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Marine fisheries management in the Eastern Central Atlantic Ocean

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ABSTRACT

Marine fishing is crucial to the socio-economy of West Africa fishery. However, the sector has many challenges, which have increased the call for an integrated approach that provides links among human needs, activities, changes in the state of the environment, and the resultant effect on ecosystem services for sustainable management in fulfilment of the Conservation on Biological Diversity and the Sustainable Development Goals. This study uses a socio-ecological framework (Drivers (D), Activities (A), Pressure (P), State (S), Impact (I) on welfare (W), and Response (R) as a Measure (M); DAPSI(W)R(M)) to assess the marine fishery sector of Ghana. Data were systematically sampled and analysed from vessel logbooks, fish manifests, observer reports, and relevant publications.

Results show that Drivers, including livelihoods and revenue, food, and social status, contribute to industrial tuna and trawl fishing, and marine artisanal fishing activities. Where illegal fishing methods such as small mesh-size nets (less than 25 mm), lights, poisonous substances, among others, are used. These activities have contributed to the pressures of selective fishing of juvenile and adult pelagic and demersal fish species. This has contributed to (changes in the State) the decline and vulnerability of *Sardinella* spp., and *Engraulis encrasicolus*, among others. The Impact on welfare includes Ghana becoming a net importer of marine species with increasing idleness of fishers due to reduced catch. Several management measures, including the Fisheries Act 625 of 2002 and Fisheries (Amendment) Regulations L.I. 2217 of 2015, and quotas in the tuna sector, among others, have been instituted to curb the effect of anthropogenic activities. Management measures, including influencing consumer behaviour for a sustainable fishery, enforcement, and data-driven management, have been recommended, in response to the targets of the Sustainable Development Goals, the United Nations Decade of Ocean and the Convention on Biological Diversity.

1. Introduction

Globally, sustainable and responsible utilisation of natural resources, including fisheries, has become essential in averting adverse impacts on ecosystems (long-term loss of biodiversity, genetic diversity, ecological structure, and bio-productivity) to ensure economic and food security

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(FAO, 2010, 2020a). The inception of international regulations and conventions, including the FAO's Code of Conduct for Responsible Fisheries and the Sustainable Development Goals (SDGs), has made these calls more imperative (Durussel et al., 2018; FAO, 2020b; UN, 2019). Hence they have informed the development of laws, policies, programmes, and institutions that support the efforts for fisheries at the local, national and regional levels (FAO, 2020b; UN, 2019).

Until the late nineteenth century, fisheries resources were regarded as inexhaustible (Hauge et al., 2007), leading to their unsustainable utilisation through overfishing, illegal, unreported, and unregulated (IUU) fishing, underestimation of impact on non-target species and productivity, overcapacity, poor estimation of ecological resilience, use of unsustainable fishing gears and methods, pollution, etc. These have contributed to severe ecological (e.g., the over 24% decline in stocks below the fishery sustainable level, erosion of spatial structure of a population, etc.) and economic losses (Cámara and Santero-Sánchez, 2019; FAO, 2022, 2020c, 2010; Hernvann and Gascuel, 2020; Jubinville et al., 2022; Maufroy, 2017). Catch losses to global fisheries in sixty years (1950–2010) are estimated to be over 330 million tonnes (Ding et al., 2017). The economic loss to marine fisheries due to inefficient management and unsustainable fishing activities globally has increased from about US$ 50 to US$ 83 billion, with IUU fishing, for instance, leading to losses between US$ 10 billion and US$ 23 billion per annum (Arnason et al., 2017; Dadzie et al., 2020; FAO, 2010; Hutniczak and Delpeuch, 2018). In West Africa, IUU fishing results in a loss of over US$ 2.3 billion annually, whereas in Ghana, IUU fishing (100 thousand tonnes) is valued between US$ 53 and US$ 81 million (Doumbouya et al., 2017; Environmental Justice Foundation and Mpoano, 2019; O'Neill et al., 2018).

Despite the challenges, fisheries globally are an essential source of protein (i.e., 3.3 billion people), livelihood, revenue (e.g., over US$ 164 billion from the global annual fish exports), and culture, especially for developing countries (Belhabib et al., 2015; FAO, 2020b; Hanich et al., 2019; Ministry of Fisheries and Aquaculture Development and Fisheries Commission, 2015).

In West Africa (including Ghana, Nigeria, Cote d'Ivoire, etc.), marine fisheries are also an essential source of livelihood (i.e., for about 6.7 million people), revenue (i.e., US$ 3.5 billion per annum, and in Ghana about US$ 1 billion per annum) and a critical source of nutrition (i.e., about 15 kg per capita) (Asiedu and Nunoo, 2016; Belhabib et al., 2015; ECOWAS Commission, 2020; The World Bank Group, 2013). The West African coast in the Atlantic Ocean is a spawning site and migratory path for the three commercial tuna species (i.e., *Katsuwonus pelamis*, *Thunnus albacares,* and *Thunnus obesus*) and the western stock of anchovy shared by Ivory Coast, Togo, Benin, and Ghana (essential hub) (Agyekum et al., 2012; Environmental Protection Agency of Ghana, 2017; Failler et al., 2014; Fisheries Committee for the West Central Gulf of Guinea, 2018; Maufroy, 2017).

Several of the marine species found in this zone are either vulnerable (e.g., *Sardinella maderensis*, *Thunnus obesus, Dentex dentex*) or endangered (e.g., *Pseudotolithus senegalensis*) due to unsustainable fishing activities and inadequate management (Polidoro et al., 2016). Approximately fifty (50) percent of the fish stocks have declined, while imports have increased (e.g., over 166 thousand tonnes between 2013 and 2018) due to illegal fishing, poor governance and data regimes, inadequate surveillance and monitoring, ineffective regional and national response, etc. (Belhabib et al., 2015; ECOWAS Commission, 2020; Fisheries Committee for the West Central Gulf of Guinea, 2018; Nyemah et al., 2017). Warmer marine temperatures are expected to also contribute to the decline in fish landed by over 20% with severe consequences for its socio-economy by 2050 (African Natural Resources Centre (ANRC), 2022).

The situation is inimical to the national integrated maritime strategy, the mandate of the Abidjan Convention, the SDGs, etc. (Agyekum et al., 2012; Environmental Protection Agency of Ghana, 2017; Failler et al., 2014; Maufroy, 2017). In recent years, for instance, it has been suggested that the *Sardinella* fishery, which stretched between Cote d'Ivoire and Togo should be closed to enable the rejuvenation of the fishery because the sub-region is experiencing changes in the population dynamics of the small pelagics (Environmental Justice Foundation, 2020).

The complexity of the marine fishery and the increasing competing interests requires an adaptive management tool with the capacity for problem-structuring that supports governance by integrating the environmental, social, and economic impact of all activities to ensure the sustainability of livelihood and food in fulfilment of the key SDGs (i.e., 1, 2, 3, 8, 10, 12, and 14) (El Mahrad et al., 2020; Elliott et al., 2017; Takyi, 2020). The post-COVID-19 era, the inception of the African Continental Free Trade Area (ACFTA), and the period of the declaration of the UN Decade of Ocean Science for Sustainable Development present an opportunity for a more prudent and holistic adaptive management approach to marine fisheries management (Apiko et al., 2021; FAO, 2021; UN, 2019; UNESCO-IOC, 2021).

Adaptive management tools with problem-structuring capacity such as the Drivers (D), Activities (A), Pressures (P), State changes (S), Impact (I) on human Welfare (W) (i.e., ecosystem services), and Response (R) as Measures (M) (DAPSI(W)R(M)), (an extension of the Drivers, Pressures, State, Impact and Response (DPSIR)) provides this framework (El Mahrad et al., 2020; Elliott et al., 2017; Hernández-López et al., 2020). The DAPSI(W)R(M) framework proceeds on the premise that human needs (e.g., physiological and biological) are what Drive human activities that generate Pressures which are the mechanism of change (Elliott et al., 2017; Smith et al., 2016). The changes in the State of the natural system are caused by one or more pressures resulting from human activities, which can have an impact on the ecosystem services (El Mahrad et al., 2020; Elliott et al., 2017; Smith et al., 2016). The societal response to the Activities, Pressures, State changes and Impact (Welfare) is the Response as Measures (e.g., closed seasons, licensing, and quota, etc.) (Elliott et al., 2017; Newton and Elliott, 2016; Takyi et al., 2022).

Therefore, this study aims to problem-structure marine fisheries management by assessing the human needs that drive (D) the activities in the marine fishery (A) and the pressures (P) generated due to the human activities in the fishery, with Ghana's marine fishery as the case study. The state (S) (change) of the species and the environment due to the pressure, the impact (I) (welfare) (W) on ecosystem services due to the change in the state of the species and environment, and the mitigating or elimination responses (R) (Measure) (M), (DAPSI(W)R(M)) established. Recommendations (Measures) that would help as a guide in addressing the challenges identified, have been provided.

2. Materials and methods

2.1. Study area

Ghana is a hub for fisheries and related activities within the West African region at the industrial and artisanal levels (Failler et al., 2014; Ministry of Fisheries and Aquaculture Development of Ghana, 2021). Ghana's exclusive economic zone (EEZ) is located in the Atlantic Ocean (Gulf of Guinea) and 85% of its total catch is from marine (Fig. 1) (Failler et al., 2014; Nunoo et al., 2014). The marine fishing industry has been part of Ghana's socio-economy before and after its independence in 1957 (Ministry of Fisheries and Aquaculture Development of Ghana, 2010; Nunoo et al., 2014).

The EEZ is on the route of the seasonal movements of three of the dominant tuna species, with about 40% of the maximum sustainable yield of the East Atlantic tuna stocks being in the exclusive economic zone (EEZ) of Ghana (Failler et al., 2014; Nunoo et al., 2014).

2.2. Data source and collection

Twenty-four logbooks were sampled from tuna vessels (i.e., 17 purse seiners and 7 poles and lines), six catch manifests from industrial

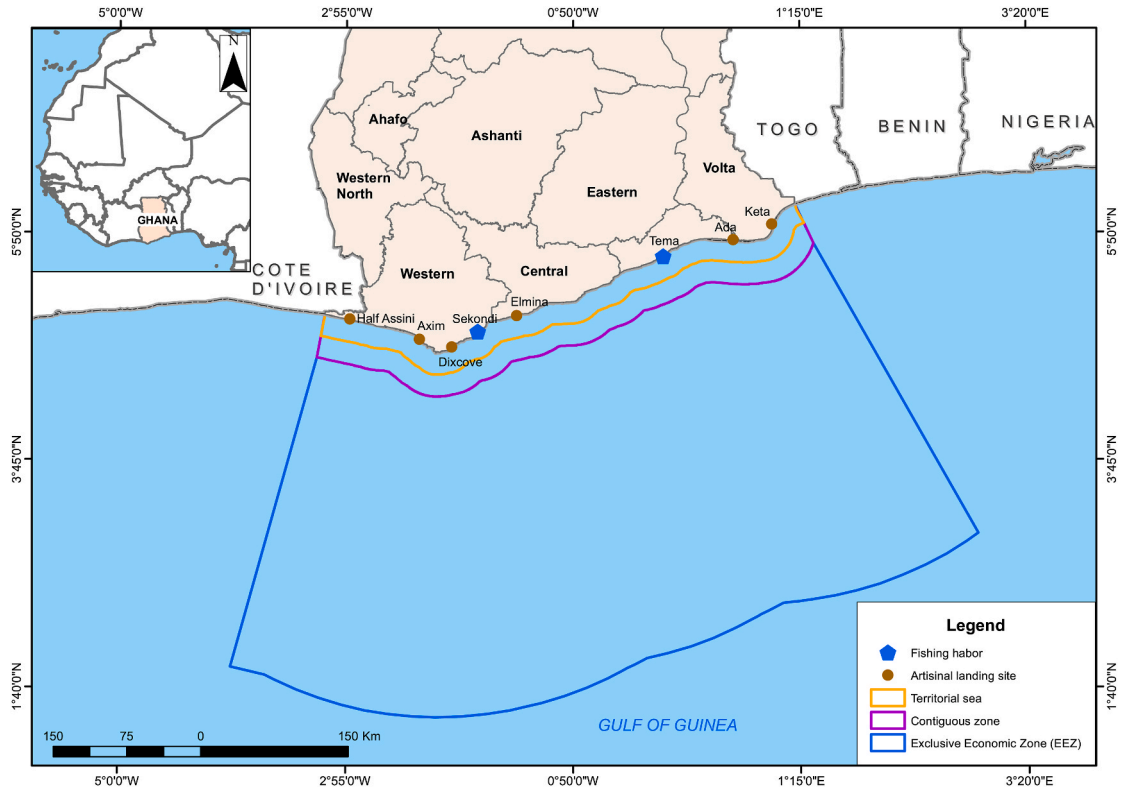

Fig. 1. The exclusive economic zone of Ghana is situated in the Gulf of Guinea and the Eastern Atlantic.

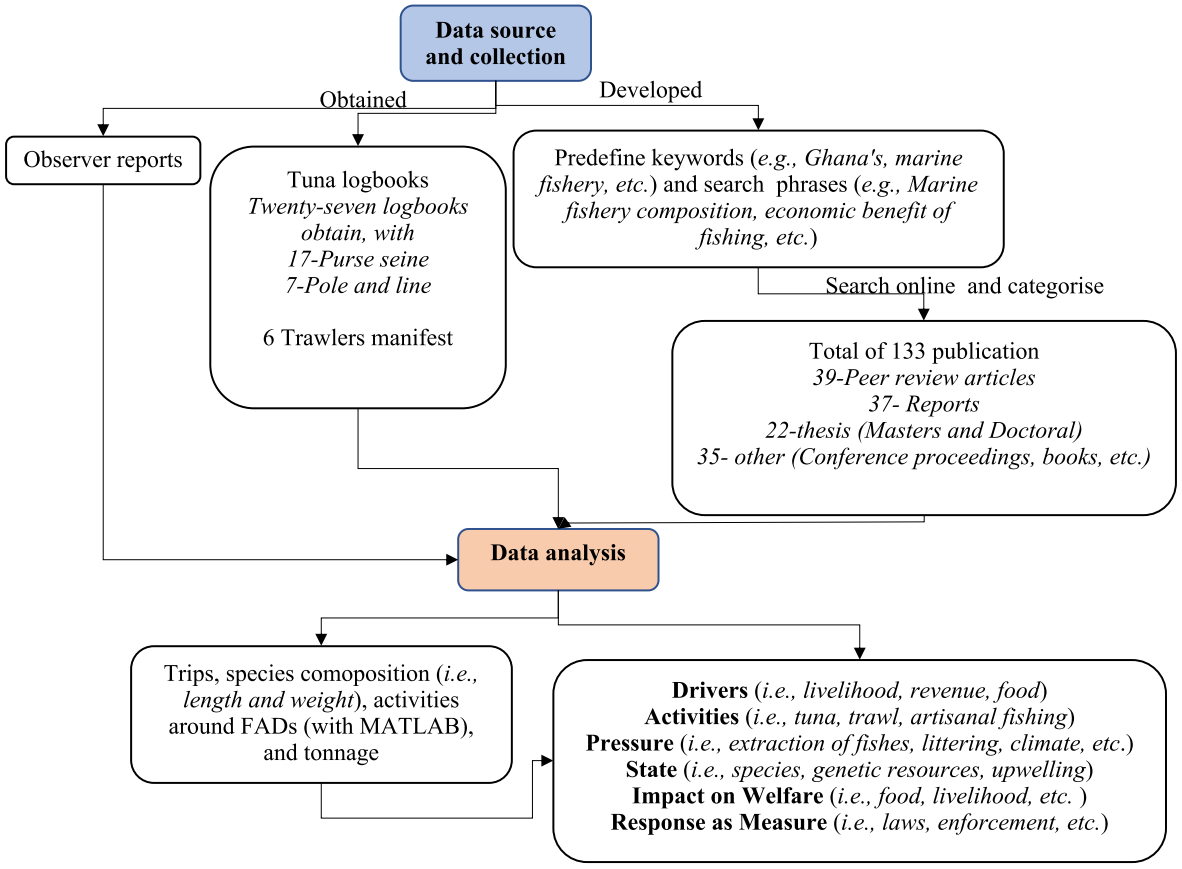

Fig. 2. The data collection and analysis approach.

trawlers, and two tuna observer reports in Ghana's fishery between 2015 and 2022 (Fig. 2). For confidentiality, the vessel names were omitted.

Furthermore, predefined keywords and phrases, including *Ghana, transhipment, Ghana's marine fishery, the importance of fishing in Ghana, livelihood and fishing in Ghana, trawl fishery in Ghana, the close season in Ghana, species caught by marine artisanal fishing in Ghana, tuna fishery in Ghana, bycatch in Ghana's fisheries, fish species that have declined in Ghana,* and *the West African marine fishery,* among others were developed as search guide and were systematically used to conduct searches in the scholarly portals (Table 1) (ScienceDirect, Multidisciplinary Digital Publishing, Taylor and Francis, Google Scholar, etc.), government agencies portals, etc. to obtain marine fishery information relevant to the study (Fig. 2) (Takyi et al., 2021, 2022). Based on the title, abstract and full-text reading, 133 publications, including 39 peer-reviewed journal articles, 37 reports (e.g., National Marine Fisheries Management Plan (2022–2026), Ghana Seafood Report, Status of the Small Pelagic Stock in Ghana – 2016, Stolen at Sea. How Illegal '*Saiko*' Fishing is Fuelling the Collapse of Ghana's Fisheries, etc.), 22 theses (masters and doctoral), and 35 works of literature (e.g., books, conference proceedings, laws, regulations, webpages, briefs), spanning the period between 1998 and 2022 were sorted out as relevant to the study (Fig. 2) (Liberati et al., 2009; Takyi et al., 2021, 2022).

2.3. Data analysis

Relevant information in the publications gathered was collated, analysed, and tabulated into:

Drivers (D) - relates to the basic needs for human welfare, including physiological and biological, psychological and self-fulfilment needs, e.g., food, livelihood, revenue, social status, etc.

Activities (A) – are the actions (e.g., industrial tuna fishing, trawl fishing, artisanal, etc.) of individuals or groups because of the desire to meet their drivers.

Pressure (P) – reflects the mechanism of change in the ecosystem due to one or more activities. Examples include the selective extraction of species, abrasion, littering, etc.

State (S) changes – relate to changes in the state of the ecosystem due to one or more pressures. For example, changes in the stock of fish species, food web, genetic resources, etc.

Impact (I) on Welfare (W) - refers to the consequences of the changes in the state of the marine ecosystem on the myriad of ecosystem services they provide. For example, food security, livelihood, cultural services, etc.

Response (R) as a Measure (M) – relates to the management measures to ease or prevent the Drivers, Activities, and Pressures causing State change and impacting ecosystem services (Impact on Welfare). For example, promulgation of laws, enforcement, closed seasons, etc., (DAPSI(W)R(M)), to explain the issues and problems relating to the use and management of marine fishing (Fig. 2) (El Mahrad et al., 2020; Elliott et al., 2017; Fiandra, 2019).

The vessel logbooks, manifests and observer logbooks were analysed for trips (i.e., durations), species composition in catch, tonnage, and activities, including setting, retrieval and checking of fish aggregation devices (FADs) with MATLAB and Microsoft Excel (Fig. 2).

Table 1
Examples of search results obtained from the predefined keywords and search phrases.

Keywords and search phrases	Scholarly Portals
Transhipment	32,073
Ghana's marine fishery	20,742
The importance of fishing in Ghana	16,937
Trawl fishing in Ghana	6839
Fish species caught by marine artisanal fishing in Ghana	17,944
The West African marine fishery	199,148

Adapted from Abalansa et al. (2021)

3. Results and discussions

3.1. Drivers

3.1.1. Source of livelihoods and revenue

The desire of individuals or governments to create livelihoods and to generate revenue through sales, salaries, and taxes in a country with a high unemployment rate of 13.9% are drivers (Ghana Statistical Service, 2022). For instance, individuals and corporate organisations gain employment in the marine fisheries sector as fishers (e.g., in the artisanal, semi-industrial, and industrial), cold store operators, suppliers (e.g., fuel, salt, Fish Aggregation Devices (FADs) material, groceries, etc.), fish processors (canning, smoking, or salting), traders (women), fisheries observers, and transporters. (Table 2) (Danquah et al., 2021; Environmental Justice Foundation, 2021a; Moreno et al., 2018; O'Neill et al., 2018). The marine fisheries sector employs over 506,000 people, with a significant number of women in coastal fishing communities (Aikins, 2018; Failler et al., 2014; O'Neill et al., 2018; Sakyi et al., 2019).

Marine fisheries in Ghana contribute to the generation of over US$ 1 billion per annum, making it an essential source of revenue for the nation (Ministry of Fisheries and Aquaculture Development and Fisheries Commission, 2015; O'Neill et al., 2018; Taylor, 2022). Ghana cans about 24,500 tonnes of tuna for foreign and local markets, and the export of canned tuna generates about US$ 152 million for the Ghanaian economy (Failler et al., 2014; Ghana Export Promotion Authority, 2022a; ICCAT, 2021). The export of whole Skipjack tuna, for instance, earned Ghana about US$ 20.7 million in 2018 (Ghana Export Promotion Authority, 2020). Ghana makes over US$ 10 million from the exports of 3500 tonnes of cuttlefish, and octopus, to the European Union (Fattibene, 2020).

The fisherman in the marine artisanal sector in Ghana makes six times more than their operational cost. For instance, between US$ 0.3 and US$ 3 per kg for a less (e.g., *Dasyatis margarita*) and high value (e.g., *Epinephelus aeneus*) fish species sales, respectively, which is (higher than the daily minimum wage of US$ 1.8 (Aheto et al., 2012; Ministry of Employment and Labour Relations, 2021). Other species could sell for about US$ 2 and US$ 23 per kg (Quagrainie and Chu, 2019). Bycatches, including sharks, could fetch between US$ 20 and US$ 30 per kg (Agyeman et al., 2021; Sekey et al., 2022).

3.1.2. Source of essential food

Ghana has an annual fish demand of about 1 million tonnes, a per

Table 2
Drivers of human activities, with examples in Ghana's marine fisheries.

Driver	Industrial	Semi-Industrial	Artisanal
Source of Livelihood	x	x	x
Fishing	x	x	x
Fish marketing	x	x	x
Suppliers (e.g., gears, fuels, salt, groceries, etc.)	x	x	x
Cold store operation	x	x	x
Canneries	x		
Stevedoring	x		
Fisheries observers	x		
Boat and canoe construction		x	x
Fish processing (i.e., salting, smoking, and drying)	x	x	x
Transportation (e.g., fish)	x	x	x
Revenue	x	x	x
Income for individuals and organisations	x	x	x
Taxes for government	x	x	x
Food	x	x	x
Maintenance of social status	x	x	x

Legend: x-present.

capita consumption of 28 kg, and the fish component in the household's food budget is about 23.7% (Table 2) (Ansah et al., 2020; Hasselberg et al., 2020; Taylor, 2022). Fish (whole or processed), whether targeted or bycatch species, is an essential food source in terms of food security for most Ghanaians due to their availability, accessibility, health benefits, and diverse use in food preparation (Hasselberg et al., 2020; Onumah et al., 2020; Sakyi et al., 2019).

Marine species, including finfish and mammals (cetaceans), are widely consumed by coastal households (Debrah et al., 2010; Quaye, 2018). Fish is one of the affordable sources of high-quality protein whose shelf life can be readily improved for months through low-cost preservation techniques such as smoking, drying, and salting (Ashitey, 2019; Debrah et al., 2010; Mensah et al., 2006). Fish diet in artisanal fisher households reduces considerably, for instance, during periods of closed fishing seasons (Ofori-Danson et al., 2019).

3.1.3. Maintenance of social status

The need to be in the position, i.e., social role, to influence decisions due to an individual having a source of livelihood and being able to generate income is essential in fishing communities (Table 2) (Danquah et al., 2021; Richmond and Casali, 2022). Because Ofori-Danson et al. (2019) identified that artisanal fishers complained of reduced social status in their community during the fishing closed season period due to the absence of livelihood and income.

3.2. Activities

3.2.1. Industrial fishing

3.2.1.1. Tuna fishing. Tuna is the largest seafood export earner for the Ghanaian fishery (Ghana Export Promotion Authority, 2022b). The commercial fishing of tuna and bycatch with purse seine nets, and pole and line mostly around fish aggregation devices (FADs) (Table 3, Fig. 3) attached with satellite location beacons (e.g., GPS buoys, GPS-echosounders buoys) and sonars to monitor fish aggregation, aboard industrial fleets (Hanich et al., 2019; Maufroy, 2017; WWF, 2011). Tuna fishing also involves the use of *Engraulis encrasicolus* and juvenile *Sardinella* spp. as bait (Akpalu, 2021; Nunoo et al., 2014). New and old FADs are deployed, retrieved, and checked (Fig. 3) at sea in the fishing of *Katsuwonus pelamis*, *Thunnus albacares, Thunnus obesus,* and associated bycatches (e.g., *Caranx crysos*, *Acanthocybium solandri,* batoids, *Carcharhinus* spp., *Chelonia mydas*, *Dermochelys coriacea*, etc.) (Source: observer reports and logbooks). The FADs contribute to a reduction in fuel costs and increase the efficiency of purse seine and bait boats in the tuna fishery (Hanich et al., 2019).

3.2.1.2. Trawl fishing. Trawl fishing includes the use of locally built wooden hulls (8–37 m), steel hulls that are over 35 m in length with over 600 hp engine capacity and freezing facilities, and are to fish beyond 30 m depth (mainly for industrial trawlers) (Table 3) (Akpalu and Eggert, 2021; Pramod and Pitcher, 2006). Industrial trawlers catch approximately 126 tonnes per trip for about 30 days (Source: Manifest). Species caught include *Sardinella* spp., *Sphyraena sphyraena, Dentex canariensis, Selene dorsalis*, *Brachydeuterus auritus*, *Pseudotolithus* spp. (endangered species), *Sepia officinalis,* frigate tuna, sole, and blue runner among others (Fig. 4) (Environmental Justice Foundation, 2020; Nunoo et al., 2014).

Table 3
Activities and some gears, and substances in the marine fishery in Ghana.

Gears	Sector/Activities			
	Industrial fishing		Semi-industrial	Artisanal
	Tuna	Trawl		
Fish aggregation devices (FADs)	x			
Purse seine	x		x	
Trawl nets		x	x	
Mosquito nets				x
Beach seine nets				x
Satellite beacons and sonars	x	x		
Poisonous substances (e.g., carbide, cyanide)				x
Light (e.g., 1000-W bulb and generators)				x
Explosive (e.g., dynamite)				x

Legend: x-present.

3.2.2. Marine artisanal fishing

This fishing category involves the use of canoes (usually 8 m–27 m with a capacity between 5 and 26 tonnes) with or without outboard engines, the use of explosives (e.g., dynamite (30 cm × 10 cm)) to stun or kill fish, gillnets, beach seine nets, small mesh-size (less than 50 mm) nets, and monofilament nets to maximise the catch (Table 3) (Afoakwah et al., 2018; Ateweberhan et al., 2012; Atuobi, 2016; Bawa, 2018; Environmental Justice Foundation and Mpoano, 2019; Lazar et al., 2018; Quagrainie and Chu, 2019). One thousand (1000) watt incandescent light bulbs powered by generators is lowered into the water column vertically at specific depths by some fishers to aggregate the fish for easy capture (Abakah and Owusu, 2023; Afoakwah et al., 2018; Tobey et al., 2016).

Poisonous substances, including dichlorodiphenyltrichloroethane (DDT), carbide, and cyanide are used to increase catch (Afoakwah et al., 2018; Atuobi, 2016; Bawa, 2018). The chemicals are either poured directly onto the water surface or attached to perforated polythene bags for gradual release during the net casting processes (Bawa, 2018). Artisanal fishers catch species, including *Sardinella aurita*, *S. sphyraena*, *Scomber colias*, *Katsuwonus pelamis*, *Thunnus albacares, Thunnus obesus, Sparus caeruleostictus*, *Auxis thazard*, *Engraulis encrasicolus*, *Carcharhinus* spp., *Epinephelus aeneus*, *Scomber colias*, *Selene dorsalis*, and *Dentex angolensis* among others (Agyeman et al., 2021; Aheto et al., 2012; Dovlo, 2020; Nunoo et al., 2014; Quagrainie and Chu, 2019).

3.3. Pressure

3.3.1. Extraction of living resources

The catch volume and the selective removal (i.e., high fishing mortality and exploitation rate) of juvenile (i.e., length at first capture is lower than the length at first maturity) and adult pelagic and demersal (i.e., exceeding the maximum sustainable yield of 24,000–42,000 tonnes) fish species (Bannerman and Cowx, 2002; Environmental Justice Foundation, 2022), constitutes pressure on the marine ecosystem. For instance, the fishing mortality rate (Table 4) of *Apsilus fuscus, Brachydeuterus auritus, Chloroscombrus chrysurus, E. encrasicolus, Sardinella maderensis, S. aurita, Scomber colias, Selene dorsalis, S. sphyraena* and *Trachurus trecae,* at 0.9 yr^{-1}, 1.1 to 1.5 yr^{-1}, 1.96 yr^{-1}, 1.8 yr^{-1}, 1.6 yr^{-1}, 2.4 yr^{-1}, 2.9 yr^{-1}, 2.1 yr^{-1}, 3.0 yr^{-1}, and 3.6 yr^{-1}, respectively, is higher than the level that ensures the maximum sustainable yield for teleost ($F_{msy} = 0.87M$) (Aggrey-Fynn and Hotor, 2021; Amponsah, 2015; Lazar et al., 2020; Zhou et al., 2012). Similarly, there is the selective extraction of tuna species, including *Katsuwonus pelamis*, *Thunnus albacares, Thunnus obesus, Auxis thazard* (Figs. 5 and 6)) at 17 tonnes per fisher-day. Other species such as *Pagellus bellottii, Dentex* spp., *Parapenaeopsis atlantica, Pseudotholitos senegalensis*, *Penaeus kerathurus, P. notialis,* and cuttlefish, among others by tuna, trawl and artisanal fleets (Aggrey-Fynn and Hotor, 2021; Ahiable, 2015; Amponsah et al., 2016b; Cook et al., 2021; Environmental Justice Foundation, 2020; Lazar et al., 2018; Nunoo and Azumah, 2015; Quagrainie and Chu, 2019).

Pressure from increasing fishing power, including fleets (i.e., number of canoes (over 11,500), trawlers, tuna vessels, etc.), days spent at sea per fleet, the number of gears and types (e.g., FADs deployed), and the catch rate per trip (Cook et al., 2021; El Mahrad et al., 2020; Ministry of Fisheries and Aquaculture Development, 2022; Takyi et al., 2021). The

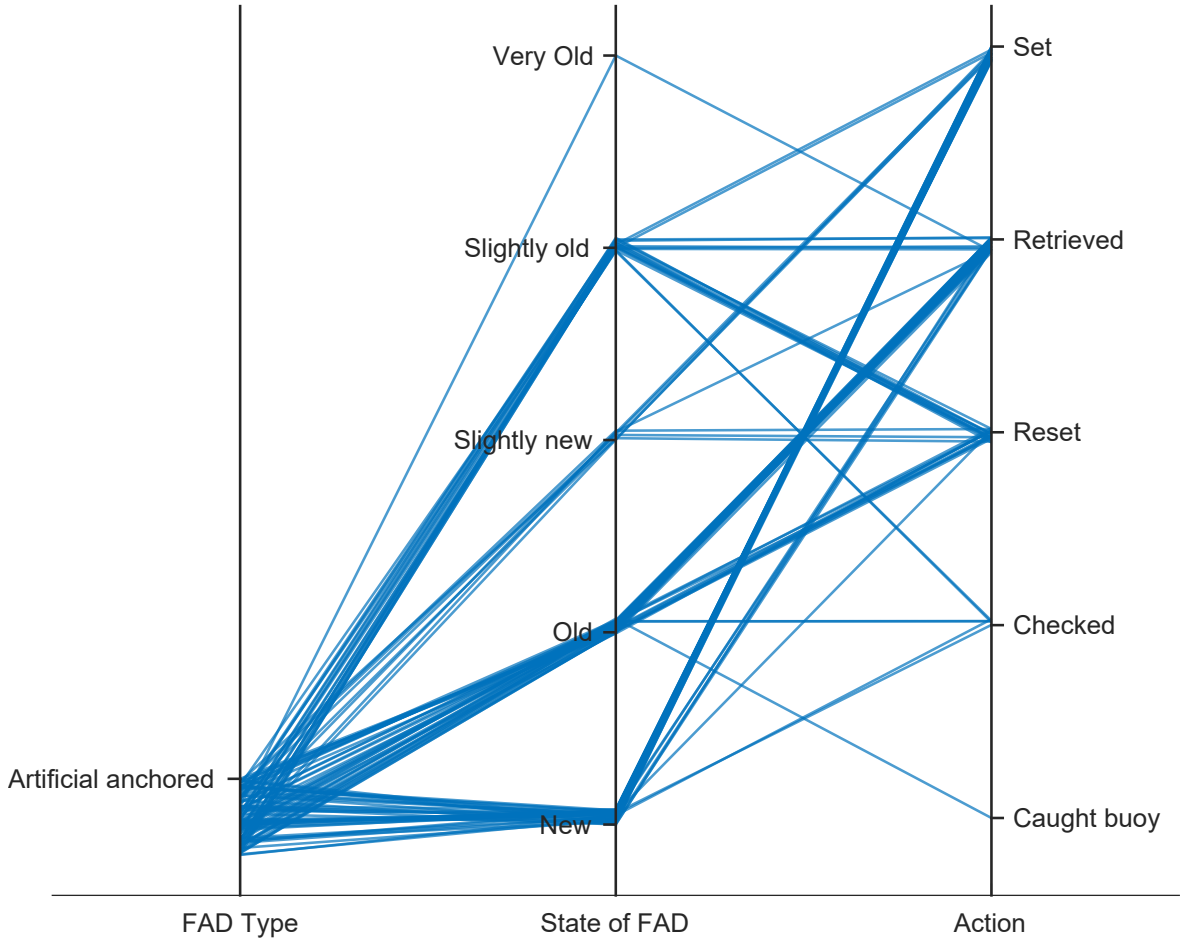

Fig. 3. Examples of activities around fish aggregation devices (FADs) at sea by industrial tuna fleets in the Ghanaian marine fishery, where fishing is undertaken around old, very old, slightly old, and new FADs. FADs are set, retrieved, reset, and checked for fish and their state (Source: Vessel Logbooks (2020–2022) and Observer Report (2019)).

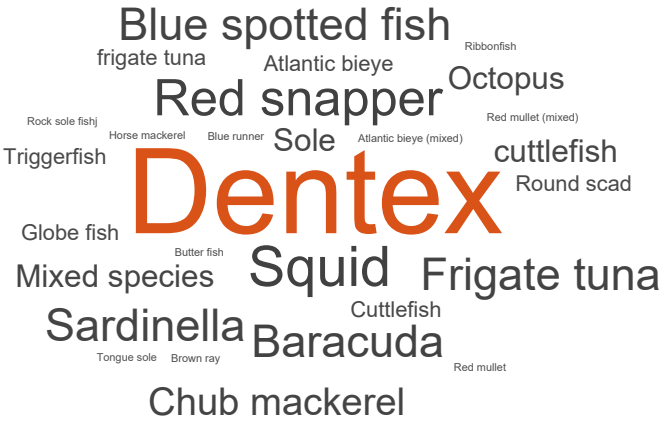

Fig. 4. Examples of fish species caught by industrial trawl fishing vessels in their relative abundance in the Ghanaian marine fishery, with *Dentex* spp. dominating the catch (Source: Fish Manifest (2022))

average days (Table 5) spent, for instance, by a pole and line and purse seiner at sea per trip are 35 and 31, respectively. A purse seiner and pole and line vessels also make about 39 and 23 sets around FADs per trip, which is about 90% or even 100% of the entire sets per trip, with a catch rate between 148 and 589 tonnes (Source: Vessel Logbooks).

3.3.2. *Abrasion*

The frequency and duration of fishing gears (trawls nets and otter boards) and explosives use constitute stress and mechanical interference in critical habitats as well as for aquatic organisms (targeted and non-targeted species) through crushing, physical rubbing, and erosion (Afoakwah et al., 2018; Schweitzer et al., 2018).

Unfortunately, the frequency of trawling, blast fishing and the number of times gears are used by each fishing craft or marine artisanal fisher has not been quantified. Hence, the extent of this problem is unknown to managers of the fisheries resources in Ghana.

3.3.3. *Introduction of synthetic and non-synthetic substances*

Pressure on the aquatic environment from the use of poisonous chemicals persists in the water column, sediments, and aquatic organisms within a certain radius. The quantity, concentration, and frequency of use are unknown.

Blast fishing with carbide generates acetylene, arsenic, and phosphorous in the aquatic environment (Bawa, 2018; Igbinaduwa et al., 2018). Currently, data on the quantities and concentration of the various poisonous chemical released into the environment per fisher per fishing trip per duration of fishing has not been quantified.

3.3.4. *Littering*

The deployment of deep artificial FADs (i.e., between 9 and 27 FADs per vessel per trip) with a structure of 50–160 m and a lifespan of one year (Moreno et al., 2018; WWF, 2011). The FADs consist of bamboos (about 12 at the floating part and 15 to 20 split bamboos attached to a

Table 4
Examples of the pressure of selective extraction on some fish species in the marine fishery.

Species	F (yr^{-1})	F_{opt}	M (yr^{-1})	L_{c50} (cm)	References
Apsilus fuscus	0.9		0.7	32.8	Aggrey-Fynn and Hotor (2021)
Brachydeuterus auritus	1.43–1.5	0.69	0.4	3.7	Bannerman and Cowx (2002); Amponsah (2015)
Caranx crysos	0.65		0.74	14.9	Amponsah et al. (2021)
Chloroscombrus chrysurus	1.96		1.3		Amponsah et al. (2021)
Decapterus rhonchus	0.80		0.29	28.2	Forson and Amponsah (2020)
Engraulis encrasicolus	1.8	0.60	1.5	3.7	Amponsah et al. (2016a)
Pagellus bellottii	1.5	0.44	1.1	9.9	Amponsah (2015)
Sardinella maderensis	1.6	0.53	1.3	5.3	Amponsah (2015)
S. auratus	2.4	0.30	0.8	6.0	Amponsah (2015)
Scomber colias	2.9	0.84	2.1	13.2–24.1	Amponsah (2015); Kassah (2020)
Selene dorsalis	2.1		1.2		Amponsah et al. (2021)
Sphyraena sphyraena	3.0		1.9	39.3	Aggrey-Fynn and Hotor (2021)
Trachurus trecae	3.60		1.14	15.3	Amponsah et al. (2021)

Legend: F_{opt}- Optimum fishing mortality; F - Fishing mortality; M -Natural mortality; L_{c50} – length at first capture.

50 m–100 m long open submerged net with an average mesh size is 100 mm) and palm fronds (i.e., 20–30 pieces) (Moreno et al., 2018).

There are petroleum-based nylon nets, ropes, plastic gallons, and an anchor (e.g., coiled iron rods or tires with a boulder), and several plastic floating buoys with slow degradation properties constitute littering pressure on the marine and coastal environments (Hanich et al., 2019; Moreno et al., 2018).

Abandoned, discarded and lost fishing gears serve are sources of litter (marine debris) in the marine ecosystem and can contribute to ghost fishing (Kuczenski et al., 2021). For instance, fibres from abandoned, discarded and lost trawl nets, and ropes have been isolated from different sizes of demersal (e.g., *D. rhonchus*) and pelagic (e.g., *S. maderensis, S. aurita*) fish species off the coast of Ghana (Adika et al., 2020; Pappoe et al., 2022).

3.3.5. Climate change

Pressure from increased sea surface temperature (0.04 °C per annum) and its effect on the behaviour and abundance of fish species (e.g., *Sardinella* spp. and *Engraulis encrasicolus*) is projected to increase between 2 and 4 °C by the year 2100 due to the effect of climate change (Environmental Protection Agency of Ghana, 2020; Hasselberg et al., 2020; Ministry of Foreign Affairs, 2018; Minta, 2003; USAID, 2017). Pressure from ocean acidification due to declining pH, carbonate ion concentration, calcite, and aragonite saturation state (Nunoo et al., 2016).

3.4. State change

3.4.1. Animal species

Marine fish stocks (nearshore, pelagic and demersal) have declined due to the pressures associated with activities in the fishery industry and the effect of climate change (i.e., weakening of upwelling) (Table 6) (Akpalu and Eggert, 2021; Cook et al., 2021; Dovlo, 2020; Lazar et al., 2018; O'Neill et al., 2018). For instance, the stock of *Sardinella* spp. (*S. aurita and S. maderensis*), one of the most important small pelagics, has declined due to selective extraction and thermal regime changes by over 110,000 tonnes with landings moving from about 140,000 tonnes to about 29,000 tonnes (Asante and Amuakwa-Mensah, 2014; Dovlo, 2020; Environmental Justice Foundation, 2020; Environmental Protection Agency of Ghana, 2017; Mensah et al., 2006; Wiafe et al., 2008). The *E. encrasicolus*, sea breams and burritos biomass have also declined and the *Balistes capriscus B. punctatus, and Thunnus obsesus* have become vulnerable while *T. albacares, Galeoides decadactylus* and *Decapterus rhonchus* are threatened with extinction (Environmental Protection Agency of Ghana, 2020; Polidoro et al., 2016). The *K. pelamis* has taken over *Thunnus albacares* as the dominant species (Adinortey et al., 2016).

The lengths at maturity of species, including *P. notalis, Chloroscombrus chrysurus,* and *B. auratus,* indicate that the sizes of species are reducing due to the pressure of selective extraction from fishing activities and the gears used (Nunoo and Azumah, 2015). For instance, a

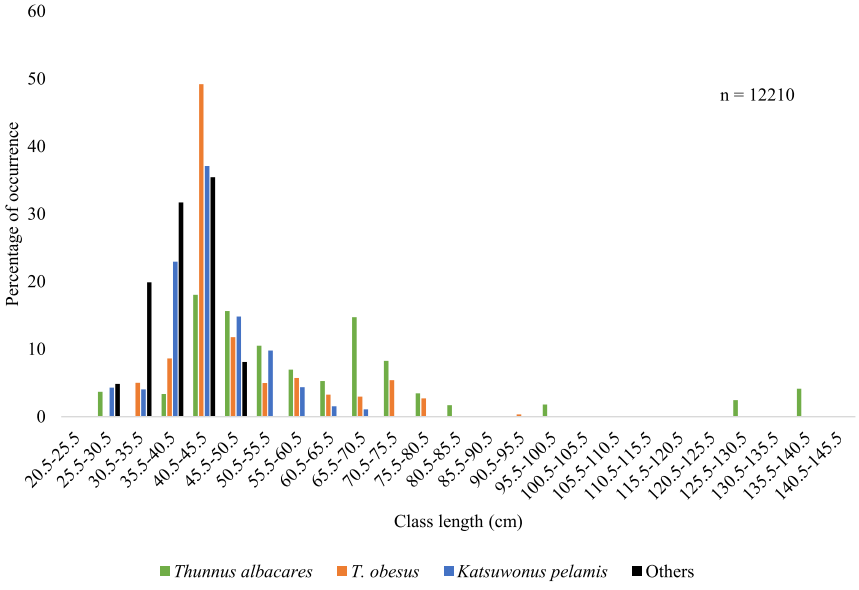

Fig. 5. Example of length distribution of tuna species caught by anonymous industrial tuna vessels (Source: Observer report (2019)).

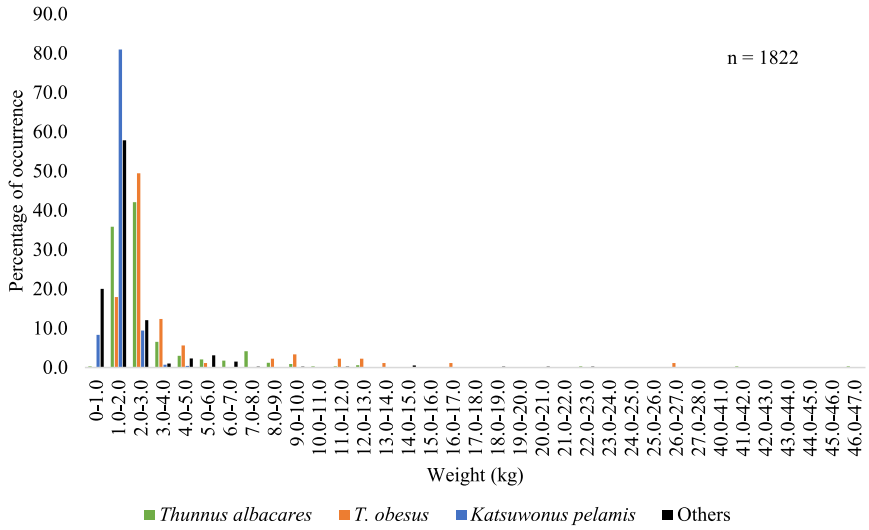

Fig. 6. Example of weight distribution of tuna species caught by anonymous industrial tuna vessels (Source: Observer report 2015)).

Table 5
Examples of days, sets and catch around fish aggregation devices (FADs) per trip for purse seine and pole and line vessels (Source: Vessel Logbook, 2020 to 2022).

Vessel	Days	Sets (FADs)	Catch around FADs (tonnes)
Purse seine	35	39	589
Pole and line	31	23	148

Table 6
Examples of the status of some fish species in Ghana's marine fishery.

Species	Status	Reference
Balistes capriscus	Vulnerable	Polidoro et al. (2016)
B. punctatus	Vulnerable	Polidoro et al. (2016)
Brachydeuterus auritus	Declined	Environmental Protection Agency of Ghana (2020)
Decapterus rhonchus	Near Threatened	Polidoro et al. (2016)
Engraulis encrasicolus	Declined	Environmental Protection Agency of Ghana (2020); Cook et al. (2021)
Ethmalosa frimbriata	Declined	Cook et al. (2021)
Galeoides. decadactylus	Near Threatened	Polidoro et al. (2016)
Katsuwonus pelamis	Become dominant	Adinortey et al. (2016)
Sardinella maderensis	Declined	Cook et al. (2021)
S. aurita	Declined	Cook et al. (2021)
Trachurus trecae	Overfished	Amponsah et al. (2021)
Thunnus albacares	Near Threatened	Polidoro et al. (2016)
T. obesus	Vulnerable	Polidoro et al. (2016)
Sea breams	Declined	Environmental Protection Agency of Ghana (2020)

recent length at maturity recorded for the three species was 19 cm compared to the 23–30 cm recorded previously (Edward et al., 2001; Nunoo and Azumah, 2015).

3.4.2. Food web

The abundance of zooplankton (e.g., *Calanoides carinatus* accounts for a significant proportion of zooplankton biomass) has declined (at a rate of over 6 ml per 1000 m^3 per year) due to the gradual warming of sea surface temperature with implications for the primary production, and larval and gamete supply as intermediate services, and the final ecosystem services (fish and genetic resources) (Elliott et al., 2017; Hilborn et al., 2022; Wiafe et al., 2008).

The state of the marine food web dynamics, especially the change in intermediate and final ecosystem services, is unknown as little or no literature is available (Brown et al., 2010; Elliott et al., 2017; Hilborn et al., 2022).

3.4.3. Genetic resources

Globally, there is enough evidence that the diversity of ocean genetic resources is under threat due to overexploitation, habitat loss, and degradation in the fishery (Blasiak et al., 2020; Kenchington et al., 2003). The state of the genetic material diversity (i.e., whether low or high), which influences the adaptive capacity of species (Hoban et al., 2020) landed in the Ghanaian marine fishery is unknown.

3.4.4. Upwelling

There are variabilities in the strength of upwelling regimes due to gradual thermal regime change. For instance, the intensity of minor upwelling is increasing, and that of the major upwelling regime is weakening due to the gradual increase in sea surface temperature. (Environmental Protection Agency of Ghana, 2020; Hasselberg et al., 2020; USAID, 2017). The state of intermediate services, such as primary production and nutrient cycling with final ecosystem provision services of fish, is scanty due to limited literature availability (Elliott et al., 2017).

3.5. Impact on welfare

3.5.1. Food security

The per capita consumption of fish has reduced from about 40 kg in the 1970s to 28 kg recently due to the decline in the availability of fish (Hasselberg et al., 2020; Taylor, 2022). Total fish landings from marine capture have been reduced by about 30% (Akpalu et al., 2018; Hasselberg et al., 2020). The small pelagics which constitute about 80% of small-scale fish landings have declined and are on the verge of collapse (Ashitey, 2019).

As a result of the shortfall in fish production, Ghana has become a net importer of fish (i.e., seafood), including mackerel, horse mackerel, *Sardinella* spp, croaker, sea bream, and red snapper, to make up the gap created by the decline in the catch (Ministry of Fisheries and Aquaculture Development of Ghana, 2015; Taylor, 2022). The situation has implications for global efforts to reduce food insecurity, the prevalence of undernourishment or stunting and the target of reducing the global

wasting rate in children (to 3%) by 2030 in fulfilment of SDG 2 (Takyi et al., 2022; UN, 2019).

3.5.2. Economic and livelihood

Ghana is likely to lose portions of the over US$ 1 billion revenue it generates annually from the fisheries sector, with subsequent effect on the jobs of over 2.9 million whose livelihoods depend on fisheries if the pressure and change in the state of the ecosystem generated by fishing activities continue (FAO, 2014; Gyesi, 2019; Ministry of Fisheries and Aquaculture Development of Ghana, 2015). Ghana has a trade deficit of over US$ 300 million due to a decline in fish (Russell, 2017). Therefore, Ghana spends over US$ 200 million (annually) that could be channelled to other development projects instead of seafood importation (Government of Ghana, 2021; USAID, 2017).

Fish caught with chemicals are of poor quality and difficult to process therefore, fish processors and traders receive a low price which affects their revenues. Fishmongers in the Central Region of Ghana posited difficulty in the processing of juvenile fish since they easily get burnt in the oven, making them unsuitable for the market. Revenues generated by artisanal fishers have fallen by about 40% over the last decade due to overfishing and poor management (Lazar et al., 2018). Their indebtedness to creditors has increased over the years due to the continuous reduction in the catch, landing of juvenile fish and the increasing operational costs (i.e., longer trips) (Gyesi, 2019; Lazar et al., 2017, 2018; Pabi et al., 2015). The ability of artisanal fishers to obtain diverse fish has been affected due to decreased catch, with an effect on incomes (Danquah et al., 2021; Russell, 2017).

Idling among artisanal fishers is increasing in some communities, including Axim, Cape Coast, James Town, Nzema West, and East Districts, due to a decline in the catch (Bawa, 2018). Fishers and fishing fleets are experiencing an increase in zero catch, with some spending more hours (more than 20 h) at sea searching for fish (Environmental Justice Foundation, 2020; Lazar et al., 2018). The decline in catch and income has also influenced some artisanal fishers to migrate internally or to neighbouring countries, including Togo, Benin and Cote d'Ivoire (Asiedu et al., 2022; Danquah et al., 2021).

Household incomes of artisanal fishers are affected when the fishing season is closed for a month annually, with cascading effect on the value chain and service providers (especially women) (Ofori-Danson et al., 2019).

3.5.3. Cultural services

Most coastal communities observe 1 day as a no fishing day: Tuesdays, and in some coastal towns, either Thursday, Wednesday, or Sunday, are revered as sacred days, and the belief that whales are gods and their death requires libations of enquiry in the spirit world (Adjei and Sika-Bright, 2019). Some clans trace their ancestry to whales and can punish offenders (Adjei and Sika-Bright, 2019). Others believe in the protection and guidance of the marine environment as a god with the power to punish (Adjei and Sika-Bright, 2019; Dosu, 2017). These cultural services are gradually being lost due to the decision by some recalcitrant fishers to flout them.

The prevailing conditions threaten the global target of ending poverty and hunger by 2030, which is usually high in developing and low-income countries, especially in sub-Saharan Africa (UN, 2019).

3.6. Existing responses

Ghana is a signatory to several international and regional conventions, including the FAO's Code of Conduct for Responsible Fisheries, the International Commission for the Conservation of Atlantic Tuna (ICCAT), the Port State Measures Agreement on IUU fishing, Fisheries Committee for the West Central Gulf of Guinea, and United Nations Convention on the Laws of the Sea, among others (African Natural Resources Centre (ANRC), 2022; FAO, 2016). Ghana has, therefore, instituted and piloted some management measures to reduce or eliminate and regulate some of the pressures, changes in the state of the ecosystem, and impact generated by fishing activities (Fig. 7, Table 7) (Crabbe, 2019; Takyi et al., 2022), which include but are not limited to:

3.6.1. Laws and enforcement

Laws, including the Fisheries Act 625 of 2002, Fisheries Regulations L.I. 1968 of 2010, and Fisheries (Amendment) Regulations L.I. 2217 of 2015 (Table 8) prescribe the planning of the fisheries, management of access, control of catch and conservation, and pollution management through the provision of gear-types, prohibition of landing juveniles, gravid fishes, mammals and unprescribed fishing gears (explosives, chemicals, etc.) have been instituted (Ministry of Food and Agriculture of Ghana, 2010; Parliament of Ghana, 2002; Tsamenyi, 2013).

There have been a few management plans, including the Fisheries management plan of Ghana: Republic of Ghana fisheries and aquaculture sector development plan 2011 to 2016, A national policy for the management of the marine fisheries sector 2015–2019, and the Fisheries management plan of Ghana: A national policy for the management of the marine fisheries sector 2022–2026 have been instituted, with measures on prevention of new trawler entrants and restriction of fishing trips to 30 days (Ministry of Fisheries and Aquaculture Development, 2022; Ministry of Fisheries and Aquaculture Development and Fisheries Commission, 2015).

A Fisheries Enforcement Unit (FEU), consisting of a multistakeholder group made-up of officers of the Fisheries Commission of Ghana, the Ghana Navy, the Marine Police, and the Airforce, has been formed to enforce the fisheries laws through patrols and sting operations (Parliament of Ghana, 2002; Yamoah, 2019). The FEU arrested about 180 small-scale fishers and seized over 1000 nets and several generators between 2014 and 2017 (Frimpong, 2017; Glover, 2017a; Ocloo, 2014). A fishing vessel arrested by the FEU was recently fined US$ 1 million for contravening the fisheries law (Graphic.com.gh, 2019). However, effective enforcement and complete implementation have been lacking due to the fear of political reprisal during elections, especially in the artisanal fishing areas.

3.6.2. Licensing and quotas

A licensing regime with fees has been instituted (Table 8), especially for industrial fishing fleets. However, the amount charged for the issuance of a license is low compared to other West African coastal countries and the destruction caused by these activities (Environmental Justice Foundation, 2021b; Ministry of Fisheries and Aquaculture Development of Ghana, 2010).

Quotas and catch certification systems are in place for only industrial tuna fishing fleets for sustainability and traceability, with a landing limit of some species, including the *Makaira nigricans,* a vulnerable species (250 tonnes) (Environmental Protection Agency of Ghana, 2017; Republic of Ghana, 2014).

3.6.3. Community-based fisheries management committees (CBFMCs)

Community-based fisheries management committees (CBFMCs) with bylaws have been established across several landing beaches for co-management of the fishery (Mensah et al., 2006; Ministry of Fisheries and Aquaculture Development, 2020). This has mostly been consultative. Hence a new fisheries co-management policy has been developed which would delegate some authority to resource users and other stakeholders (Ministry of Fisheries and Aquaculture Development, 2020).

3.6.4. The human and electronic observer programmes

In 2003, with the aid of the United States Government, the Fisheries Observer Programme was introduced to monitor the activities of fishers in the tuna industry, especially around FADs, which has been extended to the trawl fishery (Asiedu, 2015; Marine Fisheries Research Division, 2005). About 200 human observers have been trained and deployed on several fishing trips undertaken by Ghanaian-flagged industrial fishing

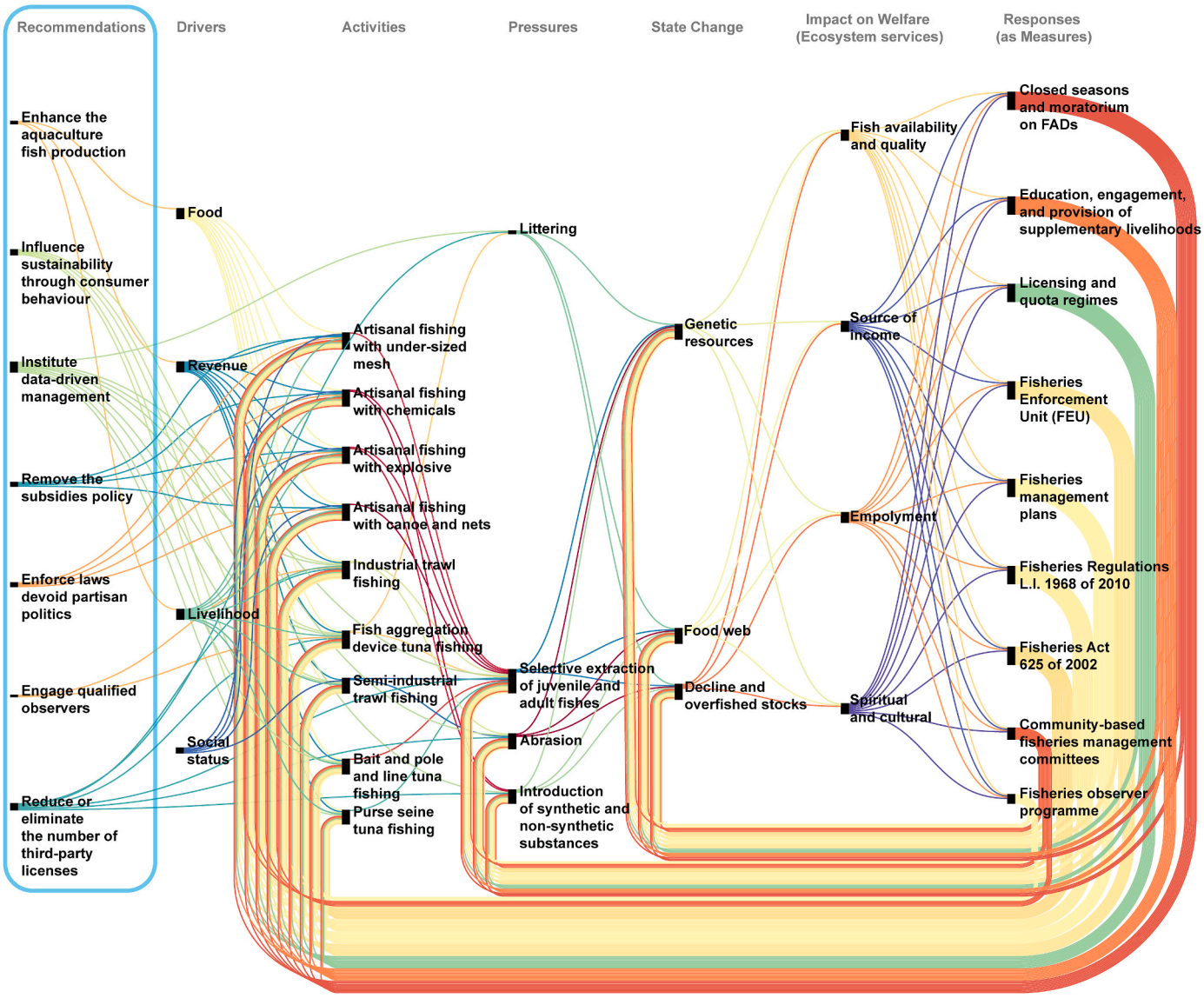

Fig. 7. The interconnection between DAPSI(W)R(M) components, where one element (e.g., food) influences one or more others (e.g., industrial trawl fishing, artisanal fishing with canoe and nets, etc.), with recommendations to address the drivers, activities, and pressures in the marine fishery (*adapted from Takyi et al. (2022)*).

Table 7
Examples of the management responses and suggestions to the several issues in the marine fishery of Ghana.

Response	Recommendations
Law and Enforcement	Enhance the aquaculture fish production
Licensing and quotas	Influencing sustainability through consumer behaviour
Community-based fisheries management committees (CBMFCs)	Remove the subsidies policy
Human and electronic observer programmes	Enforce laws devoid of partisan politics
Vessel monitoring systems	Engage qualified observers
Closed seasons and moratorium on FADs	Institute data-driven management
Sustainable FADs and illuminated nets	Establish standard catch reporting system
Education, engagement, and provision of supplementary livelihoods	Reduce or eliminate the number of third-party licenses
Culture and bans	

Adapted from Takyi et al. (2022).

vessels to curb illegalities, collect vessel catch data, and sample fish data (Teye et al., 2020).

An Electronic Monitoring System (EMS) was initiated under the Area Beyond National Jurisdiction (ABNJ) Project for prompt analysis to ensure compliance and efficiency, sustainable management, and reduction of IUU fishing (ICCAT, 2020; IWLEARN, 2018). However, the project has stalled due to a lack of funding from the Government of Ghana.

3.6.5. *Vessel monitoring systems*

A vessel monitoring system and an automatic identification system to help monitor and identify industrial fishing vessels in real-time, respectively, are in place (Asiedu, 2015; Mullié, 2019; Teye et al., 2020).

3.6.6. *Canoe frame surveys and identifications*

Periodic canoe frame surveys to ascertain the number of operational canoes in the marine fisheries are undertaken, with the latest reported frame survey taking place in 2016 (Akyeampong et al., 2013; Amador et al., 2006; Dovlo et al., 2016). A new canoe frame survey was undertaken in 2022, but data is being analysed, and results are yet to be

Table 8
Legal and institutional framework for fisheries governance in Ghana.

Governance	Law	Area of regulation	Identified gaps and biases
Fisheries plan	Fisheries Act, 625 of 2002 and Regulations L.I. 1968 of 2010, (Fisheries (Amendment) Regulations L. I. 2217 of 2015)	Applies to water bodies, including marine within the jurisdiction of Ghana. Authorisation to apply scientific data for management and allocation of fisheries resources. A regime of cooperation and consultation with local and international stakeholders.	The duration of scientific research for allocation is not available. Limited funding for implementation.
Access management	Fisheries Act, 625 of 2002 and Regulations L.I. 1968 of 2010 Fisheries (Amendment) Regulations L.I. 2217 of 2015 Ghana Maritime Authority Act 630 of 2002	Authorisation and regime for the issuance of licenses and permit conditions for commercial fishing, recreational, research, and trail fishing with accompanying fees and penalties Authorisation to monitor and inspect, prescribe types of gears, including minimum mesh size, and where they are to be used and declare close seasons and protected areas with penalties for violations.	Licensing is usually for fleets and seafarers in industrial fishing vessels. The license transfer requirement for canoes is frivolous, with no provision for the capping of fleets and gears for the fishery, and monitoring is mainly in the industrial fishery sector and sometimes for semi-industrial.
Catch control and conservation	Fisheries Act, 625 of 2002 and Regulations L.I. 1968 of 2010, (Fisheries (Amendment) Regulations L. I. 2217 of 2015)	Authorisation for the allocation of catch, prohibition of landing gravid finfish and shellfish, aquatic mammals and IUU and destructive methods with penalties, regulation of bycatches and transshipment, and prescription of the minimum fish size of fish to be landed. A regime of recording and obligation to reporting of catch by fishers.	Foreign vessels are the targets for quotas, and the law is silent on artisanal fleets and fishers. Transhipment is allowed between small-scale fleets under '*emergency*' circumstances without supervision.
Pollution management	Fisheries Act, 625 of 2002	Prevent pollution in fisheries waters with penalties	

The table was adapted from Takyi (2020): unpublished thesis

released. In 2017, the canoe identification card was initiated in the artisanal fishery to regulate access and improve the management of fishery resources, especially the small pelagic (Ministry of Fisheries and Aquaculture Development, 2022).

3.6.7. Closed seasons and moratorium on FADs

An annual two-month (July to August) and one-month (i.e., July) closed fishing season for trawlers and artisanal fisheries, respectively, to help with the rejuvenation and protection of fish stocks has been instituted (Abbey, 2020; Owusu and Nkrumah, 2022). However, due to the multispecies nature of the fishery, some stakeholders have called for a change in the dates for the closed season because they believe it is inimical to their livelihood.

An annual two and half month (from January to mid-March) moratorium on fishing on FADs by industrial tuna fishing vessels has also been instituted (Fonteneau et al., 2016; ICCAT, 2020; Ministry of Food and Agriculture of Ghana, 2010).

3.6.8. Sustainable FADs and illuminated nets

A collaborative project between the International Seafood Sustainability Foundation (ISSF), the Ghana Tuna Association (fishers) and the Fisheries Commission of Ghana aimed to reduce the impact of FADs on endangered species (e.g., sea turtles and sharks), and the use of slowly degradable material by introducing non-entangling and biodegradable FADs has been initiated (Moreno et al., 2018). The project has stalled due to a lack of commitment from the various stakeholders, especially the fishers.

To reduce the catch and entangling of sea turtles as bycatch in marine artisanal fishery, solar-powered lights that illuminate nets were piloted, which showed a decline in 80% of turtles caught (Allman et al., 2021).

3.6.9. Education, engagement, and provision of supplementary livelihoods

Several educational outreach campaigns, dialogues events, and alternative and supplementary livelihoods (i.e., for artisanal fishers) to create awareness of sustainable fishing, reduce fishing pressure and illegal fishing methods and improve interagency collaboration have been initiated by the Ministry of Fisheries and Aquaculture Development and Fisheries Commission, non-governmental organisations, academic institutions, and donor agencies (Ameyaw et al., 2012; Glover, 2017b).

The Ministry of Fisheries and Aquaculture Development has also introduced a programme called Aquaculture for food and jobs, which is aimed to improve fish production and availability through aquaculture (Akoto, 2021).

3.6.10. Culture and bans

Traditional beliefs, including the prohibition of fishing on Tuesdays, especially in artisanal fishery, with sanction from, 'the god' because fish even caught are not allowed to be sold (Adjei and Sika-Bright, 2019; Dosu, 2017). However, this belief is ineffective in recent times as some fishers have resorted to violating it (Adjei and Sika-Bright, 2019; Dosu, 2017).

The Ministry of Fisheries and Aquaculture Development has banned pair-trawling, transhipment (locally referred to as *Saiko*), and other illegal fishing activities at sea due to the associated negative ecological impact, the need for traceability of catch in the fishery, and the avoidance of sanctions by the European Union (EU) concerning the export of seafood to the EU market (Environmental Justice Foundation, 2021c, 2020, 2018; European Commission, 2021; O'Neill et al., 2018).

3.7. Recommendations

The responses so far have not been integrated and directed at the problems highlighted in this study (Fig. 7, Table 7). Therefore, the following are recommended:

Enhance aquaculture fish production: Policies on aquaculture (e.g., *Oreochromis niloticus, Clarias gariepinus, Penaeus monodon,* etc.), including the Government of Ghana's flagship program, christened *Aquaculture for Food and Jobs* (Akoto, 2021), should be given the much touted attention and logistics; and it could be enhanced to include implementation of successful mariculture. These can help supplement and reduce loss of revenue during closed seasons and the dependency on wild seafood and serve as a source of livelihood in fulfilment of SDGs 1 (ending poverty), and 2 (ending hunger and achieving food security) (Ofori-Danson et al., 2019; UN, 2019).

Influence sustainability through consumer behaviour: Consumer behaviour has been essential in influencing the activities of fishers and their catch in other countries. For instance, eco-labelling (e.g., Marine Stewardship Council (MSC) Fisheries Certification) (Defaux et al., 2018) of fishery products for the local and international market can contribute to the reduction in the pressure of extraction of fish and other species (i.e., endangered or threatened) through traceability for the sustainability

of the fisheries (i.e., improve stocks and genetic diversity). This would contribute to ensuring sustainable consumption, production and conservation of marine resources in fulfilment of SDGs 12 and 14 (UN, 2019).

Remove the subsidies policy: Input subsidies (about US$ 40 million annually) (Okyere and Chuku, 2020), including premix fuel and nets, in the small-scale fishery, could be channelled into government flagship programmes such as *Aquaculture for Food and Jobs*. Input subsidies could also be used as incentives (i.e., financial rewards) for voluntary surrender of unapproved fishing gears, and provision of information to reduce the pressure of extraction and abrasion.

Enforce laws devoid of partisan politics: The appropriate laws in the Fisheries Act and Regulations (e.g., prohibition on catching juvenile fish, the use of unapproved fishing gear, transhipment, discards, etc.) should be enforced without partisan considerations, improved species and genetic diversity, food security and livelihoods. Partisan politicisation of the fishers and the fishing industry should be reduced or eliminated for effective and efficient implementation of the provisions in the Fisheries Act 625 of 2002 and Fisheries Regulations L.I. 1968 of 2010.

Review and amend fisheries laws: The Fisheries Act 625 of 2002 and the Fisheries Regulations L.I. 1968 of 2010 need to be reviewed and amended to make them relevant, efficient, and effective in tackling current and future challenges of the fishery industry, especially with IUU fishing.

Engage qualified observers: The Ministry of Fisheries and Aquaculture Development and the Fisheries Commission must engage observers with a background in biological, conservation and environmental sciences who would appreciate the work they have been tasked with to ensure efficiency in compliance, data collection, and analysis. An audit of observers' activities should be conducted annually to ensure the maintenance of high-quality personnel.

Institute data-driven management: A comprehensive and coordinated data collection and analysis regime (supported by digitisation and digitalisation) of all aspects of the fishery (i.e., artisanal, semi-industry and industry), the pressures, the state of the marine food web, the genetic characteristic of marine species landed, the loss of ecosystems and revenue to the economy, among others. Although the purchase of the research vessel has been delayed (i.e., a major challenge for independently conducting comprehensive research for effective policy decisions), the Ministry of Fisheries and Aquaculture Development must expedite action on its acquisition since it will be a pivot in driving the management of marine fisheries locally, regionally, and globally.

Establish standard catch reporting: For traceability, adequate identification, and sustainability, the report of fishers' catches in the artisanal and trawl industry (e.g., fish manifest where *AA* - represent red snapper or barracuda or blue spotted fish, *B* - *Dentex* spp. and frigate tuna) must be standardised like what pertains in the industrial tuna fishery since there are discrepancies in the reporting format between vessels. The standardisation would give managers a clear picture of the state of species.

Reduce or eliminate the number of third-party licenses: One characteristic of the West African and Ghanaian fisheries is the problem of third-party licensing (which contributed to the decline in about 50% of fish stock) (Pichon and Pietsch, 2020) for countries, which is hampering the efforts to reduce extraction pressure, abrasion, and littering in the fisheries. It encourages the involvement of foreign interests with ties to government officials and the concealment of beneficiary owners of industrial fleets are some of the challenges of the fishery (Environmental Justice Foundation, 2020; Environmental Justice Foundation and Mpoano, 2019). A stop to this practice would improve the diversity and availability of fish stocks and contribute towards the global target of ensuring sustainable production, and the conservation of marine and ocean resources in fulfilment of SDGs 12 and 14 (UN, 2019).

Enhance conflict resolution mechanism: The issue of conflicts in the Ghanaian marine fishery is a challenge in ensuring sustainability (Table 9), e.g., the conflict between artisanal fishers and industrial trawlers over the latter's invasion of fishing grounds (i.e., 30 m depth areas a preserve of artisanal fishers) due to targeting of common species (Asiedu-Addo, 2018; Bokpe, 2017; Glover, 2015; Koranteng, 1998). Similarly, conflicts exist over the destruction of artisanal fishers' nets by industrial vessels, between artisanal fishers and administrators (e.g., MoFAD and FC) over the use of light, unapproved nets and chemicals for fishing, and between fisheries observers and crew (Asiedu-Addo, 2018; Bokpe, 2017; Glover, 2015; Okyere and Chuku, 2020). In some fishing communities in Ghana, for instance, small-scale fishers are divided between anti-illegal fishing and pro-illegal fishing along political party lines (Abbey and Anane, 2017; Bokpe, 2017). These challenges can be addressed through stakeholders' acknowledgement of the problem, encouraging stakeholder engagement with the proffering of solution(s), monitoring, and follow-ups.

Table 9
Typology of conflict in marine fisheries in Ghana.

Conflict type	Sector involved	Example of conflicting parties
User	Intra and intersectoral	Artisanal fishers versus Transhipment "*Saiko*" operators Artisanal fishers versus light fishers Artisanal fishers versus industrial trawlers Artisanal fishers versus the oil and gas industry
Management	Intersectoral	Tuna fishing versus fisheries management/laws Trawling versus fisheries management/laws Transhipment versus opposition to fisheries management measures Light fishing versus fisheries management/laws Artisanal fisher versus fisheries management/laws Trawlers versus non-profit organisations Tuna fishers versus regional bodies (e.g., International Commission for the Conservation of Atlantic Tuna (ICCAT))

Adapted from Arlinghaus (2005).

Enhance the monitoring, control, and surveillance activities: The addition of dedicated patrol boats (currently unavailable) (Jonny-Nuepke, 2021) with personnel would enhance the *in-situ* monitoring, control, and surveillance of fishing activities. This would help Ghanaian Navy (i.e., currently tasked with the duty) concentrate on security duties, including piracy which is becoming a challenge in the Gulf of Guinea.

4. Conclusion

As a formal decision support tool DAPSI(W)R(M) provides the connection between human needs and changes in the state of the environment as well as the ecosystem services and needed management measures. The current approach to fisheries management has not yielded the necessary impact regarding the sustainability of Ghana's marine fishery sector. The situation persists although the sector continues to contribute significantly to the country's annual gross domestic product, providing essential food, and livelihood support for millions of people.

Hence, fishers in industrial (tuna and trawl) fishing and artisanal fishing sub-sectors have resorted to the use of unsustainable and sometimes illegal fishing gears (e.g., small mesh size nets, etc.) and obnoxious substances (e.g., DDT, carbide, and cyanide), which are detrimental to targeted and non-targeted species. Consequently, the fishery of species, including *Sardinella* spp. (important West African species), *T. albacares,* and *E. encrasicolus,* among others, have either declined or become vulnerable or near threatened with extinction due to the selective extraction pressures exerted on them through fishing.

The ecosystem services, including provisioning (food security), livelihood and cultural services have been affected making Ghana a net importer of fish to make up for the short fall due to the decline of marine catch. To ensure sustainability (Response using Measures), laws, and several interventions at the national and regional levels, including Fisheries Act 625 of 2002, Fisheries Regulations L.I. 1968 of 2010,

observer programmes, licenses, and quota, vessel monitoring systems, and the closed seasons, among others.

However, the measures implemented have been inadequate hence suggestions, including influencing sustainability through consumer behaviour, removing the subsidies for artisanal fishers, enforcement, establishing standard catch reporting, and management of the fishery must be data-driven, which is essential for the targets in the Sustainable Development Goals, the Convention on Biological Diversity, United Nations Decade of Ocean, the African 2050 marine integrated strategy, and the African Continental Free Trade Area. These can contribute to the resolution of the several conflicts (i.e., inter and intra) and stakeholder issues such as transhipment, IUU fishing, and poor data reporting.

The study establishes the causal effect among human needs, fishing, and state change, with unique insight into West African marine fishery and an opportunity for managers, scientists, and policymakers to effectively collaborate for sustainable fisheries management.

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.

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