycyclic aromatic hydrocarbons (PAHs) contamination in the sediments of Tema Harbour, with concentrations ranging between about 2.8 and 5130 μg/kg dry weight (Botwe et al., 2017).

Large, coarse, and fragile sediments, which are weakly bonded with poor water-holding capacities, characterise areas with beach sand mining activities along the coast (Jonah, 2015; Jonah and Adu-Boahen, 2014). These area also have large steep inclines, and exposed clayey or stony substratum that contribute to coastal erosion and make it difficult for nesting sea turtles to climb and access the beach (Jonah, 2015; Jonah and Adu-Boahen, 2014; Tanner, 2013).

The construction of infrastructure (e.g., dams and sea defence) and climate change have considerably reduced freshwater and seawater inflow as well as sediment supply from some areas, including the shoreline in Faana (Bortianor) and Tema, and into coastal wetlands such as the Keta and Sakumo II lagoons and other coastal areas, contributing to the increased rate of coastal erosion (Appeaning Addo et al., 2020; Issaka et al., 2019; Oteng-Ababio et al., 2011). Additionally, due to the construction of the sea defence, the sandy portion of the Elmina beach has become shorter and steeper, coupled with intensified erosion, decreased wave heights, and significant loss of sand (Angnuureng et al., 2022). The sea level along the coast of Ghana has risen by about 5.3 cm over the past 21 years due to pressure from climate change and human activities (GoG, 2021).

3.4.3.1. Primary production. Coastal upwelling is weakening, causing a decline in colder zooplankton species and an increase in warmer species. The biomass of the dominant zooplankton species, *Calanoides carinatus*, for instance, is declining, with a possible increase in the biomass of *Temora stylifera* and *Pennilia avirostris,* due to the effect of climate change (EPA, 2021). Some lagoons (e.g., Keta Lagoon) have become highly hypereutrophic, resulting in a significant loss of phytoplankton diversity in the last two decades, and lost about 11 genera due to pressure from human activities (Addo et al., 2014; Mahu et al., 2023).

3.4.4. Genetic resources

Genetic diversity is essential for the adaptation and resilience of coastal and marine organisms but can be affected by pressure from human activities and climate change (Rogers et al., 2021; Thompson et al., 2021). However, the State Change of genetic resources of coastal and marine organisms due to pressures from human activities and climate change is lacking as there is paucity of data.

Table 4
Examples of ecosystem services that have been impacted.

Provision services	Regulating services	Cultural services	Reference
Food (*fish*) Freshwater	Climate regulation Waste removal	Livelihood, and revenue (e.g., *fishers*) Aesthetics and recreational (e.g., coastline of Winneba and La, Korle Lagoon, etc) Security and safety	Adu-Gyamfi et al. (2020); Johnson (2020); EPA (2021); Ayilu et al. (2023)

3.5. Impact (on human welfare)

As evidenced by the impacts presented in Table 4. These alterations in the ecosystem's condition bear significant implications for the well-being of human populations, warranting meticulous examination and consideration in the context of sustainable resource management and decision-making (see Fig. 3 and Table 4).

3.5.1. Availability of fish as food and water

Considering the declining fish stocks in Ghana's coastal and marine environments, the country is grappling with inability to meet local demands for fish, necessitating the adoption of fish importation as a measure to enhance availability (Ashitey, 2019; Taylor, 2022). Moreover, certain coastal areas, specifically Keta and Winneba, have experienced a notable reduction in the supply and accessibility of freshwater for domestic and agricultural purposes, owing to coastal erosion and the intrusion of saltwater into the aquifers (Awo et al., 2017; Johnson, 2020).

3.5.2. Livelihood, and revenue

Some male fishers in coastal communities in the Central Region have to resorted to the diversification of livelihoods, such as masonry, commercial driving, and trading due to a decline in fish catch (Danquah et al., 2021). The development of new sea defence infrastructure in the Keta, Anloga, and Ada East Districts places significant constrain on the livelihood of fishers residing in these areas (Gbedemah, 2023). Additionally, coastal erosion has brought substantial hardships on households in Keta, particularly in terms of diminished land area, with severe implications for agriculture and commercial activities (Tornyeviadzi et al., 2023).

The revenue of artisanal fishers and coastal fishing communities has declined, with fishmongers in Bortianor losing about US$ 370 per month due to the decline in fish catch resulting from overfished stock (Ayilu et al., 2023; Sarpong, 2022). Artisanal fishers in the Western Region have also experienced income reduction from about US$ 854 to US$ 279 per annum due to the impact of oil production (Kophy, 2019).

3.5.3. Safety and loss of economic properties

Human activities such as sand mining have increased the frequency and scale of coastal erosion and flooding (e.g., at Fumeve, Agorkedzi, Ada, and Moree), increasing the vulnerability of such coastal communities Appeaning-Addo and Adeyemi, 2013; Gyekye, 2021; Ofori, 2021; Osman et al., 2016).

About 37 % of the eastern coastal land of Ghana has been lost between 2005 and 2017 due to the effect of tidal waves (Darko et al., 2022; Senanu, 2021). Rampant coastal flooding due to human activities and pressure from climate change is reported to have displaced about 4000 people in Keta and 1000 people in Nkontompo, destroyed properties, including 40 homes and 0.6 km^2 of land in Keta, and caused coastal erosion at Anlo Beach at Shama (Adu-Gyamfi et al., 2020; Ayisi, 2022; Olympio and Amos-Abanyie, 2014; Tornyeviadzi et al., 2023; Yarboi-Tetteh, 2023). Additionally, the reduction in sediment supply to the coast and saltwater intrusions have contributed to the loss of infrastructure such as coastal roads between Keta and Havedzi township and properties such as arable land and houses in Ningo-Prampram and Keta (Armah et al., 2004; Darko et al., 2022).

Some wide dunes and beaches (e.g., Cape Coast, Elmina, and Moree) that served as landing spaces for artisanal fishers have been lost and turned rocky, contributing to the relocation of some fishers from these communities (Jonah and Adu-Boahen, 2014; Yarboi-Tetteh, 2023).

3.5.4. Reduction and loss of aesthetic and recreational value

The aesthetic and recreational value of some wetlands (e.g., Fosu, Korle, Sakumo II lagoons), beaches, and nearshore waters have been reduced due to the construction of sea defence (e.g., in the Abakam, and Anloga and Ada East districts), waste disposal activities (Plate E),

Plate E. An example of devaluation of aesthetic and recreational value due to the use of the coastal beach as a waste dump site. *Photo credit: Richard Takyi.*

erosion (e.g., Winneba), the bad odour and invasion of seaweeds such as *Sargassum* spp. and *Ulva clathrate* (EPA, 2021; Gbeckor-Kove et al., 2021b; Gbedemah, 2023; Johnson, 2020).

3.6. Responses and management measures

Several management measures (see Fig. 3) to reduce anthropogenic impact on the ecosystem have been implemented or are ongoing by several sectors. These include but are not limited to the following:

3.6.1. Coastal and marine wildlife management

Fisheries management policies (e.g., closed seasons) and laws (e.g., prohibition on landing mammals and gravid fish) have also been instituted to manage and reduce the impact of fishing activities and associated pressures (MoFAD, 2020; Tetra Tech, 2022). Additionally, a new Wildlife Resource Management Bill 2022 that consolidates all laws relating to wildlife, with provision for the prohibition of the killing or hunting of all protected animals (e.g., *Cetacea* spp., manatees, and sea turtles) and harvesting their eggs, among others, has recently been passed by the Parliament of Ghana.

Traditional and cultural beliefs that prevents hunting of sea turtles (e.g., sea turtles as sacred animals in Ada, Akwidaa, and Winneba), closes fishing activities (e.g., no-fishing on Tuesdays) and restoration of mangroves to serve as a nursery for fish belonging to the “god” of the lagoon are also present (Alexander et al., 2017; Dosu, 2017; Sagoe et al., 2021).

3.6.2. Coastal wetlands and marine ecosystem management

Some six coastal wetlands, including Songhor, Sakumo II, Keta, and Muni-Pomadze lagoons, have been designated as Ramsar sites under the Ramsar Convention to ensure their ecological integrities are protected (Ramsar, 2015). Additionally, several national policies and actions on climate change (i.e., the Ghana National Adaptation and Mitigation Plan), coastal protection (i.e., investment in control structures) and proper siting of industries have been initiated (GoG, 2021; MoFAD, 2022). Laws and regulations on pollution, mining and fishing (i.e., the Fisheries Act 625 of 2002 and Regulations L.I. 1968 of 2010), and institutions (e.g., Environmental Protection Agency of Ghana) have been put in place to controlled and managed the pressure from human activities on coastal and marine environments (Charuka et al., 2023; MoFAD, 2022; Nyarko et al., 2014; Ocloo, 2016). There are also bylaws and actions of the 26 coastal local assemblies, which include environmental protection, shoreline management, prevention and mitigation of flood hazards, and conservation of significant wetland ecosystems (Accra Metropolitan Assembly, 2019; Kankam and Robadue, 2013).

3.6.3. Adaptation to coastal erosion and flooding

Coastal afforestation, through the replanting of degraded forest, including mangroves and coconut trees, has been initiated by the GoG and coastal communities (e.g., Prampram) with support from other stakeholders to reduce the effect of coastal erosion and flooding (Darko et al., 2022; Kemp, 2023). Local communities in the Keta, Anloga, and Ada East districts use adaptation strategies such as filling beaches with sand, building away from the seashore, and raising the foundation of buildings to combat coastal erosion and flooding (Gbedemah, 2023).

3.6.4. Clean up exercises

Periodic clean up exercises along beaches and in coastal wetlands by non-governmental and governmental organisations, coastal communities, and foreign volunteers has helped to rid the environment of plastics, and other solid wastes (Adam, 2021; Prah, 2022; UNDP Ghana, 2022).

4. Response (as management measures)

In addition to the existing management measures, the implementation of the following recommended responses to address the drivers, activities, pressures, and change in the state of the coastal and marine environments could be considered by managers, scientists, decision makers and other stakeholders.

4.1. Provision of supplementary livelihood

There is the need to intensify efforts at offering supplementary livelihoods and other opportunities to fishers, mangrove harvesters, sand miners, and hunters (poachers) of sea turtles and waterbirds to reduce the pressure from their activities. Needs assessment of the resource exploiters and the availability of a ready market for products should be the basis for supplementary livelihood to ensure the sustainability of the revenues and livelihoods as well as contribute to the reduction of poverty.

4.2. Protect threatened, vulnerable, and endangered species and habitats

The protection of vulnerable, threatened, and endangered species and habitats should be intensified through enforcement and co-management to ensure ownership. Protected areas should be designated to reduce pressure from human activities.

4.3. Improve sanitation management

The current sanitation measures around coastal and marine environments should be improved through the provision of efficient waste disposal and collection systems, enforcement of the polluter-pay bylaws and the practice of waste separation.

4.4. Green infrastructure construction

Coastal infrastructure and the services they provide significantly affect national economies and people’s quality of life (Quintero, 2015). It is essential to adopt green infrastructure construction within and around coastal and marine environments to protect biodiversity, reduce pressure, state change and impact on welfare.

4.5. Adopt marine spatial planning (MSPs)

It is essential to have an MSP operational framework that can help to maintain the value of biodiversity while allowing sustainable utilisation of the economic potential of the resources. The MSP should be climate-ready, innovative and ecosystem-based, aided by technology and artificial intelligence (The World Bank, 2021).

4.6. Adopt preventive measures to coastal disaster risk management

Institution of robust Early Warning Systems (EWS) coupled with indigenous knowledge would ensure resilience against potential disasters. The EWS adopted must be preventive and not reactive with the support of technology (e.g., artificial intelligence).

4.7. Research-led development and management

Scientific research that integrates and regards the coastal and marine environment as a socio-ecological system should lead the management measures to remove siloed thinking and implementation. It would contribute to addressing the myriad of stakeholders and sector issues and ensure integration for the sustainability of the resources.

5. Conclusion

The present study employs the DAPSI(*W*)R(M) framework to expose the drivers of human activities within the coastal and marine environment of Ghana, encompassing physiological needs (i.e., food, water, and shelter), safety, livelihoods, and esteem needs. These drivers encompass a wide range of human activities, including fishing, seawater treatment for domestic and commercial purposes, mangrove harvesting, waterbirds and sea turtles hunting, vegetables and crops farming, oil and gas mining and infrastructure construction, among others.

The impact of these human activities has led to the exacerbation of pressures, notably the selective extraction of fisheries resources, mangroves, beach sand, and oil and gas. The resulting consequences include abrasion, desiccation, smothering, and substratum loss, as well as the introduction of heavy metals and plastic materials, and the mounting pressure from climate change. As a consequence of these single and multiple pressures, adverse effects on coastal and marine ecosystems have been identified. These include declines in the small pelagic species and demersal biomass, degradation of wetland mangroves and contamination of sediments, water and aquatic organisms with plastics, high heavy metals, and faecal coliform. Moreover, sea level rise and the increasing incidence of erosion and flooding have impacted the Ghanaian coastal areas. The impact on ecosystem services due to the state change in the coastal and marine environment includes food (fish) availability because of the decline in fish catch, water (because of saltwater intrusion), and loss of revenue, infrastructure, and properties, among others. In response to the challenges, national policies, laws, and regulations, with bylaws and traditional rules for the management of fisheries, coastal wetlands and wildlife, and marine environment from fishing pressure and pollution, among others, have been initiated.

Despite these previous management efforts, the unsustainable practices and degradation of the coastal and marine environment persists. Thus, the study recommends implementing supplementary livelihood options based on comprehensive needs assessments of resource exploiters. Additionally, the adoption of co-management approaches, coupled with ownership incentives, is suggested for protecting sensitive habitats and threatened, vulnerable and endangered species. The integration of grey infrastructure solutions is also proposed as part of a multifaceted strategy to address the complex challenges facing the coastal and marine environment.

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

The authors are unable or have chosen not to specify which data has been used.

Acknowledgement

We are thankful to Blue Resources Research and Policy Institute for funding and logistic support.

References

Abalansa, S., El Mahrad, B., Icely, J., Newton, A., 2021. Electronic waste, an environmental problem exported to developing countries: the good, the bad and the ugly. Sustain 13, 1–24. https://doi.org/10.3390/su13095302.

Abelson, A., Reed, D.C., Edgar, G.J., Smith, C.S., Kendrick, G.A., Orth, R.J., Airoldi, L., Silliman, B., Beck, M.W., Krause, G., Shashar, N., Stambler, N., Nelson, P., 2020. Challenges for restoration of coastal marine ecosystems in the anthropocene. Front. Mar. Sci. 7, 1–14. https://doi.org/10.3389/fmars.2020.544105.

Accra Metropolitan Assembly, 2019. Local Government Bulletin. Ghana.

Adam, I., 2021. Tourists' perception of beach litter and willingness to participate in beach clean-up. Mar. Pollut. Bull. 170, 1–12. https://doi.org/10.1016/j.marpolbul.2021.112591.

Adams, M., 2021. The Governance Structure and its Impact on Port Performance: A Case of Port of Tema. World Maritime University, Ghana.

Addae, B., Oppelt, N., 2019. Land-use/land-cover change analysis and urban growth modelling in the Greater Accra Metropolitan Area (GAMA), Ghana. Urban Sci. 3, 1–20. https://doi.org/10.3390/urbansci3010026.

Addo, B., 2023. 2023 water week conference organised [WWW document]. URL http://mswr.gov.gh/2023-water-week-conference-organised/ (accessed 6.26.23).

Addo, C., Ofori-Danson, P.K., Mensah, A., Takyi, R., 2014. The fisheries and primary productivity of the Keta lagoon. World J. Biol. Res. 6, 15–27.

Addo, S., Boateng, C.M., Diyie, R.L., Duodu, C.P., Ferni, A.K., Williams, E.A., Amakye, A. O., Asamoah, O., Danso-Abbeam, H., Nyarko, E., 2022. Occurrence of microplastics in wild oysters (Crassostrea tulipa) from the Gulf of Guinea and their potential human exposure. Heliyon 8, 1–11. https://doi.org/10.1016/j.heliyon.2022.e12255.

Adinortey, C.A., 2014. Antibiotic Resistance, Phylogenetic Grouping and Virulence Potential of "*Escherichia coli*" Isolated from Clinical and Environmental Samples from the Cape Coast Metropolis of the Central Region of Ghana. University of Cape Coast.

Adjimah, A.J.D., Luki, B.N., 2017. Assessing the economic cost benefit analysis of fractionating raw condensate into specific products by the Atuabo gas processing plant, Ghana. J. Econ. Sustain. Dev. 8, 65–94.

Adotey, J., Acheampong, E., Aheto, D.W., Blay, J., 2022. Carbon stocks assessment in a disturbed and undisturbed mangrove forest in Ghana. Sustain 14, 1–14. https://doi.org/10.3390/su141912782.

Adu-Gyamfi, B., Shaw, R., Yan, W., 2020. Assessment of housing exposure to accelerated coastal erosion in Keta municipality of Ghana. Int. J. Disaster Risk Reduct. 44, 1–10. https://doi.org/10.1016/j.ijdrr.2019.101450.

Agyekumhene, A., Yankson, P., Stemle, L., Allman, P., 2021. Sea turtle nesting activity in Ghana, West Africa. Chelonian Conserv. Biol. 20, 273–280. https://doi.org/10.2744/CCB-1487.1.

Agyeman, N.K., 2022. Ningo-Prampram Sea defence project reaches 50% [WWW document]. URL https://www.graphic.com.gh/news/general-news/ningo-prampram-sea-defence-project-reaches-50.html (accessed 11.30.22).

Agyeman, N.A., Blanco-Fernandez, C., Steinhaussen, S.L., Garcia-Vazquez, E., Machado-Schiaffino, G., 2021. Illegal, unreported, and unregulated fisheries threatening shark conservation in african waters revealed from high levels of shark mislabelling in Ghana. Genes (Basel) 12, 1–12. https://doi.org/10.3390/genes12071002.

Aheto, D., Asare, C., Mensah, E., Aggrey-Fynn, J., 2011. Rapid assessment of anthropogenic impacts of exposed sandy beaches in Ghana using ghost crabs (Ocypode spp.) as ecological indicators. Momona Ethiop. J. Sci. 3, 93–103. https://doi.org/10.4314/mejs.v3i2.67715.

Ahmed, I., Ofori-Amanfo, D., Awuah, E., Cobbold, F., 2018. Performance assessment of the rehabilitated mudor sewage treatment plant at James Town Accra-Ghana. J. Water Resour. Prot. 10, 725–739. https://doi.org/10.4236/jwarp.2018.108041.

Akita, L.G., Laudien, J., Nyarko, E., 2020. Geochemical contamination in the Densu Estuary, Gulf of Guinea, Ghana. Environ. Sci. Pollut. 27, 42530–42555.

Akwetey, M.F.A., Abrokwah, S., Adade, R., Dali, G.L.A., Akuoko, I.S.G., 2021. Towards conservation of coastal wetlands: an assessment of the ecological health status of a neglected lagoon in Ghana. Nat. Sci. 19, 42–53.

Akwetteh, L.N., Xu, C., Putri, M.D.P.W., Okoe, L.N., 2021. The current railway development and its influencing factors in Ghana. Open J. Soc. Sci. 09, 228–244. https://doi.org/10.4236/jss.2021.93015.

Alexander, L.K., Agyekumhene, A., Allman, P., 2017. The role of taboos in the protection and recovery of sea turtles. Front. Mar. Sci. 4, 1–9. https://doi.org/10.3389/fmars.2017.00237.

Amponsah, S.K., Amarquaye, N.C., 2021. Species composition, abundance and diversity of beach seine catches at Sakumono landing beach, Ghana. Int. J. Fauna Biol. Stud. 8, 15–21. https://doi.org/10.22271/23940522.2021.v8.i1a.786.

Amponsah, S.K.K., Ackah, R., Amekor, W.D., Berchie, A., Apraku, A., 2023. Shark fishing in Ghana: what we ought to know. Sharks - Past, Present Futur. 11, 1–17. https://doi.org/10.5772/intechopen.109301.

Angnuureng, D., Appeaning Addo, K., 2013. Impact of sea defense structures on downdrift coasts: the case of Keta in Ghana. Acad. J. Environ. Sci. 1, 104–121. https://doi.org/10.15413/ajes.2013.0102.

Angnuureng, D.B., Amankona, G., Brempong, E.K., Attipoe, E., 2022. Short-term effect of sea defense on shoreline and wave variability in Elmina Bay, Ghana. J. Coast. Conserv. 26, 1–14. https://doi.org/10.1007/s11852-022-00906-y.

Anim, D.O., Nkrumah, P.N., David, N.M., 2013. A rapid overview of coastal erosion in Ghana. Int. J. Sci. Eng. Res. 4, 1–7.
Appeaning Addo, K., Brempong, E.K., Jayson-Quashigah, P.N., 2020. Assessment of the dynamics of the Volta river estuary shorelines in Ghana. Geoenvironmental Disasters 7, 1–11. https://doi.org/10.1186/s40677-020-00151-1.
Appeaning-Addo, K., Adeyemi, M., 2013. Assessing the impact of sea-level rise on a vulnerable coastal community in Accra, Ghana. Jamba J. Disaster Risk Stud. 5, 1–8. https://doi.org/10.4102/jamba.v5i1.60.
Armah, A.K., Amlalo, D.S., 1998. Coastal Zone Profile of Ghana. Gulf of Guinea Large Marine Ecosystem Project, Accra, Ghana.
Armah, A.K., Biney, C., Dahl, S.Ø., Povlsen, E., 2004. Environmental Sensitivity Map for Coastal Areas of Ghana. Accra, Ghana.
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, 1–25. https://doi.org/10.1016/j.isci.2023.106858.
Ashitey, E., 2019. Ghana: Fish and Seafood Report. Accra, Ghana.
Asiedu-Addo, S., 2021. Sea defence projects on course [WWW document]. URL. https://www.graphic.com.gh/news/general-news/ghana-news-sea-defence-projects-on-course.html.
Atayi, J., Twumasi, Y.A., Ning, Z.H., Asare-Ansah, A.B., 2022. A study on the shoreline changes and land use/land cover along the Keta coastal zone. Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. - ISPRS Arch. XLVI-M-2–2, 39–45. https://doi.org/10.5194/isprs-Archives-XLVI-M-2-2022-39-2022.
Atta-Quayson, A., 2018. Position Paper on Salt Sector in Ghana. Accra, Ghana.
Atubiga, J.A., Donkor, E., 2022. Diminishing lagoon services in the era of urbanization: a case of muni-Pomadze lagoon in Ghana. J. Soc. Sci. 18, 164–170. https://doi.org/10.3844/jssp.2022.164.170.
Awo, F.N., Gordon, C., Appeaning-Addo, K., 2017. Physico-chemical quality of groundwater in Keta south. Ghana. J. Heal. Environ. Res. 3, 51–56. https://doi.org/10.11648/j.jher.20170303.12.
Ayilu, R.K., Fabinyi, M., Barclay, K., Bawa, M.A., 2023. Blue economy: industrialisation and coastal fishing livelihoods in Ghana. Rev. Fish Biol. Fish. 1–18 https://doi.org/10.1007/s11160-022-09749-0.
Ayisi, E., 2022. As rising seas destroy Ghana's coastal communities, researchers warn against a seawall-only solution [WWW document]. In: URL. https://news.mongabay.com/2022/03/as-rising-seas-destroy-ghanas-coastal-communities-researchers-warn-against-a-seawall-only-solution/ (accessed 3.22.22).
Badu, B.E., Armah, A.K., Dankwa, H.R., 2019. Fish as bioindicators of habitat degradation in coastal lagoons of Ghana. Bonorowo Wetl. 9, 9–26. https://doi.org/10.13057/bonorowo/w90102.
Bell, C., Huggins, J., Benson, J., Joubert, L., Okafor-Yarwood, I., 2021. Pirates of the Gulf of Guinea: A Cost Analysis for Coastal States.
Boafo, Y.A., Asiedu, A.B., Addo, K.A., 2014. Assessing landcover changes from coastal tourism development in Ghana: evidence from the Kokrobite-Bortianor. Assess. Landcover Chang. From coast. Tour. Dev. Ghana 6, 9–20.
de Boer, M.N., Saulino, J.T., Van Waerebeek, K., Aarts, G., 2016. Under pressure: cetaceans and fisheries co-occurrence off the coasts of Ghana and Côte d'Ivoire (gulf of Guinea). Front. Mar. Sci. 3, 1–19. https://doi.org/10.3389/fmars.2016.00178.
Botwe, B.O., Kelderman, P., Nyarko, E., Lens, P.N.L., 2017. Assessment of DDT, HCH and PAH contamination and associated ecotoxicological risks in surface sediments of coastal Tema harbour (Ghana). Mar. Pollut. Bull. 115, 480–488. https://doi.org/10.1016/j.marpolbul.2016.11.054.
Bowen, R.E., Frankic, A., Davis, M.E., 2006. Human development and resources use in the coastal zone: influences on human health. Oceanography 19, 62–71.
Boye, C.B., Addo, K.A., Wiafe, G., Dzigbodi-Adjimah, K., 2018. Spatio-temporal analyses of shoreline change in the Western region of Ghana. J. Coast. Conserv. 22, 769–776. https://doi.org/10.1007/s11852-018-0607-z.
Charuka, B., Angnuureng, D.B., Agblorti, S.K.M., 2023. Mapping and assessment of coastal infrastructure for adaptation to coastal erosion along the coast of Ghana. Anthr. Coasts 6, 1–16. https://doi.org/10.1007/s44218-023-00026-6.
Chatting, M., Al-Maslamani, I., Walton, M., Skov, M.W., Kennedy, H., Husrevoglu, Y.S., Le Vay, L., 2022. Future mangrove carbon storage under climate change and deforestation. Front. Mar. Sci. 9, 1–14. https://doi.org/10.3389/fmars.2022.781876.
Chevrollier, L.A., Koski, M., Søndergaard, J., Trapp, S., Aheto, D.W., Darpaah, G., Nielsen, T.G., 2022. Bioaccumulation of metals in the planktonic food web in the Gulf of Guinea. Mar. Pollut. Bull. 179, 1–10. https://doi.org/10.1016/j.marpolbul.2022.113662.
Chico-Ortiz, N., Mahu, E., Crane, R., Gordon, C., Marchant, R.A., 2020. Microplastics in Ghanaian coastal lagoon sediments: their occurrence and spatial distribution. Reg. Stud. Mar. Sci. 40, 1–7. https://doi.org/10.1016/j.rsma.2020.101509.
Clark, G.F., Johnston, E.L., 2016. Australia State of the Environment Report: Coasts. Canberra, Australia.
Clottey, C.A., Nukpezah, D., Koranteng, S.S., Darko, D.A., 2022. Assessment of physicochemical parameters and heavy metals contamination in Korle and Kpeshie lagoons. Ghana. Indo Pacific J. Ocean Life 6, 36–50. https://doi.org/10.13057/oceanlife/o060105.
Dali, G.L.A., Aheto, D.W., Blay, J., 2023. Mangrove resource utilization and impacts in the Pra and Kakum estuaries of Ghana. Reg. Stud. Mar. Sci. 63, 1–12. https://doi.org/10.1016/j.rsma.2023.103035.
Danquah, J.A., Roberts, C.O., Appiah, M., 2021. Effects of decline in fish landings on the livelihoods of coastal communities in central region of Ghana. Coast. Manag. 49, 617–635. https://doi.org/10.1080/08920753.2021.1967562.
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.
Dosu, G., 2017. Perceptions of socio-cultural beliefs and Taboos among the Ghanaian Fishers and Fisheries Authorities: A Case Study of the Jamestown Fishing Community in the Greater Accra. The Arctic University of Norway, Region of Ghana.
Dzakpasu, M.F.A., 2019. Ecological assessment of some coastal lagoons and extuaries in Ghana: Abiotic and biotic approaches. University of Cape Coast.
Dzita Turtle Protection, 2021. – Protecting egg-laying turtles in Ghana [WWW Document]. URL https://ghanaturtles.com/ (accessed 5.20.23).
Ekumah, B., Armah, F.A., Afrifa, E.K.A., Aheto, D.W., Odoi, J.O., Afitiri, A.R., 2020. Geospatial assessment of ecosystem health of coastal urban wetlands in Ghana. Ocean Coast. Manag. 193, 105226 https://doi.org/10.1016/j.ocecoaman.2020.105226.
El Mahrad, B., Abalansa, S., Newton, A., Icely, J.D., Snoussi, M., Kacimi, I., 2020. Social-environmental analysis for the management of coastal lagoons in North Africa. Front. Environ. Sci. 8, 1–17. https://doi.org/10.3389/fenvs.2020.00037.
Elliott, M., Burdon, D., Atkins, J.P., Borja, A., Cormier, R., de Jonge, V.N., Turner, R.K., 2017. "And DPSIR begat DAPSI(W)R(M)!" - a unifying framework for marine environmental management. Mar. Pollut. Bull. 118, 27–40. https://doi.org/10.1016/j.marpolbul.2017.03.049.
Environmental Protection Agency of Ghana, 2020. National Compedium of Environment Statistics, 2019 (Accra).
EPA, 2021. State of the Marine Environment Report for Ahanta West, Ellembelle. Jomoro and Nzema East districts in the Western Region of Ghana, Accra, Ghana.
FAO, 2022. The state of world fisheries and aquaculture 2022, in brief to the state of world fisheries and aquaculture 2022. Rome. https://doi.org/10.4060/cc0463en.
Faseyi, C.A., Miyittah, M.K., Yafetto, L., Sowunmi, A.A., Lutterodt, G., 2022. Pollution fingerprinting of two southwestern estuaries in Ghana. Heliyon 8, 1–9. https://doi.org/10.1016/j.heliyon.2022.e10337.
Gari, S.R., Newton, A., Icely, J.D., 2015. A review of the application and evolution of the DPSIR framework with an emphasis on coastal social-ecological systems. Ocean Coast. Manag. 103, 63–77. https://doi.org/10.1016/j.ocecoaman.2014.11.013.
Gbeckor-Kove, P.D., Badu-Yeboah, K., Kudjawu, J., Agyekumhene, A., Agbogah, K., Opoku-Mensah, K., Jayson-Quashigah, P.-N., Annang, T.Y., Gbekor, M., Diawuoh, G., 2021a. Coastal erosion in a Changing Climate. Accra, Ghana.
Gbeckor-Kove, P.D., Badu-Yeboah, K., Kudjawu, J., Agyekumhene, A., Agbogah, K., Opoku-Mensah, K., Jayson-Quashigah, P.-N., Annang, T.Y., Gbekor, M., Diawuoh, G., 2021b. Biodiversity Conservation in Ghana's Western Coastal Zone. Accra, Ghana.
Gbedemah, S.F., 2023. Eruditing from indigenous adaptation strategies for resilient and sustainable coastal erosion management in southeastern Ghana. Discov. Sustain. 4, 1–19. https://doi.org/10.1007/s43621-023-00123-z.
Ghana Business News, 2019. GPHA to dredge heavily polluted Chemu lagoon at cost of over GH¢7.5m [WWW Document]. URL https://www.ghanabusinessnews.com/2019/12/06/gpha-to-dredge-heavily-polluted-chemu-lagoon-at-cost-of-over-gh¢7-5m/ (accessed 7.12.23).
Ghana Export Promotion Authority, 2022a. Highlights of 2021 Non-traditional Export Performance. Accra, Ghana.
Ghana Export Promotion Authority, 2022b. Analysis of 2021 Non-traditional Export Statistics (Accra).
Ghana Investment Promotion Council, 2022. Ghana's Recreation and Tourism Sector Report.
Ghana National Gas Company, 2022. PURC tarrif proposal.
Ghana News Agency, 2023. Sustaining increase oil production in Ghana through consistent investment and policy [WWW document].
Ghana Statistical Service, 2013. Regional Analytical Report - Central Region, 2010 Population and Housing Census. Accra, Ghana.
Ghana Statistical Service, 2019. Ghana Living Standards Survey Round 7 (GLSS7): Main Report. Accra.
Ghana Statistical Service, 2022. Ghana Annual Household Income and Expenditure Survey, Highlights: 2022 First and Second Quarters Report on Food Insecurity. Multidimensional Poverty and Labour Statistics, Accra, Ghana.
Ghana Water Company Limited, 2019. Teshie-Nungua desalination project [WWW Document]. URL https://www.gwcl.com.gh/projects/teshie-nungua-desalination-project/ (accessed 11.21.22).
GoG, 2021. Ghana's Adaptation Communication to the United Nations Framework Convention on Climate. Accra, Ghana.
GPHA, 2021. Tema and Takoradi Port Statistics. Accra, Ghana.
GPHA, 2023. Tema and Takoradi Port Statistics. Accra, Ghana.
Graphic.com.gh, 2019. Akufo-Addo Cuts Sod for Shoreline Military Base to Secure Oil and Gas Installations [WWW Document]. URL. https://www.graphic.com.gh/news/general-news/akufo-addo-cuts-sod-for-shoreline-military-base-to-secure-oil-and-gas-installations.html.
Greater Accra Regional Co-ordinating Council, 2016. About GAR [WWW Document]. URL https://www.gtarcc.gov.gh/index.php/about-gar/#:~:text=It has a coastline of,to Ada in the east.
Gyan, W.R., Alhassan, E.H., Asase, A., Akongyuure, D.N., Qi-Hui, Y., 2020. Assessment of postharvest fish losses: the case study of Albert Bosomtwi-Sam fishing harbour, Western region. Ghana. Mar. Policy 120, 1–7. https://doi.org/10.1016/j.marpol.2020.104120.
Gyekye, J., 2021. W/R: Tidal waves wreck havoc at Anlo Beach at Shama, hundreds displaced [WWW document]. In: URL. https://www.gbcghanaonline.com/general/w-r-tidal-waves-wreck-havoc-at-anlo-beach-at-shama-hundreds-displaced/2021/ (accessed 5.20.23).

Hofmann, B., 2022. Mainstreaming earth system governance into the UN decade of ocean science for sustainable development. Earth Syst. Gov. 12, 1–6. https://doi.org/10.1016/j.esg.2022.100139.
Issaka, H., Makinde, O.D., Theuri, D.M., 2019. Dynamics of the interaction of species in the Keta-Anlo wetland ecosystem of Ghana. Glob. J. Pure Appl. Math. 15, 803–827.
Johnson, A., 2020. Assessing the Impacts of Climate Change of Coastal Winneba. Universidade do Porto, Ghana.
Jonah, F.E., 2015. The state of Ghana's coasts: human impacts, management and way forward. Doi:10.13140/RG.2.2.36600.65280.
Jonah, F.E., Adu-Boahen, K., 2014. Coastal environmental injustice in Ghana: the activities of coastal sediment miners in the Elmina, Cape Coast and Moree area. GeoJournal 81, 185–196. https://doi.org/10.1007/s10708-014-9612-4.
Jonah, F.E., Adjei-Boateng, D., Agbo, N.W., Mensah, E.A., Edziyie, R.E., 2015a. Assessment of sand and stone mining along the coastline of Cape Coast. Ghana. Ann. GIS 21, 223–231. https://doi.org/10.1080/19475683.2015.1007894.
Jonah, F.E., Agbo, N.W., Agbeti, W., Adjei-Boateng, D., Shimba, M.J., 2015b. The ecological effects of beach sand mining in Ghana using ghost crabs (ocypode species) as biological indicators. Ocean Coast. Manag. 112, 18–24. https://doi.org/10.1016/j.ocecoaman.2015.05.001.
Kankam, S., Robadue, D., 2013. Model bye-laws for coastal management in Ghana: Experiences from Shama District, Western region. In: Integrated Coastal and Fisheries Governance Initiative (ICFG) for the Western Region of Ghana. Narragansett.
Kastning, T., 2011. Basic Overview of Ghana's Emerging Oil Industry. Accra, Ghana.
Kemp, Y., 2023. Ghana to grow mangroves to revive fish stocks, increase carbon storage [WWW Document]. URL https://www.esi-africa.com/west-africa/ghana-to-grow-mangroves-to-revive-fish-stocks-increase-carbon-storage/#:~:text=Ghana to grow mangroves to revive fish stocks%2C increase carbon storage&text=Ghana is to plant 3%2C000,for the next 20 years. (accessed 7.15.23).
Kophy, I.Y., 2019. Ghana's Oil Industry: The Livelihood Implications for Fishing Communities in the Western Region. University of Development Studies.
Koranteng, K.A., 2022. Time to block all revenue leakages at Tema ports [WWW document]. In: URL. https://newsghana.com.gh/time-to-block-all-revenue-leakages-at-tema-ports-kwabena-adu-koranteng-writes/ (accessed 11.18.22).
Kortei, N.K., Quansah, L., 2016. Ghana news: plastic waste management in Ghana - a complete failure and the consequences. GraphicOnline 4.
Kutir, C., Agblorti, S.K.M., Campion, B.B., 2022. Migration and estuarine land use/land cover (LULC) change along Ghana's coast. Reg. Stud. Mar. Sci. 54, 1–11. https://doi.org/10.1016/j.rsma.2022.102488.
Lazar, N., Yankson, K., Blay, J., Ofori-Danson, P., Markwei, P., Agbogah, K., Bannerman, P., Sotor, M., Yamoah, K., Bilisini, W., 2020. Status of the Small Pelagic Stocks in Ghana in 2019. Scientific and Technical Working Group, USAID/Ghana Sustainable Fisheries Management Project (SFMP).
Löf, A., Ericsson, M., Löf, O., 2022. Marine mining and its potential implications for low- and middle-income countries. Helsinki. https://doi.org/10.35188/UNU-WIDER/2022/303-1.
Mahu, E., Danso, P., Edusei, M.O., DeGraft-Johnson, K.A.A., 2023. Impact of agricultural practices on ecosystem health of lagoons: a case study of the Keta lagoon complex in Ghana, West Africa. Environ. Monit. Assess. 195, 1–15. https://doi.org/10.1007/s10661-023-11253-2.
Marine and Coastal Resources (esa), 2021. Large oil spills detected every month in Ghana's coastal waters [WWW Document]. URL https://eo4sd-marine.eu/news/large-oil-spills-detected-every-month-ghana's-coastal-waters (accessed 5.26.23).
Masud, M.M., Shahabudin, M.S., Baskaran, A., Akhtar, R., 2022. Co-management approach to sustainable management of marine protected areas: the case of Malaysia. Mar. Policy 138, 1–11. https://doi.org/10.1016/j.marpol.2022.105010.
Maya, W., 2020. West Africa's Biggest Shrimp Farm (2000 Acres) in Ghana.
Mensah, J., 2019. Managing environmental sanitation in the catchment area of Benya lagoon, Ghana: education, regulation or infrastructure management as a matter of strategic priority? Cogent Soc. Sci. 5, 1–16. https://doi.org/10.1080/23311886.2019.1709347.
Mensah, E.F., 2021. Agavedzi small scale salt miners call on gov't for support [WWW document]. In: URL. https://www.gbcghanaonline.com/news/business/agavedzi-small-scale-salt-miners-call-on-govt-for-support/2021/?fbclid=IwAR15EHQJnBfXtmYbVY-d5g0t1wXFrc46RfMz936UyAJFwFEBC-Mu1KYWobA (accessed 11.24.22).
Ministry of Environment Science Technology and Innovation, 2016. National Biodiversity Strategy and Action Plan. Accra, Ghana.
Ministry of Environment Science Technology and Innovation, 2022. Environmental and and Social Management Framework. West Africa Coastal Areas Resilience Investment Project II, Accra, Ghana.
Ministry of Foreign Affairs, 2018. Climate Change Profile: Ghana. Accra, Ghana.
Ministry of Tourism Arts and Culture, 2020. Tourism Report 2020. Accra, Ghana.
MoF, 2018a. The Budget Statement and Economic Policy of the Government of Ghana for the 2019 Financial Year. Accra, Ghana.
MoF, 2018b. 2013 Reconciliation Report on the Petroleum Holding Fund. Accra, Ghana.
MoF, 2019. The Budget Statement and Economic Policy for 2020 Financial Year. Accra, Ghana.
MoF, 2020. The Budget Statement and Economic Policy of the Government of Ghana for the 2021 Financial Year. Accra, Ghana.
MoF, 2021a. The Budget Statement and Economic Policy of the Government of Ghana for the 2022 Financial Year. Accra, Ghana.
MoF, 2021b. Annual Report on the Petroleum Funds for 2021, Presented to Parliament on 17th November, 2021. Accra, Ghana.
MoFA, GSS, FAO, WFP, 2020. Comprehensive Food Security and Vulnerability Analysis (CFSVA) Ghana. Accra, Ghana.
MoFAD, 2019. Fish production [WWW Document]. URL https://www.mofad.gov.gh/publications/statistics-and-reports/fish-production/ (accessed 12.5.19).
MoFAD, 2020. Co-Management Policy for the Fisheries Sector. Accra, Ghana.
MoFAD, 2021. Medium term expenditure framework for 2022-2025. Accra, Ghana. https://doi.org/10.1057/978-1-349-96042-2_5436.
MoFAD, 2022. Fisheries Management Plan of Ghana: A National Policy for the Management of the Marine Fisheries Sector 2022–2026. Accra, Ghana.
Ngnenbe, T., 2020. GWCL asks Teshie desalination plant to operate at full capacity [WWW document]. In: URL. https://www.graphic.com.gh/news/general-news/ghana-news-gwcl-asks-teshie-desalination-plant-to-operate-at-full-capacity.html (accessed 11.21.22).
Nicholls, R., Hanson, S., 2007. Climate change could triple population at risk from coastal flooding by 2070, finds OECD [WWW document]. In: URL. https://www.oecd.org/newsroom/climatechangecouldtriplepopulationatriskfromcoastalfloodingby2070findsoecd.htm (accessed 3.21.22).
Nkansah-Poku, J., Philippe, R., Quaicoe, R.N., Dery, S.K., Ransford, A., 2009. Cape Saint Paul Wilt disease of coconut in Ghana: surveillance and management of disease spread. OCL - Ol. Corps Gras Lipides 16, 111–115. https://doi.org/10.1684/ocl.2009.0247.
Northrop, E., Schuchmann, P., Burke, L., Fysll, A., Alvarez, S., Spenceley, A., Becken, S., Kato, K., Roy, J., Some, S., Veitayaki, J., Markandya, A., Galarraga, I., Greno, P., Ruiz-Gauna, I., Curnock, M., Wood, M.E., Yin, M.Y., Riedmiller, S., Carter, E., Haryanto, R., Holloway, E., Croes, R., Ridderstaat, J., Godovykh, M., 2022. Opportunities for Transforming Coastal and Marine Tourism - Towards Sustainability, Regeneration and Resilience. Washington DC.
Nuamah, F., Tulashie, S.K., Debrah, J.S., Pèlèbè, R.O.E., 2023. Microplastics in the Gulf of Guinea: an analysis of concentrations and distribution in sediments, gills, and guts of fish collected off the coast of Ghana. Environ. Res. 1–36 https://doi.org/10.1016/j.msec.2022.112712.
Nukpezah, D., Quarshie, J.T., Nyarko, E., Hogarh, J.N., 2021. Characterisation of litter and their deposition at the banks of coastal lagoons in Ghana. Heliyon 1–19. https://doi.org/10.2139/ssrn.3865493.
Nunoo, F.K.E., Agyekumhene, A., 2022. Mangrove degradation and management practices along the coast of Ghana. Agric. Sci. 1057–1079 https://doi.org/10.4236/as.2022.1310065.
Nunoo, F.K.E., Asiedu, B., 2013. An investigation of fish catch data and its implications for management of small-scale fisheries of Ghana. Int. J. Fish. Aquat. Sci. 2, 46–57.
Nunoo, F.K.E., Azumah, D.Y.M., 2015. Selectivity studies on beach seine deployed in nearshore waters near Accra. Ghana. Int. J. Fish. Aquac. 7, 111–126. https://doi.org/10.5897/ijfa14.0458.
Nunoo, F.K.E., Asiedu, B., Amador, K., Belhabib, D., Pauly, D., 2014. Reconstruction of Marine Fisheries Catches for Ghana, 1950–2010, Working Paper Series. Vancouver.
Nyarko, E., Nkrumah, J., Owusu-Mensah, B., 2014. National Ballast Water Management Strategy.
Ocloo, D.R., 2016. GPHA to fine shipping company for polluting Tema harbour [WWW document]. In: URL. https://www.graphic.com.gh/news/general-news/gpha-to-fine-shipping-company-for-polluting-tema-harbour.html (accessed 5.25.23).
Ocloo, D.R., 2022a. Seal revenue leakages at Tema port - Ofori-Atta charges GRA [WWW document]. In: URL. https://www.graphic.com.gh/business/business-news/seal-revenue-leakages-at-tema-port-ofori-atta-charges-gra.html (accessed 11.17.22).
Ocloo, D.R., 2022b. Ghana navy holds maritime counter-terrorism simulation exercise [WWW document]. In: URL. https://www.graphic.com.gh/news/general-news/ghana-navy-holds-maritime-counter-terrorism-simulation-exercise.html (accessed 6.27.23).
OECD, 2022. OECD Work in Support of a Sustainable Ocean.
Ofori, F.N.K., 2021. The socio-economic challenges and opportunities of Ghana's coastal communities: the cases of Ada and Keta. London. https://doi.org/10.1080/13673882.2021.00001101.
Ofori-Atta, K., 2023. The Budget Statement and Economic Policy of Ghana for the 2023 Financial Year, Restoring and Sustaining Macroeconomic Stability and Resilience for Inclusive Growth & Value Addition. Accra, Ghana.
Ofori-Danson, P.K., Appeaning Addo, K., Sackey, A.D., 2022. On the mass stranding event of of melon-headed whales, Peponocephala electra, in April 2021 at Axim, Ghana: possible causes and data needs. Medicon 1, 13–19.
Okyere, I., 2019. Implications of the deteriorating environmental conditions of river Pra estuary (Ghana) for marine fish stocks. J. Fish. Coast. Manag. 1, 15–19. https://doi.org/10.5455/jfcom.20190315062201.
Olympio, G., Amos-Abanyie, S., 2014. Effects of shoreline erosion on infrastructure development along the coastal belt of Ghana: case of Nkontompo community. J. Sci. Technol. 33, 39–50. https://doi.org/10.4314/just.v33i3.5.
Osman, A., Nyarko, B.K., Mariwah, S., 2016. Vulnerability and risk levels of communities within Ankobra estuary of Ghana. Int. J. Disaster Risk Reduct. 133–144.
Oteng-Ababio, M., Owusu, K., Addo, K.A., 2011. The vulnerable state of the Ghana coast: the case of Faana-Bortianor. Jàmbá J. Disaster Risk Stud. 3, 429–442. https://doi.org/10.4102/jamba.v3i2.40.
Pichon, E., Pietsch, M., 2020. Piracy in the Gulf of Guinea EU and International Action, Briefing.
Prah, C., 2022. UN Ghana cleans Ussher fort beach [WWW document]. In: URL. https://ghana.un.org/en/188050-un-ghana-cleans-ussher-fort-beach (accessed 7.15.23).
Quimbayo, J.P., Silva, F.C., Barreto, C.R., Pavone, C.B., Lefcheck, J.S., Leite, K., Figueiroa, A.C., Correia, E.C., Flores, A.A.V.V., 2022. The COVID-19 pandemic has altered illegal fishing activities inside and outside a marine protected area. Curr. Biol. 32, R765–R766. https://doi.org/10.1016/j.cub.2022.06.030.
Quintero, J.D., 2015. A Guide to Good Practices for Environmentally Friendly Roads.
Rabone, M., Harden-Davies, H., Collins, J.E., Zajderman, S., Appeltans, W., Droege, G., Brandt, A., Pardo-Lopez, L., Dahlgren, T.G., Glover, A.G., Horton, T., 2019. Access to

marine genetic resources (MGR): raising awareness of best-practice through a new agreement for biodiversity beyond national jurisdiction (BBNJ). Front. Mar. Sci. 6, 1–22. https://doi.org/10.3389/fmars.2019.00520.
Ramsar, 2015. Ghana: Keta Lagoon Complex Ramsar Site. Ramsar Inf. Sheet 23.
Rogers, A.D., Baco, A., Escobar-Briones, E., Gjerde, K., Gobin, J., Jaspars, M., Levin, L., Linse, K., Rabone, M., Ramirez-Llodra, E., Sellanes, J., Shank, T.M., Sink, K., Snelgrove, P.V.R., Taylor, M.L., Wagner, D., Harden-Davies, H., 2021. Marine genetic resources in areas beyond national jurisdiction: promoting marine scientific research and enabling equitable benefit sharing. Front. Mar. Sci. 8, 1–22. https://doi.org/10.3389/fmars.2021.667274.
Roy, P., Rao, I.N., Martha, T.R., Kumar, K.V., 2022. Discharge water temperature assessment of thermal power plant using remote sensing techniques. Energy Geosci. 3, 172–181.
RSIM Directorate, 2022. 2021 Statistical Report. Accra, Ghana.
Sackitey, B.K., 2019. Baseline Environmental Quality Assessment of Offshore Cape Three Point. Kwame Nkrumah University of Science and Technology, Ghana.
Sagoe, A.A., Aheto, D.W., Okyere, I., Adade, R., Odoi, J., 2021. Community participation in assessment of fisheries related ecosystem services towards the establishment of marine protected area in the greater cape three points area in Ghana. Mar. Policy 124, 1–12. https://doi.org/10.1016/j.marpol.2020.104336.
Salifu, L.Y., 2019. Greater Accra Resilient Integrated Development Project, Draft Final Report: Environmental and Social Audit of Kpone Landfill. Accra, Ghana.
Sarpong, G., 2022. How fishers & fishmongers are battling for survival on the frontier of climate change in Ghana [WWW document]. In: URL. https://www.modernghana.com/news/1172644/how-fishers-fishmongers-are-battling-for-surviva.html (accessed 7.15.23).
Schratzberger, M., Neville, S., Painting, S., Weston, K., Paltriguera, L., Broderick, A.C., Gray, T., 2019. Ecological and socio-economic effects of highly protected marine areas (HPMAs) in temperate waters. Front. Mar. Sci. 6, 1–7. https://doi.org/10.3389/fmars.2019.00749.
Schumm, R., Rochette, J., Rankovic, A., 2021. Giving Greater Attention to the Ocean in the Development and Implementation of the Post-2020 Global Biodiversity Framework. Paris.
Seidu, I., Brobbey, L.K., Danquah, E., Oppong, S.K., van Beuningen, D., Seidu, M., Dulvy, N.K., 2022. Fishing for survival: importance of shark fisheries for the livelihoods of coastal communities in Western Ghana. Fish. Res. 246, 1–15. https://doi.org/10.1016/j.fishres.2021.106157.
Sekey, W., Obirikorang, K.A., Alimo, T.A., Soku, M., Acquah, B., Gyampoh, B.A., Adjei-Boateng, D., Asare-Ansah, O., Ashiagbor, G., Kassah, J.E., 2022. Evaluation of the shark fisheries along the coastline of Ghana, West Africa. Reg. Stud. Mar. Sci. 53, 1–12. https://doi.org/10.1016/j.rsma.2022.102434.
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, 143–157. https://doi.org/10.1007/s11273-022-09906-z.
Senanu, T., 2021. Ghana's coastal communities threatened by erosion, sand harvesting [WWW document]. In: URL. https://www.voanews.com/a/ghana-s-coastal-communities-threatened-by-erosion-sand-harvesting-/6374516.html (accessed 5.20.23).
Skaten, M., 2018. Ghana's Oil Industry: Steady Growth in a Challenging Environment. Oxford Institute for Energy Studies, Oxford. https://doi.org/10.26889/9781784671044.
Takyi, R., Hassan, R., El Mahrad, B., Adade, R., 2021. Socio-ecological analysis of artisanal gold mining in West Africa: a case study of Ghana. J. Sustain. Min. 20, 206–219.
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, 1–15. https://doi.org/10.1016/j.scitotenv.2022.156234.
Takyi, R., Addo, C., El Mahrad, B., Adade, R., ElHadary, M., Nunoo, F.K.E., Essandoh, J., Chuku, E.O., Iriarte-Ahon, F., 2023. Marine fisheries management in the eastern Central Atlantic Ocean. Ocean Coast. Manag. 244, 1–16. https://doi.org/10.1016/j.ocecoaman.2023.106784.
Tanner, C., 2013. Sea turtle conservation in Ghana's Western region: the bigger picture. Mar. Turt. Newsl. 9–12.
Taylor, J., 2022. Ghana Seafood Report. Accra, Ghana.
Tech, Tetra, 2022. Feed the future Ghana fisheries recovery activity, Fisheries Co-Management Training Report June 2022.
Teye, C., Nunoo, F.K.E., Ofori-Danson, P.K., 2020. An assessment of observer deployment on industrial trawlers in Ghana. Reg. Stud. Mar. Sci. 39, 1–7. https://doi.org/10.1016/j.rsma.2020.101474.
The Business & Financial Times, 2022. MIIF eyes multi-billion dollar salt industry [WWW Document]. URL. https://thebftonline.com/2022/08/03/miif-eyes-multi-billion-dollar-salt-industry/ (accessed 11.18.22).
The World Bank, 2021. Improved Resilience of Coastal Communities in Côte d'Ivoire and Ghana.
Thompson, C.E.P., Pelletier, T.A., Carstens, B.C., 2021. Genetic diversity of north American vertebrates in protected areas. Biol. J. Linn. Soc. 132, 388–399. https://doi.org/10.1093/biolinnean/blaa195.
Tornyeviadzi, P., Amoako, C., Adarkwa, K.K., 2023. Living on the edge: coastal erosion and landlessness in Keta, Ghana. SSRN Electron. J. 1–39. https://doi.org/10.2139/ssrn.4451231.
Trouillet, B., Jay, S., 2021. The complex relationships between marine protected areas and marine spatial planning: towards an analytical framework. Mar. Policy 127, 1–11. https://doi.org/10.1016/j.marpol.2021.104441.
UN, 2017. People and ocean, marine pollution,biodiversity,climate change. In: The Ocean Conference, 5–9 June 2017. New York, p. 7.
UNCTAD, 2022. Review of Maritime Transport 2022 - Navigating Stormy Waters. New York.
UNDP Ghana, 2022. Plastic Punch, UNDP, and EU collaborate to mark 2022 World Ocean Day in Accra – urging citizens to take action to save the oceans from plastic pollution [WWW Document]. URL https://www.undp.org/ghana/press-releases/plastic-punch-undp-and-eu-collaborate-mark-2022-world-ocean-day-accra-—-urging-citizens-take-action-save-oceans-plastic (accessed 7.17.23).
UNESCO, 2020. International Policy Frameworks, World Water Development Report 2020.
UNESCO-IOC, 2021. The United Nations decade of ocean science for sustainable development (2021−2030) implementation plan. Paris. https://doi.org/10.1201/b19263-17.
United Nations, 2017. The Conservation and Sustainable Use of Marine Biological Diversity of Areas beyond Jurisdiction- a Technical Abstract of the First Global Integrated Marine Assessment.
Van Dyck, I.P., Nunoo, F.K.E., Lawson, E.T., Dyck, Van, Irene, P., Nunoo, F.K.E., Lawson, E.T., 2016. An empirical assessment of marine debris, seawater quality and littering in Ghana. J. Geosci. Environ. Prot. 4, 21–36. https://doi.org/10.4236/gep.2016.45003.
Van Waerebeek, K., Debrah, J.S., Ofori-Danson, P.K., 2014. Cetacean landings at the fisheries port of Dixcove, Ghana in 2013-14: a preliminary appraisal. In: IWC Scientific Committee Annual Meeting, SC65B, Slovenia, May 2014 SC/65b/SM17, pp. 1–4. https://doi.org/10.13140/RG.2.1.4079.2401.
Volta River Authority, 2021. 2021 annual report and finanacial statement.
van Waerebeek, K., Ofori-Danson, P.K., Debrah, J., 2009. The cetaceans of Ghana, a validated faunal checklist. West African J. Appl. Ecol. 15, 1–20. https://doi.org/10.4314/wajae.v15i1.49428.
Wiafe, G., 2010. Coastal and Continental Shelf Processes in Ghana (No. N00014–08–1–1128).
Yarboi-Tetteh, D.O., 2023. Tidal waves displaced 100 residents, destroy property at Moree [WWW document]. In: URL. https://www.ghanaiantimes.com.gh/tidal-waves-displaced-100-residents-destroy-property-at-moree/ (accessed 5.20.23).