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# Diagnostic analysis of the Canary Current System of West Africa: the need for a paradigm shift to proactive natural resource management

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## ABSTRACT

Large exports of land-based contaminants to the ocean exacerbate the effects of climate change, pollute ocean waters, disrupt biogeochemical cycles, harm marine organisms, and consequently jeopardise food security and the livelihoods of ocean-dependent communities. The Canary Current Large Marine Ecosystem (CCLME) is characterised by a mix of the Atlantic Ocean basin waters, reverse flow from the Mediterranean Sea, and inland waters from adjacent countries. This biodiversity-rich ecosystem is a source of ecosystem goods and services that provide sustenance for populations in the coastal states of West Africa and beyond. However, with the ocean surface warming, ocean productivity and fisheries' outputs have declined across multiple trophic levels. Therefore, in this diagnostic study based on a systematic literature review (publications from 2009 to 2020), we (a) provide an integrative assessment of the CCLME with the exception of Morocco, in the context of the modular large marine ecosystem framework using the categories 'environmental' (productivity, fish and fisheries, pollution, and ecosystem health) and 'non-environmental' (socioeconomic and governance), and (b) identify knowledge gaps and data scarce regions. The key drivers of change in the CCLME were identified as fishing pressure, land-based pollution, coastal habitat loss, and climate change. Productivity, land-based pollution, and ecosystem health were priority areas for data collection in the CCLME, with data deficiencies particularly apparent in The Gambia and Guinea. Therefore, to mitigate further degradation and accelerate progress toward sustainable management of the CCLME, research should be conducted in these priority areas of data deficiency. Furthermore, as most drivers of change in this ecosystem are related to weak management and a lack of regulatory enforcement, we recommend effective implementation, monitoring, and enforcement of existing national and transboundary regulations, as well as ecosystem-based human-centred management approaches, as proactive strategies for decoupling anthropogenic disturbances from climate change and optimising the productivity of the CCLME.

**Descriptors:** Anthropogenic disturbance, Canary Current Large Marine Ecosystem, Climate change, Land-based pollution, Productivity.

## 1. INTRODUCTION

Climate change and anthropogenic disturbances are an increasing threat to the sustainability of the planet. Despite efforts to protect the deteriorating health of Earth's ocean, the scope of current conservation measures is insufficient to address the issues that threaten ocean sustainability (IOC-UNESCO, 2017; Laffoley et al., 2020). The interconnected ocean covers

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>70% (361 million km$^2$) of the Earth's surface and is the planet's largest ecosystem. It can be divided into five ocean basins: the Arctic, Indian, Southern, Pacific, and Atlantic (Laffoley et al., 2020). Human health and well-being depend on the ocean because it provides multiple ecosystem goods and services including food, minerals, energy, international trade, recreation, and cultural activities (Visbeck et al., 2014; Melanie et al., 2017). It also regulates global oxygen levels, carbon sequestration, and nutrient cycling (Laffoley et al., 2020). Despite the numerous benefits derived from the ocean, humans are pressuring ocean resources through ocean-based economic growth, human development, and unregulated access (Visbeck et al., 2014). Given the importance of ocean resources and the pressures to which they are currently exposed, the restoration of regional ocean health is becoming increasingly important, as marine environments continue to deteriorate (Franke et al., 2020).

For the governance and protection of the ocean and its resources, the 1982 United Nations Convention on the Law of the Sea (UNCLOS) granted coastal states sovereign rights in exclusive economic zones (EEZs) within an area up to 200 nautical miles (370 km) from coastlines. EEZs constitute 39% of the ocean (O'Leary et al., 2020) and account for more than 90% of global marine fisheries (Palomares et al., 2020). Because the effects of country-level activities in this dynamic ocean area are not constrained by national borders, the large marine ecosystems (LMEs) approach to the assessment and management of marine resources and their environments was introduced at an international symposium convened at the annual meeting of the American Association for the Advancement of Science in 1984 (Sherman and Hempel, 2008). LMEs are large units of ocean space of approximately 200,000 km$^2$ or more that were delineated along EEZs of coastal states based on ecological (bathymetry, hydrography, productivity, and trophic relationships) rather than political or economic (Sherman and Hempel, 2008; Sherman et al., 2009) criteria. The LME system includes a multidisciplinary five-modular approach (productivity, fish and fisheries, pollution and ecosystem health, socioeconomics and governance, each with its own set of indicators) that is used to track the changing state of the ecosystem and facilitate the implementation of corrective actions that can sustain or restore resources and environments (Sherman and Hempel, 2008). The majority of EEZs fall entirely or partially within regional LMEs. Consequently, maintaining and conserving fisheries, marine species, and ecosystems can be accomplished by combining interventions on land, in freshwater, and in the ocean (IPBES, 2019 Global Assessment Report).

The Canary Current Large Marine Ecosystem (CCLME, Figure 1) is one of sixty-six regional LMEs, one of seven that surround Africa, and one of four eastern boundary upwelling ecosystems (EBUEs): the Canary, California, Benguela, and Humboldt Current systems. EBUEs account for 1% of global ocean surface area and 20% of global fisheries catch (Chavez and Messié, 2009; Fischer et al, 2019). They are characterised by coastal upwelling-related fronts that occur between cold near-shore waters and warm offshore waters (Nieto et al., 2012). The CCLME is dominated by wind-driven permanent (20 – 26°N) and seasonal (13 –20°N) upwelling zones (Gómez-Letona et al., 2017). The permanent upwelling front, off the Mauritanian-Senegalese coast, makes it a nutrient-rich, highly productive system (Arístegui et al., 2009; Ramos et al., 2017). Among the different regions in the CCLME (Figure 1), the coastline orientation of adjacent countries, variable width of the continental shelf, and presence of several capes (from north to south: Cape Ghir, Cape Juby, Cape Bojador, Cape Barbas, Cape Blanc, Cape Timiris and Cape Verde; shown in Figure 1) contribute to differences in upwelling intensities (Demarcq and Somoue, 2015). The CCLME has a surface area of $1.125 \times 10^6$ km$^2$ and is located in Northwest Africa, between longitude 15.30° W and latitude 24.65° N (Conti and Scardi, 2010). The Canary Current affects seven adjacent countries from north to south: the Canary Islands (Spain), Morocco, Mauritania, Cabo Verde, Senegal, The Gambia, Guinea Bissau, and Guinea. The capital cities for each are along the coast and combine for a population of 64.5 million people (Sambe et al., 2016). Mauritania, in the far north, is particularly vulnerable to desertification because 90% of its national territory lies within the Sahara Desert, as well as to sea-level rises and coastal erosion in its coastal areas (NDC Mauritania, 2015). Cabo Verde, a small island developing state (SIDS) with formally designated an archipelago since 1977 (Le Tixerant et al., 2020), has a relatively small

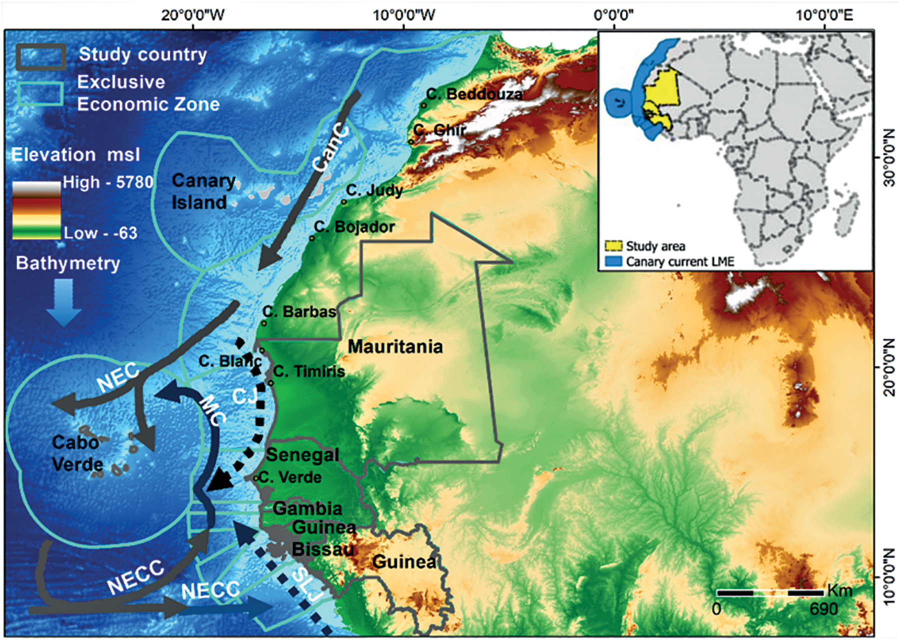



**Figure 1.** Schematic surface circulation in the CCLME and the focus countries of this study. The Upwelling system comprise permanent currents (dark gray lines), winter–spring seasonal currents (green lines), summer–autumn seasonal currents (blue lines), dash lines are currents identified only from altimetry. CanC = *Canary upwelling current*; CJ = Canary jet; NEC= *The North Equatorial current*; MC= *The Mauritania current*; NECC= *The North Equatorial counter–current*; SLJ= *Sierra Leone Jet* (adapted from Faye et al., 2015).

land surface area compared with the other coastal states. However, it has an extended EEZ relative to other countries (Table 1). The archipelago has a hot desert-type climate and consists of ten islands and five islets (Mitchell-Thomé, 1972). Freshwater scarcity is a problem; at 500 $m^3$/year/person, the archipelago has the second lowest water availability in sub-Saharan Africa (Intended Nationally Determined Contributions Cabo Verde, INDC 2015a). As a SIDS, Cabo Verde takes 8% of its annual domestic freshwater supply from the ocean (Food and Agricultural Organisation of the United Nations ("FAO"), 2016) making use of approximately twenty expensive and energy intensive desalination units (INDC, 2015a). Guinea Bissau, also classified as a SIDS due to its island characteristics, includes an archipelago of over 88 volcanic islands and islets (Fernandes, 2012) and has 22% of its land area covered by water. The physical characteristics of the countries that border the CCLME are presented in Table 1.

The CCLME is a class 1 highly productive ecosystem (Failler, 2014), i.e. a marine eco-region with the highest productivity in terms of primary (phytoplankton) and secondary (zooplankton) production (Berraho et al., 2015). Among the LMEs that surround Africa, the CCLME was the largest contributor to reported fish catches in 2014 (41% of total), with an estimated economic value of USD 7.1 billion (Zeller et al., 2020). The total annual value of ecosystem goods and services, including fisheries, timber and non-timber forest products, climate regulation, waste treatment, and tourism and recreation provided by the marine and coastal ecosystem of the CCLME has been estimated at USD 11.7 billion (Interwies and Görlitz, 2013). Consequently, the CCLME is a vital resource not only for countries within its influence zone but also for much of West Africa (CCLME project, 2016). However, as in other ocean basins, pollution in the CCLME is widespread, worsening, and, in most countries, poorly controlled (Landrigan et al., 2020), highlighting the need for proactive resource management.

In previous studies conducted within the framework of the FAO-United Nations Environment Project (UNEP)-Global Environment Facility projects, transboundary diagnostic analyses (CCLME project, 2014; CCLME project, 2016) of the CCLME did not include a time-bound literature review. In addition, the main

**Table 1.** Physical and soci-economic characteristics of the focused adjacent countries of the CCLME.

| Parameters | Mauritania | Cabo Verde | Senegal | The Gambia | Guinea Bissau | Guinea |
|---|---|---|---|---|---|---|
| [a] Total surface area (km$^2$) | 1,030,700 | 4,033 | 196,710 | 10,600 | 36,130 | 245,857 |
| [a] Continental water (km$^2$) | 39,000 | 0 | 4,180 | 2,100 | 8,010 | 140 |
| [a] Coastline length (km) | 754 | 965 | 718 | 80 | 274* | 320 |
| EEZ (km$^2$) | 173,728 | 804,694 | 158,936 | 23,184 | 107,301 | 10,500[a] |
| Average annual precipitation (mm) | 660 | 261 | 500 | 1,450 | 2,030 | 4,000 |
| Population (in 1000) | 4,124 | 535 | 1,525 | 2,188 | 1,826 | 1,246 |
| Population density (average of 2013–2017) inhabitant/km$^2$ | 4,282.57 | 135.6 | 80.58 | 185.9 | 55.51 | 55.72 |
| [b]UNDP Human Development Index (2020) | 0.5 | 0.67 | 0.51 | 0.50 | 0.48 | 0.48 |

*Length of coastline (excludes the oceanic islands): Los Bijagós Archipelago: 80 islands (20 inhabited)

[a] FAO, 2016. AQUASTAT Main Database - Food and Agriculture Organization of the United Nations (FAO). http://www.fao.org/aquastat/en/ [website accessed on 21/12/2020; 15:10].

[b] UNDP HDI Ranking 2020. http://hdr.undp.org/en/content/latest-human-development-index-ranking?utm_source=EN&utm_medium=GSR&utm_content=US_UNDP_PaidSearch_Brand_English&utm_campaign=CENTRAL&c_src=CENTRAL&c_src2=GSR&gclid=CjwKCAjw8KmLBhB8EiwAQbqNoJnB65pSMDof85TdvedaI4DECS2z2zhu65IOQnNzqG0nbhOpwsfx_xoCJMUQAvD_BwE

objective of these studies was to identify priority transboundary issues and propose a series of policy recommendations and reforms that could address the transboundary concerns through a Strategic Action Programme adopted by all countries (CCLME project, 2016). Therefore, given that the CCLME is a dynamic system, the present diagnostic study builds on these previous studies and on other CCLME studies through systematic literature review. Specifically, the present research aims to (1) determine what is currently known about the condition of biological (fisheries) resources and ecosystem health of the CCLME; (2) contribute to the economies of individuals as well as nations, and (3) facilitate the development of management frameworks and policy instruments that govern access to the CCLME, its uses, and its conservation. This research also sought to identify priority knowledge and capacity building needs, begin to develop possible solutions, and establish a baseline for a decadal comparison consistent with the UN Decade of Ocean Science for Sustainable Development (2021–2030; https://www.oceandecade.org).

The steps of the current systematic literature review (Figure 2) were adopted from the works of Denyer and Tranfield (2009) and Mengist et al., (2020), and the diagnosis of the CCLME was completed through a focus on selected core indicators of the ecosystem-based five-modular approach (Table 2), which could be broadly classified by its environmental (productivity, fish and fisheries, pollution, and ecosystem health) and non-environmental (socioeconomics and governance) parameters. In addition, but with the exception of Morocco, the assessment was downscaled to the coastal areas and national EEZ (sub-LME) levels to comprise a holistic view of the contributions and local realities of the adjacent coastal states under investigation, namely Mauritania, Cabo Verde, Senegal, The Gambia, Guinea Bissau, and Guinea, which is also part of the Guinea current LME (GCLME) (Figure 1).

A systematic search was conducted in October 2020. The literature search strategy included three electronic databases: Google Scholar, Web of Science, and JSTOR using paired search terms as follows: 'productivity', 'fisheries', 'pollution', 'socioeconomic', 'governance' AND 'CCLME' OR 'canary current' OR the name(s) of the focus country. The main inclusion criteria were publications that focused on one or more of the selected indicators, one or more of the focus countries, and that had been produced within the last decade (2009–2020). Publications in several languages (English, French, Portuguese, Spanish, and Russian) were considered, as were various document types (academic papers, grey literature, and national policy documents) and methodologies (qualitative, quantitative, and mixed research). Inclusion screening was performed by two reviewers independently. Following the information extraction, supplemental literature on aspects deemed necessary were

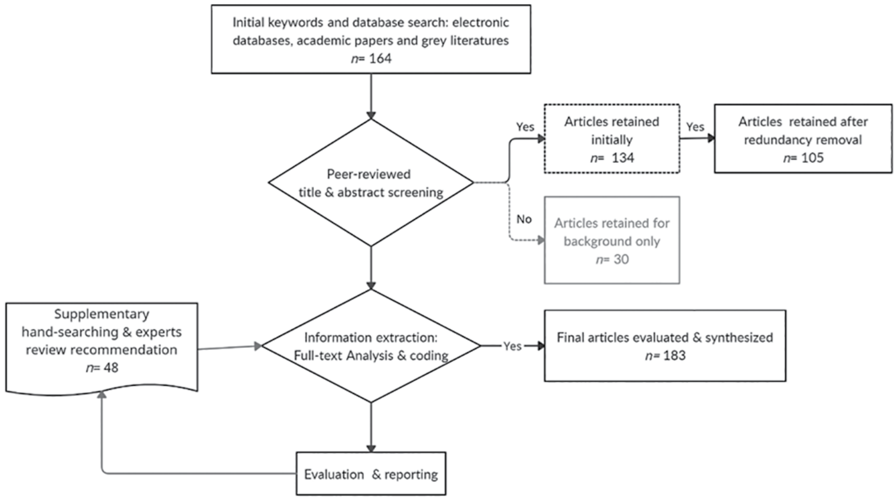



**Figure 2.** Systematic literature review steps adopted from Denyer and Tranfield (2009) and Menguist et al., 2020.

**Table 2.** Selected indicators based on the 5-LME modular themes and distribution of papers by country.

| Modular theme | Indicators | Multi-country | Mauritania | Cabo Verde | Senegal | The Gambia | Guinea Bissau | Guinea |
|---|---|---|---|---|---|---|---|---|
| Productivity | Primary productivity, chlorophyll-*a* (chl-*a*), phytoplankton & zooplankton biomass and diversity, nutrient levels | 9 | 2 | 4 | 2 | 0 | 0 | 2 |
| Fish & Fisheries | Fish stocks, Reported landings, illegal, Unregulated & unreported (IUU) fisheries | 16 | 5 | 3 | 5 | 2 | 6 | 1 |
| Pollution and Ecosystem Health | Climate variability and sea surface temperature (SST). Nutrients and toxic heavy metals, plastic debris, changes in land use coverage, changes in extent of mangroves Marine Protected Area (MPA) coverage, | 5 | 1 | 2 | 8 | 0 | 0 | 0 |
| Socioeconomics | Contribution to Gross Domestic Products (GDP), % fish protein, employment generation | 16 | 6 | 6 | 10 | 1 | 10 | 1 |
| Governance | Regional and national governance frameworks and performance | 13 | 5 | 4 | 6 | 1 | 5 | 1 |
| Total | | 59 | 19 | 19 | 31 | 4 | 21 | 5 |

obtained from expert review recommendations and hand-searching reference lists. Data were extracted and subsequently synthesised using STATA software (version 16; STATA Corporation, USA); results are presented in Table 2. Subsequently, a causal chain analysis was conducted that included information and evidence from the literature search; results are displayed in Figure 6.

The analysis on pollution and ecosystem health was complemented by an analysis of land use change metrics (e.g. percentage change and yearly loss) for major land use types (i.e. forest, mangrove, settlement, and agriculture). Changes to these major land uses are primarily driven by human activities, such as intensive agriculture and deforestation, which serve as important land-based sources of nutrient and trace metal transfer into the ocean. The extent of changes to these major land uses for the CCLME countries was computed for 2000 and 2013 from the West Africa land use land cover time series of US Geological Survey data (Tappan et al., 2016). Data for each land use category (e.g. forest) were aggregated from all sub-classes (e.g. sub-forest) in the time series maps, which contained 25 land categories; results are presented in Table 3.

## 2. The current state of knowledge on the biological resources and ecosystem health of the CCLME

After an extensive literature search, research on the CCLME conducted between 2009-2020 and focusing on one or more LME modular themes was categorised into academic papers (journal articles: 65; theses: 5) and grey literature (produced by institutions: 26; national official documents: 7). The geographic scope of most studies was at the LME to sub-LME level (multi-country). On a country-level scale, Senegal was highlighted as a high-data density area, whereas the EEZs of The Gambia and Guinea were understudied (Table 2). These findings agree with those of Brugiere and Kormos (2009), who stated that the biodiversity of Guinea was the least well-studied of those in West Africa.

### 2.1. The productivity of the CCLME

In terms of marine biodiversity, 14,095 taxa are known to exist in the CCLME; these are dominated by arthropods (22.3%), molluscs (21.6%), algae (15%), and chordates (14.3%) (Abedellahi et al., 2014). In the CCLME, climate variability, upwelling intensity and plankton biomass are intricately linked (Sánchez-Garrido et al., 2021). Primary productivity tends to vary annually: 323 gCm$^{-2}$ year$^{-1}$ was reported in 2015 (Fanning et al., 2015), whereas 372 gCm$^{-2}$ year$^{-1}$ was reported in 2016 (Sambe et al., 2016). Multi-decadal analyses show a general decreasing trend in chlorophyll-*a* (chl-*a*) levels (Chavez & Messié, 2009). Annual mean chl-a varies between 0.37 mg/m$^3$ (Fanning et al., 2015) and 1.31 mg/m$^3$ (Sambe et al., 2016). In the annual cycle of chl-*a* in the CCLME, it reaches its maximum levels (0.57 mg/m$^3$) in February and minimum levels (0.24 mg/m$^3$) in September (Fanning et al., 2015). Microphytoplankton populations in the CCLME are composed mainly of dinoflagellates and diatoms, and the number of phytoplankton species appears to decrease from north to south (Abdellahi et al., 2014; FAO, 2014). The biomass of these microscopic plants, which constitute the base of aquatic food webs, are projected to decrease by 35% in 2050, with changes of similar magnitude likely in the overall biomass of fish (Blanchard et al., 2012). In the food

**Table 3.** Extent (km$^2$) of major land uses in 2000 and 2013 in the CCLME focus countries.

| | Forest | | Mangrove | | Agriculture | | Settlements | |
|---|---|---|---|---|---|---|---|---|
| | 2000 | 2013 | 2000 | 2013 | 2000 | 2013 | 2000 | 2013 |
| Mauritania | 660 | 588 | | | 888 | 2,216 | 100 | 264 |
| Cabo Verde | 236 | 248 | | | 328 | 344 | 72 | 80 |
| Senegal | 3,208 | 2,904 | 1,396 | 1,496 | 34,152 | 42,856 | 784 | 1,392 |
| The Gambia | 308 | 244 | 560 | 652 | 2,724 | 3,216 | 148 | 188 |
| Guinea Bissau | 2,560 | 2,244 | 1,644 | 1,580 | 4,776 | 5,672 | 220 | 248 |
| Guinea | 16,900 | 16,520 | 1,712 | 1,736 | 26,584 | 42,348 | 628 | 920 |

Data source: Tappan et al., 2016

web of the CCLME, zooplankton occupies a key position and plays an important role in compacting organic matter, critical to the functioning of the ocean's biological pump (Berraho et al., 2015). Along the Senegal-Guinea maritime area, zones of high zooplankton biomass usually correspond to areas with high dissolved oxygen concentrations (4.0–4.5 mL/L) and low salinities (31.5–34.5 ppt) (Ndour et al., 2018). Sardinellas and other higher trophic species, including other fish and marine mammal species, rely on zooplankton (e.g. copepods) as a primary food source (Messié & Chavez, 2017). In general, zooplankton biomass decreases from nutrient-rich coastal waters to oligotrophic offshore waters. (Berraho et al., 2015). Zooplankton reaches its annual peak abundance (~3 gC/m$^2$) between March and April following upwelling event and nitrate supply (Messié & Chavez, 2017). Copepods are the dominant group of zooplankton, accounting for between 60 – 95% in the CCLME (Salah et al., 2012; FAO, 2014; Berraho et al., 2015).

At the sub-LME level, The Mauritanian EEZ has a chl-*a* concentration of 0.5–10.0 mg/m$^3$ and a nitrate concentration of 4.6–9.0 µmol/L (Clark et al., 2016). In this environment, flagellates (~87%) are the dominant phytoplankton group, followed by diatoms (~13%) and dinoflagellates (~0.1%). During the intense upwelling winter period of February to March (Benazzouz et al., 2013, 2014; Ndoye et al., 2014), zooplankton biomass and diversity are highly variable (Glushko and Lidvanov, 2012). This zone represents the southern limit of the distribution of temperate copepods (i.e. *Calanus helgolandicus*, *Temora longicornis* and *Oncaea curta*) and the northern boundary for tropical species (i.e. *Undinula vulgaris*, *Eucalanus pileatus*, *Euchaeta paraconcinna*, *Acartia plumosa* and *Corycaeus africanus*) (Berraho et al., 2015). The distribution of chl-*a* off the coast of Cabo Verde is influenced by several synergistic factors that vary according to the oscillation of physical parameters in the North Atlantic Ocean. Maximum chl-*a* levels (0.960–1.043 mg/m$^3$) occur annually between October and November (Ramos et al., 2012). Approximately 80 species of epibenthic algae and 142 species of microalgae have been identified in the area (Varela et al., 2011) as well as 295 species of zooplankton (copepods). Zooplankton biomass, assessed in spring 2003, varied with depth and light conditions: 10 mg/m$^3$ at 700-m depth during daytime, 100 mg/m$^3$ at 100-m depth during daytime and rising to 130 mg/m$^3$ at night (Martin and Christiansen, 2009). Diurnal variations in zooplankton biomass were confirmed by Denda and Christiansen (2014) with values of 14.7 g/m$^2$ and 18.3 g/m$^2$ for day and nighttime, respectively.

In the coastal waters of Senegal between 1999 and 2009, chl-*a* levels were 0.37–2.45 mg/m$^3$ with a mean chl-*a* of 1.06 mg/m$^3$ (Diankha et al., 2013). Diatoms represent 93% of the total microphytoplankton biomass (Demarcq and Somoue, 2015). In the Senegalo-Mauritanien (northern section of the Senegal EEZ) upwelling system, only the average values of microphytoplankton and zooplankton biomasses were available, 3.6 and 1.5 gCm$^{-2}$, respectively, for 1996 and 2005 (Mbaye, 2015). In the Senegambian area (southern section of the Senegal EEZ), zooplankton biomass data, as cited by Berraho et al. (2015), date back four decades (1982 and 1983). Although this data might not reflect the current distribution, annual average zooplankton abundance was 2,000 ind./m$^3$ with bimodal peaks; the primary peak was in November-January in 1982/83 (15,000 ind./m$^3$), and the secondary peak was in May-August 1982 (5,000–10,000 ind./m$^3$), respectively.

The Republic of Guinea Bissau has one of the most biodiversity-rich EEZs on the Northwest African coast because of its extensive continental shelf and highly diverse coastal ecosystems, which include estuaries, islands, rivers, and mangroves (Intchama et al., 2018). It also has one of the highest chl-*a* concentrations at 3.8 µg/L, with a maximum zooplankton biomass of 900 mg/m$^3$ (Ndour et al., 2018). Similar to the entire CCLME, copepods account for 57% of zooplankton biomass, followed by zoes (20%) and jellyfish (10%) (Soromou et al., 2020). The dominant species, accounting for approximately 80% of zooplankton, are copepods such as *Paracalanus quasimodo*, *Oithona brevicornis*, *Oithona simplex*, *Oithona spinulosa*, and *Oithona nana* (Berraho et al., 2015). However, zooplankton distribution in the Guinean EEZ is uneven because of environmental factors (Soromou et al., 2020).

### 2.2. Fish and fisheries of the CCLME

Although ocean upwelling intensities are increasing and sea surface temperatures are rising, overfishing remains the greatest threat to marine biodiversity and the ocean's long-term sustainability (Tedsen et al., 2014; Watkins et al., 2014; Bakun et al., 2015). The increasing global demand for fish, particularly from emerging markets, as well as conservation efforts in other regions, have made African waters a magnet for fleets from all over the world (Watkins, 2014). The CCLME contains one of the most productive fishery zones with commercially significant fisheries (Sambe et al., 2011; Sambe et al., 2016; Failler, 2020; FAO, 2020; Vazquez et al., 2021). Fishery activity is classified based on fleet characteristics (especially boat length and engine power) as either artisanal (small-scale) or industrial (large-scale). Artisanal fleets consist of small (3–11 m in length) wooden boats equipped with outboard engines of up to 25 horsepower, whereas industrial fleets include much larger vessels (up to 25 m long) with inboard engines of up to 500 horsepower (INDP, 2012). Total catches by industrial fleets have risen substantially from 819,000 tonnes (1950) to 7.4 million tonnes (2010), with 55% by foreign industrial fleets. During the same period, small-scale commercial and non-commercial catches have increased from 85,000 tonnes to 779,000 tonnes (Belhabib et al., 2015). Fish populations in the CCLME are dominated by small pelagics such as sardines (*Sardina pilchardus*), sardinellas (*Sardinella* sp.), horse mackerels (*Trachurus* sp.) (Sambe et al., 2016; CCLME project, 2016), as well as species from lower trophic levels. In 1986, the Spanish Institute of Oceanography performed the only systematic assessment of demersals biomass (43,645 tonnes) to date in the CCLME. A more recent survey from 1995 presented only partial data on demersal stocks (Belhabib, 2019).

The profile of fishing fleets varies greatly between adjacent countries. For example, in Mauritania, foreign industrial fleets account for approximately 80% of the annual catch. More than 72 marine species of economic value are caught in the CCLME, including cephalopods, crustaceans, demersal fish, small pelagics, tuna, oysters, and prawns (CCLME project, 2014). The dominant fish species caught include the round sardinella (*Sardinella aurita*), milk shark (*Rhizoprionodon acutus*), law croaker (*Pseudotolithus senegallus*), and the meagre (*Argyrosomus regius*), which are at risk of overexploitation (Gorez, 2018; Trégarot et. al., 2020). In almost two decades (1991-2009), total catches from the EEZ of Mauritania increased from 350,000 tonnes to over 1 million tonnes, with approximately 80% by industrial pelagic fleets (Barham et al., 2014). According to a report by the Comite Scientifique pour la Conservation de la Faune et la Flore Marines de l'Antarctique (CSC, 2010), crustaceans, cephalopods, and small pelagics were overfished by European fleets. The steady increase in fishing intensity has led to a severe decrease in biomass and signs that fisheries are becoming massively overexploited (Trégarot et. al., 2020). In 2010, an assessment of demersals classified them into twelve overfished species, three fully exploited species and seven unexploited species. Demersal biomass has decreased by about 75% since 1982, whereas the fishing effort was 30% higher than the maximum sustainable yield (40% for finfish). Some of the species affected include the flathead mullet (biomass decrease of 13%), meagre (−11%), spottail spiny turbot (*Psettodes belcheri*; −10%), canary drum (*Umbrina canariensis*; −8.3%), European squid (−8.3%), white grouper (−7.2%), and octopus (−5.5%) (Meissa and Gascuel 2015). The fishery sector of Mauritania is one of the fastest growing in West Africa and accounts for a quarter of the country's gross domestic product (GDP) and half of its exports. In 2013, the average annual catch was 600,000 tonnes from Northwest Africa, with 300,000 tonnes comprised of round sardinella harvested from Mauritania alone (Gorez, 2018). Fishing production exceeds 500,000 tonnes but is dominated by foreign fleets (95%). There are two main industrial fishing strategies: sardinella-oriented (dutch-type trawlers), i.e. sardinellas constitute 65% of the total catch, and mackerel-oriented (Russian–type trawlers) with catches that are dominated by horse mackerel (58%), chub mackerel (15%), and sardinellas (mostly as bycatch and representing 20%) (Braham et al., 2014). Artisanal fishery landings are reported to have increased from 15,000 tonnes in 1994 to over 114,000 tonnes in 2009 (Mauritanian Institute of Oceanographic Research and Fisheries, IMROP, 2010). Sardinella biomass and diversity is higher in July-September (spawning/warm period), which might be due to the higher upwelling index or changes in fishing strategy or efficiency (Barham et al., 2014). Furthermore, demersal fish catches decreased from 55,000 tonnes in 2006 to approximately 28,000 tonnes in 2009, whereas pelagic catches rose from about 200,000 tonnes in the 1990s to >800,000 tonnes in 2010 (IMROP, 2010; Binet et al., 2013).

Cabo Verde is an important marine hotspot due the presence of rare species of high scientific value, such as the melon-headed whale (*Peponocephala electra*) (Varela et al., 2011). Its fisheries are dominated by marine fishing, which mainly targets pelagic species (FAO, 2011). Artisanal fisheries target mostly demersal species for local consumption and market sale, whereas industrial fisheries target mostly pelagic fish that are used to supply the fish processing industry and for exportation (Almada et al., 2015). In Cabo Verde, 315 fish species have been identified, of which 6.3% are endemic to the archipelago (Wirtz et al., 2013) and 150 are commercially valuable (González and Tariche, 2009). Fishing potential has been estimated at between 36,000 and 46,000 tonnes, composed mainly of large apex predators, tuna, small pelagics, and demersal fish (Almada et al., 2015). In recent years, the stock of some of the overfished species, including sharks (*Squalus melanurus*) and mackerels (*Decapterus macarellus*), has declined (Almada et al., 2015; Luz and Viera, 2020).

In Senegal, the total marine fish catch comprises 250 taxonomic groups dominated by *Pomatomus saltatrix* (currently commercially extinct in Senegal), Sparidae fish, and small pelagic fish, especially sardinellas (Belhabib et al., 2014). In 2018, marine fisheries landed 524,852 tonnes, artisanal fisheries sector landed 398,643 tonnes (76%), and industrial fisheries landed 126,209 tonnes (24%) (Mbaye et al., 2018). The industrial fleets are dominated by Senegal-flagged vessels (94%), whereas only 6% are foreign–owned (Mbaye et al., 2018). In West Africa, Senegal is second only to Nigeria in fish production, with an annual catch of approximately 450,000 tonnes (Blédé et al., 2015). Pelagics make up about 80% of the fish catches and are an essential source of animal protein for West African populations (Failler, 2014, 2020). A 2018 survey of 141 vessels showed that Senegalese vessels consisted of 106 trawlers, eleven tuna vessels, and five sardine seiners, while foreign fleets consisted of sixteen tuna and three hake vessels (Mbaye et al., 2018). Recent indications show a significant decline in abundance of West African demersal resources, particularly in Senegal where grouper biomass, for example, has reduced by 90%. Species such as the sawfishes are under threat of extinction due to their low population growth rate, high catchability in fisheries, and high market value (Fernandez–Carvalho et al., 2014; Dulvy et al., 2016). In addition, in Senegal, the abundance index of octopus (*Octopus vulgaris*), a commercial cephalopod with high economic value, decreased from 13.7 kg/day at sea in 1999 to 3.3 kg/day at sea in 2016 (Diedhiou et al., 2019). In contrast, landing volumes increased from 2,980 tonnes in 1997 to 5,932 tonnes in 2016, with octopi constituting 80% of the total cephalopod catch (Diedhiou et al., 2019).

In The Gambia, about 500 pelagic and demersal fish species have been identified. The dominant fish species are sardinellas, bonga shad, mackerels, and other Clupeoides species (Ragusa, 2014; Belhabib et al., 2016b). The total catch by industrial fleets in 2005 was estimated at 4,600 million tonnes (Ragusa, 2014). Fish catches declined from 308,000 tonnes/year in 1990 to 76,700 tonnes/year in 2010 (Belhabib et al., 2016b). In 2016, total capture production was approximately 58,261 tonnes, of which 55,686 tonnes was from marine catches and 2,575 tonnes from inland waters (FAO, 2018a). Artisanal fishery is dominant in The Gambia, with primary targets including bonga shad (*Ethmalosa fimbriata*) which takes place in marine, brackish, and freshwater zones (Mendy, 2008). Subsistence fishing in The Gambia falls under one of the following categories: shellfish collection (mostly undertaken by women), fish given to women for helping men with their fishing activities, line and net fishing by men, and crab gathering by children (Anon, 2012).

The Guinea Bissau EEZ is one of the most productive zones in West Africa. A fish inventory has identified 327 species with an estimated fishery potential of >15,000 tonnes for shrimp, 30,000 tonnes for demersal species, and 100,000 tonnes for small pelagics (Niang, 2009). In artisanal catches, 53% of the catch is composed of small pelagic fish (Cabral, 2015). The industrial catch in Guinea Bissau is approximately 152,042 tonnes and consists mainly of bony fish (83%), crustaceans (10%), and cephalopods (7%) (Cabral, 2015). Total fish catch has been estimated at 85,000 tonnes, of which 20,400 tonnes (24%) comes from artisanal fisheries, which represents 62% of domestic market fish consumption (Cassamá, 2017). A stock assessment campaign, conducted in 2018 covering twelve miles from the coastline and depths of up to 600 metres, estimated the catch potential at 300,000 tonnes including fish (79%), crustaceans (14%), and cephalopods (9%) (The

Istanbul programme implemented in Guinea Bissau, 2020). Recently, Belhabib (2019) estimated an annual fish potential of 250,000 tonnes, similar to the values from the CCLME project in 2014. Some species are overfished in these waters due to the prevalence of illegal fleets and the high fishing efficiency of foreign fleets (Edmundson, 2014; Intchama et al., 2018). For instance, eighteen sharks and twenty rays were recorded, but no sawfish were documented in Guinea Bissau waters between 2009 and 2010 (Jung et al., 2011).

In Guinea, fish species were identified belonging to fourteen families and eighteen species of fish larval. Families of fish larvae included pelagics (Clupeidae, Carangidae, Pristigasteridae, and Hemiramphidae), demersal fish (Sciaenidae, Polynemidae, Drepanidae, Sphyraenidae, and Albulidae) and benthic fish (Cynoglossidae, Tetraodontidae, Gobidae, Mugilidae, and Trichiuridae) (Goumou et al., 2020). Artisanal fisheries provide >80% of national catches; 81.8% of artisanal fishers use conical nets known as '*Tèté yèlè*' made from mosquito nets, whereas the remaining 18.2% use synthetic 5 mm mesh nets (Goumou et al., 2020). Such fishing has led to the unsustainability of the ichthyofauna. In 2017, total marine catch was around 100,000 tonnes, but this mostly came from industrial fishing practised by foreign fleets; the output of inland fisheries represented around 30,000 tonnes of the catch (FAO, 2019a).

The data suggest that fisheries are declining in the CCLME (Sambe et al., 2011), which is currently experiencing ecosystem overfishing primarily due to '*fishing down the trophic level*' for small pelagic fishes (Links et al., 2020). The increased demand for fishmeal and fish oil due to the high prices of these commodities in world markets has triggered the establishment and multiplication of fishmeal factories along the West African coast (Greenpeace, 2019). In Mauritania, fish meal production has rapidly expanded over the last few years, with 29 plants in place by 2015 (Gorez, 2018) and 33 by 2019 (Greenpeace, 2019). In Senegal, there are now more than a dozen officially registered fishmeal plants and others operating clandestinely. There are three plants in The Gambia (Greenpeace, 2019). Fishmeal factories have recently begun using an increasing number of fresh fish, particular small pelagics such as round and flat sardinellas and bonga (Gorez, 2018; Greenpeace, 2019). In total, the fish catch for fishmeal and fish oil from the three countries was 695,154 tonnes in 2018; 4–5 kg of wild fish is required to produce 1 kg of fishmeal (Greenpeace, 2019).

## 2.3. Pollution and ecosystem health

West Africa is one of the most vulnerable regions to climate change; its effects could lead to negative changes in marine resources that threaten the livelihoods and well-being of local communities who depend on fisheries for food and income (Lam et al., 2012). These impacts, including changes in the intensity and seasonality of precipitation, upwellings, coastal currents, salinity, oxygen, and acidity levels, are likely to be aggravated by mineral, oil, and gas exploitation, the degradation of mangroves and other coastal habitats, and the damage to coastal infrastructures, which increases the food security risk of coastal communities and fishers (Sambe et al., 2011; Nyadzi et al., 2020). The rate of sea-level rise in West Africa, particularly between 10°N and 10°S, is slightly higher than the global average of 3.5–4.0 mm/year (Scambos and Stammerjohn, 2020). Sea surface temperatures (SST) have risen at a rate of 0.28°C per decade between 1982 and 2013 (Vélez-Belch et al., 2015). According to more recent estimates (from 1982 to 2019), the rate is actually 0.58°C per decade; the CCLME is classified as a fast-warming LME (Sweijd and Smit, 2020). Increases in SST are associated with lower primary production, disruption of trophic interactions, and decline in fish production and growth rates (Blanchard et al., 2012). Other side effects of climate change include hypoxic events and ocean acidification (Bakun et al., 2015). Aside from natural stressors and fishing pressures, there are numerous other sources of ocean pollution, both sea-based (upwelled waters, offshore exploration, and ballast waters) and land-based, with the latter accounting for 80% of the pollution that threatens the health of the ocean (Lee et al., 2016; Sweijd and Smit, 2020; Landrigan et al., 2020). Land-based pollution sources include the uncontrolled disposal of solid waste and the discharge of domestic and industrial effluents, especially from highly industrialised and densely populated coastal cities (Sherman and McGoven, 2012). Agricultural runoff into riverine areas is also a major source of land-based nutrient export to the ocean (Wang et al., 2020).

Toxic heavy metals can bioaccumulate in marine organisms and ultimately find their way into humans via dietary pathways in the food web . In the CCLME, coastal upwelling is the primary natural source of cadmium, while the phosphate industry is the primary source of anthropogenic cadmium (Auger et al., 2015). Morocco, the northernmost country of the CCLME, is the second largest global phosphate producer, extracting 27 million tonnes per year for processing into phosphoric acid and fertilizers (Auger et al., 2015). Due to the industry's release of mercury and an estimated 236 tonnes of cadmium into the ocean during manufacturing, regional cadmium levels in mussels are higher than the recommended values of 1 $\mu g g^{-1}$ and thus unfit for consumption (Auger et al., 2015). Elevated levels of cadmium were found in some bivalves and cephalopods from the Mauritania coast, while levels of lead and mercury were within recommended limits in these organisms (Toure et al., 2016). The main stressors affecting important fishery spawning areas and nurseries in the Senegalese EEZ are fishing pressures, offshore oil and gas exploration activities, and pollution (Ismala et al., 2019). Cadmium and arsenic levels were found to be high in some mussels (Diop et al., 2015; Ndiaye et al., 2017). Chromium, lead, vanadium, and nickel concentrations have been found to be high in sea lettuce (*Ulva lactuca*), whereas cadmium, copper, and selenium concentrations have been found to be high in the tissues of some fish, including flathead mullet and tilapia (Diop et al., 2015). However, bioaccumulation of mercury in fish tissues is strongly dependent on their size and foraging habitat; coastal demersals had higher mercury elevations than offshore pelagic species (Le Croizier et al., 2019). Though concentrations of mercury, polychlorinated biphenyls, and polycyclic aromatic hydrocarbons in fish tissues from Dakar landing sites were well within the guideline of $0.5 \mu g g^{-1}$ deemed acceptable by the European Union for daily human consumption (Net et al., 2015), care should be taken in the consumption of contaminated fish as the tolerable weekly intake levels of 1.3 $\mu g\ kg^{-1}$ established by the European Food Safety Authority (EFSA) can easily be exceeded (Le Croizier et al., 2019). Significantly, a data gap was identified in terms of heavy metal pollution from other EEZs.

Numerous estuaries and transboundary river systems drain into the CCLME, including the Casamance River, Senegal River, Gambia River, Rio Cacheu, Geba River, Koliba/Corubal River, and Konkoure River. However, basin-scale data on the pollution (nutrients and microplastics) exports of these rivers to the CCLME have not been reported to date.

Marine plastic pollution has increased 10-fold since 1980 (IPBES Global Assessment Report, 2019). In 2010, mismanaged plastic debris from African coastal countries constituted 14% (4.4 million metric tonnes) of the total global waste entering the ocean (Jambeck et al., 2015). In 2019, global plastic production was 368 million tonnes (UNDP, 2021). Plastic debris is the type of land-based pollution that most noticeably affects the ocean and its organisms (Jambeck et al., 2018). However, country-level data for plastic debris pollution entering the ocean in West Africa remain limited (Tavares et al., 2020). Along the beach of Cabo Verde, marine litter also poses challenges to marine wildlife conservation as well as to human health and well-being (Fernandes, 2019). A study by Fernandes (2019) of three of the most consumed demersal fish (*Sparisoma cretense*, *Cephalopholis taeniops*, and *Diplodus prayensis*) showed that 94.5% (52 of 55) had microplastic (<5 mm in size) in at least one of their tissues, with an average number of 4.8 ± 4.0 pieces of plastic per fish. Furthermore, marine debris on beaches where sea turtles nest extend the time needed for hatchlings to reach the ocean, a journey whose time determines the chance of survival from predators such as birds, ghost crabs, and other animals (Ramos et al., 2012). On the Senegal beach, plastic accounted for 98% of waste. Densities at a depth of 10 cm were 25 times higher than on the surface, with a significant density difference observed between urban and rural settings (Tavares et al., 2020). In Guinea Bissau, untreated urban sewers in the central part of the capital are discharged directly into the river. As a result, 70% of solid waste for the urban environment is washed into the ocean during the rainy season (NBSAP Guinea Bissau, 2015). In Guinea, the environmental problems have arisen mostly due to the lack of effective coordination and consultation mechanisms for environmental management (Ukwe and Ibe, 2010). In the capital city, waste systems have not been developed to clear the apparent plastic from the ocean surface (Borowski, 2017). Pollution arising from exploration and mining activities is also a major threat to the ocean (Donkor, 2012) and to public health. Much of the land-based waste in the ocean has been flushed there. It contaminates the shoreline, jeopardises marine and coastal flora and fauna, and negatively affects the livelihoods of locals (Borowski, 2017).

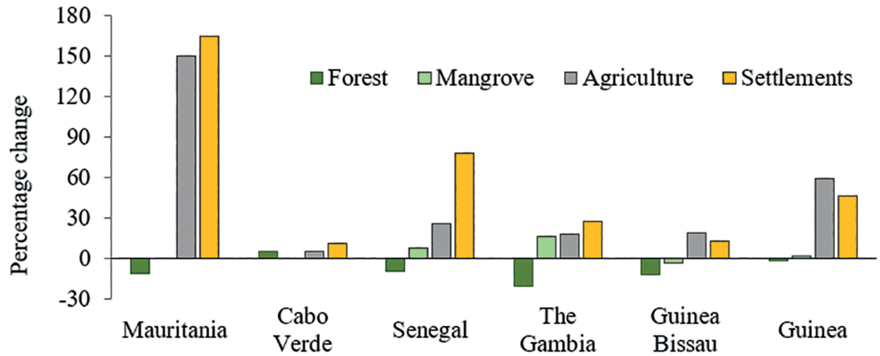
A higher supply of nutrients to the ocean enhances phytoplankton bloom (Chavez and Messié, 2009). Indeed, the nutrient-rich environments of the CCLME are susceptible to harmful algal blooms (Pitcher and Fraga, 2015). In the CCLME, such algal blooms have yet to be studied in detail off the coast of Northwest Africa (Trainer et al., 2010; Pitcher and Fraga, 2015). However, the dense blooms of up to $10^7$ cells/L that typically occur in spring and summer are associated with stratified ocean conditions induced by freshwater runoff (Trainer et al., 2010). Furthermore, several species of dinoflagellates, including *Alexandrium*, *Gymnodinium*, and *Pyridium* species, have been implicated in some form of fish poisoning (Pitcher and Fraga, 2015).

Atmospheric inputs to the ocean's surface of mineral aerosols or desert dust, that is soil particles suspended in the atmosphere by strong winds, are a major source of iron (Mahowald et al., 2009) and other nutrients that stimulates primary productivity in the CCLME (Gelado-Caballero, 2015). Iron is a key determinant of the biological productivity in ocean upwelling systems (Capone et al., 2013). North Africa accounts for 55% of global dust emissions, with areas of highly active sources being Niger, Mali, and Senegal (Gelado-Caballero, 2015). Because of the proximity to the Sahara and Sahel Deserts, mineral aerosol inputs to the CCLME are among the highest of any ocean basin (Arístegui et al., 2009), making it an iron-rich zone (Capone et al., 2013). Depending on aridity, annual average dust deposition in the Northeast Atlantic can range from 140 Tg/year to 276 Tg/year (Gelado-Caballero, 2015). There are three annual dust seasons: two strong (November-March and May-September) and one low (October-December) (Gelado-Caballero, 2015). However, natural climate variability and human land use changes, such as agricultural intensification, deforestation, and any other soil disturbances, can influence dust generation and mineral aerosol entrainment in the atmosphere (Mahowald et al., 2009; Gelado-Caballero, 2015). The loss of natural vegetative cover exposes soil layers, which results in dry soils and increased dust emissions into the atmosphere.

Forest loss per year was lowest in Mauritania and highest in Guinea Bissau, with a peak in 2013 (Table 4). Ecosystem services from coastal 'blue' forests in the CCLME were valued at an estimated USD 18,017 million year and USD 19,351 million year from mangrove and seagrass beds, respectively. However, data on coral reefs have yet to be collected (Trégarot et al., 2020). In Mauritania, fish grounds are mostly near the shore and are associated with seagrass beds (Trégarot et al., 2020), but information on seagrass coverage in the CCLME countries is lacking. In terms of mangrove coverage, the countries associated with the CCLME, excluding Cabo Verde and Mauritania (no available data), had approximately 5,464 $km^2$ of area as of 2013 (Table 3), which represents approximately 37% of the total mangrove coverage of West African countries, estimated at 14,753.44 $km^2$ (Hu et al., 2020). The highest mangrove area extension between 2000 and 2013 was observed in The Gambia (Figure 3). Nearly 10% of Guinea Bissau is covered by mangroves, but forest fires destroy 1.2 $km^2$ of these annually. Additionally, whole trees are cut down in some areas during oyster harvesting (INDC, 2015b). Wet rice cultivation, or rice paddy farms, grown by the Balanta ethnic group within mangroves areas account for 80% of annual

**Table 4.** Yearly forest loss ($km^2$) in the CCLME focus countries (data source: University of Maryland/hansen/global_forest_change_2019_v1_7).

| | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mauritania | 0.01 | 0.02 | 0.01 | 0.24 | 1.84 | 2.23 | 0.18 | 0.00 | 0.02 | 0.22 | 0.30 |
| Cabo Verde | 0.54 | 0.14 | 0.56 | 1.32 | 1.13 | 1.52 | 0.00 | 0.00 | 0.00 | 0.43 | 0.06 |
| Senegal | 82.87 | 61.60 | 17.21 | 40.22 | 144.82 | 74.22 | 38.31 | 41.96 | 77.02 | 40.18 | 41.32 |
| The Gambia | 7.14 | 7.80 | 4.25 | 7.24 | 17.42 | 18.42 | 6.32 | 3.06 | 7.64 | 4.90 | 4.64 |
| Guinea Bissau | 117.60 | 66.72 | 60.75 | 73.51 | 405.48 | 187.50 | 198.90 | 264.01 | 269.02 | 230.72 | 274.58 |
| Guinea | 7.14 | 7.80 | 4.25 | 7.24 | 17.42 | 18.42 | 6.32 | 3.06 | 7.64 | 4.90 | 4.64 |




| | Mauritania | Cabo Verde | Senegal | The Gambia | Guinea Bissau | Guinea |
|---|---|---|---|---|---|---|
| Forest | -10,9 | 5,1 | -9,5 | -20,8 | -12,3 | -2,2 |
| Mangrove | | | 7,2 | 16,4 | -3,9 | 1,4 |
| Agriculture | 149,5 | 4,9 | 25,5 | 18,1 | 18,8 | 59,3 |
| Settlements | 164,0 | 11,1 | 77,6 | 27,0 | 12,7 | 46,5 |

**Figure 3.** Percentage change in major land uses in the CCLME countries of study between 2000 and 2013 (data source: Tappan et al., 2016).

rice production (yields of 1,700–2,600 kg/ha) (NBSAP Guinea Bissau, 2015). Mangrove areas are favourable for farming because they do not require additional fertilisers and demand relatively little water (NBSAP Guinea Bissau, 2015). However, these farming practises are damaging to mangroves.

In 2007, mangroves covered 2,039 km$^2$ of the coastline of Guinea (Feka and Ajonina, 2011), but by 2013 only 1,736 km$^2$ remained (Tappan et al. 2016). Coastal development activities have indisputably contributed to the stripping of mangrove forests in Guinea. A clear example is the development of the Kamsar port, which resulted in the loss of approximately 700 km$^2$ of mangrove forests (Feka and Ajonina, 2011).

## 3. Contributions of marine resources to individuals and national economies

### 3.1. Socioeconomic considerations

Though the focus countries discussed herein are linked by the CCLME, they differ in terms of social, political, economic, and environmental contexts (Table 1). Except for Cabo Verde, these are designated among the least developed countries by the United Nations, feature extreme poverty, and have annual gross national incomes of USD 1,035 or less. Cabo Verde greatest source of wealth is the ocean. Per capita consumption of fishery resources increased from 23.0 kg to 26.5 kg between 2003 and 2011 (Medina and Gomes, 2015). Approximately 78 coastal communities depend on fishing as the primary source of income (Varela et al., 2011). According to a general fleet census (Varela et al., 2011), between July and August 2011, artisanal fleets were comprised of 1,239 boats, with 3,717 fishermen aged 12–87 and 987 fisherwomen aged 16–76. More recently, Gonzalez et al. (2020) reported that in 2017, there were 1,588 boats and 5,078 fishers in the national small-scale fishing sector, that is, within three nautical miles, with earnings ranging from USD 23 to 47 per week per fisherman, based on data collected from the National Directorate of Marine Economy. Adopting fishing as a profession was driven mainly by long-standing family tradition; 47% of fishers belonged to this category (Varela et al., 2011). Alternatively, 32% became fishers due to a lack of alternative sustenance and livelihood, 20% because of passion, and only 2% for profit. Of the women fishers, 53.6% sought to maintain family tradition, 18% lacked alternatives, 11% found that fishing with other women provided much needed peer support, while others reasons included family support and taste (Varela et al., 2011). Gomes and Medina (2015) reported that fisheries contribute between 2% and 10% to GDP. However, this depends on the activities considered: primary (fish harvesting), auxiliary (post-harvest processing and sales), or associated activities (tourism, shipbuilding, and production of fishing nets and gear) (Monteiro, 2012). Tuna fisheries account for 85% of exports (Lopes et al., 2019).

In Mauritania, the average seafood consumption per capita is estimated at 8–10 kg per year, predominantly from the artisanal sector, but reaches as high as 20 kg per year in the coastal cities of Nouakchott and Nouadhibou (FAO, 2019b). The Sub-Regional Fisheries Commission (SRFC, 2016) reported that fisheries amounted to 6% of the national GDP in 2013. In 2018, employment in the fishing sector was estimated at 180,420 people (FAO, 2019b).

In Senegal, in 2013 (FAO, 2019c) and 2019 (Greenpeace, 2019), fish and seafood contributed to approximately 43% and 70% of animal protein intake, respectively. However, 75% of households still suffer from chronic poverty (WFP, 2018). Yearly per capita seafood consumption increased from 23.9 kg in 2017 (FAO, 2019c) to 29.9 kg in 2019 (Greenpeace, 2019). In 2015, the sector provided more than 53,100 direct and an estimated 540,000 indirect jobs, mainly in artisanal fishing and processing (FAO, 2019c). In 2015, fisheries accounted for approximately 3.2% of national GDP (FAO, 2017). Threats to the sector include the construction of fishmeal factories along the coast and near landing sites, which has increased fishing pressure on small pelagics since 2010 (Mbaye, 2018). Furthermore, local fishers face difficulties finding fish due to sophisticated industrial fishing fleets in the artisanal zones, and sometimes encounter foreign ships that wreck their nets. This leads to conflict, frustration, and the potential loss of livelihood and food security (Jönsson, 2019). Given that the majority of Senegalese depend on fishery, overfishing of small pelagics and other marine resources has contributed to a rise in poverty and the forced migration of fishers (Jönsson and Kamali, 2012). The depletion of marine biological stocks has driven fisherfolk further into the ocean, with most now positioned up to 30 nautical miles from their community of origin (Binet et al., 2012). These movements could be for multiple reasons, including a number of fishing techniques (Binet et al., 2012) and trans-shipment operations, i.e. the transfer of fish to larger vessels at sea (Interpol, 2014; Daniels et al., 2016). Today, the depletion of CCLME fish stock is linked to an increase in illegal fishing (Interpol, 2014). If nothing is done to address the societal issue of fisher migration, fishers will be forced to travel longer distances and to increase efforts to catch rare species and smaller fish using prohibited techniques. Some fisherfolk have already begun long illegal migrations to Europe, while others leave Senegal and Mauritania yearly to fish in the Canary Islands, Morocco, or Spain (Binet et al., 2012).

In The Gambia, fish account for 40% of national protein intake (Ragusa, 2014). In 2016, per capita fish consumption was 28.3 kg (FAO, 2016), which was higher than the annual average of 20.3 kg. In 2015, fisheries represented 1.8% of GDP (FAO, 2018a). Inland waters also contribute significantly to the total production of fisheries. In 2015, 4,659 fishers were employed in the sector, 3,237 and 1,422 in marine and inland waters, respectively (FAO, 2018a). In Guinea Bissau, approximately 69.3% of the population live below the international poverty line of USD 1.90 per day, whereas 33% are extremely poor (Light Survey on Poverty Assessment, ILAP II, 2010 in INDC, 2015b). The highest proportion of poor households, 39.6%, was recorded within the agriculture and fishing employment sectors (INDC, 2015b). In 2016, fish consumption per capita was estimated to be relatively low at 1.3 kg (FAO, 2018b). Indeed, bivalves and gastropods are the main protein source for the Bijagós population, though data on these gastropods is lacking (NBSAP Guinea Bissau, 2015). Fish protein represents only 0.8% of total protein in the diet. Fishing is practised by farmers in the off season, as they migrate to Bijagós' archipelago during the dry season (targeting mostly elasmobranchs, pelagic sharks, and rays for their fins) and return to grow rice during the wet season (Tedsen et al., 2014). Fisheries employ approximately 2.0% and 5.2% of the total population and active population, respectively, with the potential value of fish estimated at between USD 150-200 million Biai (2009). The number of artisanal fishers employed ranges from five to eight per canoe, or 'pirogue,' earning an average of 161 USD per month, whereas the person in charge earns between USD 275–344 from fish sales (Cassamá, 2017). The rich marine resources of Guinea Bissau have contributed little to national economic development. In fact, these resources have been extensively exploited by foreign countries, whether through bilateral agreements (Figure 4) or simply through illegal and unregulated fishing (Intchama and Araújo, 2010; Dias, 2016). The fisheries sector in Guinea Bissau accounts for 3.3% of GDP. Fish exports represent up to 50% of government revenue, mainly from agreements and licences issued to foreign-flagged industrial vessels


**Figure 4.** Bilateral and multilateral marine fishing agreements between studied CCLME countries (blue rectangles) and beyond (grey circles). Dashed blue lines represents agreements between CCLME countries. Data source: ecolex.org.

(Tedsen et al., 2014; Cassamá, 2017). The fisheries sector also makes significant contributions to food security and employment (Cassamá, 2017). In 2015, one in two persons lived on less than USD 1 per day, and approximately 55% of the population lived below the poverty line (SRFC, 2016). In 2016, annual per capita fish consumption was low, at an estimated 9.8 kg (FAO, 2019a). Nevertheless, the fisheries sector is one of the major providers of direct and indirect employment to an estimated 150,000 people (FAO, 2019a). According to the SRFC (2016), fisheries represent approximately 2% of GDP because of artisanal fisheries and the aforementioned employment levels.

In the CCLME, as in other LMEs, illegal, unregulated, and unreported (IUU) fishing, sometimes known as pirate fishing, is a major concern (Diop et al., 2011; Martini, 2013; Watkins, 2014; Daniels et al., 2016). Developing countries with weak governance are the most vulnerable to IUU fishing by both domestic and international fishers. IUU is inversely proportional to governance indicators, i.e., nations in Africa and Asia with the worst governance indicators have the largest IUU (Childs and Hicks, 2019). When combined with weak governance, corruption in the form of bribery, favouritism, political influence, and other conflicts of interest (common in IUU fishing in Africa) facilitate illegal activities (Martini, 2013). Illegal fishing offences include fishing in protected or prohibited territorial waters, fishing without a licence or with a fraudulent licence, using prohibited gear, catching beyond legal limits, under-reporting catch, and harvesting protected species (Daniels et al., 2016; Standing, 2017). The incursion of foreign industrial fleets into waters reserved for artisanal small-scale fisheries fleets could be a potential source of conflict between artisanal fishers, industrial domestic, and foreign fleets (Belhabib et al., 2020).

To mitigate conflicts and competition between industrial fleets and artisanal fisheries, some countries have designated complete or partial inshore fishing areas with widths between 11-22 km from the coastline to the sea. In Cabo Verde, for instance, fishing by industrial foreign fleets is entirely prohibited in territorial waters (Belhabib et al., 2020). However, monitoring, controlling, and surveillance (MCS) of these areas is inadequate in most countries; foreign incursions persist (Belhabib et al., 2020). Though Guinea Bissau has a heavy presence of foreign fleets, the majority is unaccounted for in the official registry (Intchama et al., 2018).

West Africa has some of the world's highest rates of IUU fishery activity (Watkins, 2014). In the region, fish catches are up to 40% higher than reported (Agnew et al., 2009; Watkins, 2014). In Mauritania, the lack of data on traditional artisanal fishing is a barrier to the sector's growth (Niang, 2009). In Cabo Verde, long-term data on fisheries catch is lacking, as is the availability of effective monitoring and surveillance systems (Lopes et al., 2019). In Senegal, IUU loss in 2012 was estimated at USD 300 million, equivalent to 2% of GDP (Koutob et al., 2013), and artisanal fishing is significantly underreported. Unreported stocks have reached four times the official data, though this has recently improved to approximately 1.6 times (Belhabib et al., 2014). In The Gambia, local fish catches were also underreported to the FAO; fish catches were actually twice the reported values (Belhabib et al., 2014, 2016). In particular, there is a current lack of knowledge on the state of fish stocks in The Gambia (NDP, 2018), where fishery statistics are outdated and an institutional reappraisal to stem fish stock underreporting is needed (Belhabib et al., 2015, 2016). Furthermore, records are sparse from the equally important post-harvest sector including unloading, processing, and marketing (Sambe et al., 2011). In Guinea Bissau, industrial fisheries generated over USD 458 million from its EEZ, of which USD 75 million was taken illegally and only 40% of catches were reported (Intchama et al., 2018). In 2017, total catch was 370,000 tonnes/year. However, less than 2% was reported to the FAO (Intchama et al., 2018). Knowledge gaps on fishery resources in Guinea Bissau can be attributed to political instability, lack of good socioeconomic governance, and resource management (Cabral, 2015). Pandemics have also hampered conservation efforts. The annual regional cost of illegal fishing in West Africa was estimated at USD 2.3 billion during 2010–2016 (Doumbouya et al., 2017; Bähr, 2018), but at that time the loss was particularly high in Guinea, one of the countries affected by the Ebola crisis (Doumbouya et al., 2017).

In addition, recreational fishing (for leisure) in West Africa has expanded over the years, with annual unreported catches reaching 34,000 tonnes, equivalent to USD 152 million in revenue (Belhabib et al., 2016a). This sector is often assumed to have an insignificant impact on fisheries. However, it accounts for 1%, 141%, 17%, 278%, and 25% of artisanal fishers in Mauritania, Cabo Verde, Senegal, The Gambia, and Guinea Bissau, respectively. Nevertheless, the accounting of fish stocks has improved in general across the CCLME countries. For example, the total landings reported to the FAO by these countries has increased from 22% to 69% between 1970 and 2008 (Caramelo, 2010; FAO, 2010).

### 3.2. Management frameworks and policy instruments governing access to the CCLME, its uses and its conservation

In these West African countries, there are international (conventions on biodiversity, pollution, and fishing agreements), national (laws, decrees, and orders), and even local (co-management agreements, such as of artisanal fisheries) laws governing the management of the coastal and marine environment (Le Tixerant et al., 2020). At the international level, the UNCLOS provides an overarching legal framework for ocean governance. Given the interconnectedness of the ocean, appropriate regional governance frameworks have been created to address its sustainability and that of its resources. At a regional level, in the CCLME, all the focus countries, including Cabo Verde in 2019, are signatories to regional conventions and agreements, including the Convention for Cooperation in the Protection, Management and Development of the Marine and Coastal Environment of the Atlantic Coast of the West, Central and Southern Africa Region, and a protocol for cooperation in combating pollution in cases of emergency (the Abidjan Convention). The Abidjan Convention provides a regional framework for combating pollution as well as for protecting and developing the marine environment and coastal areas. Other regional conventions include the Regional Partnership for Coastal and Marine Conservation, a sub-regional coalition of actors (including Mauritania, Cabo Verde, Senegal, The Gambia, Guinea Bissau, Guinea, and Sierra Leone) working on the problems of the West African coastline. In addition, the focus countries have adopted other regional management tools including marine protected areas (MPAs).

Consistent with the requirements of overlapping conservation objectives in international agreements such as the Convention on Biological Diversity (CBD, 2010) Aichi biodiversity target, goal 11, which states that 'by 2020, […] at least 10% of marine and coastal areas […] are conserved through ecologically representative and well-connected networks of protected areas managed efficiently and equitably and other effective conservation measures by zone,' and the UN Sustainable Development Goal 14.5, which is to 'conserve at least 10% of coastal and marine areas […],' governments are now designating protected areas (defined as a 'geographically defined area, which is designated or regulated and managed to achieve conservation objectives' (Article 2 of the Convention on Biological Diversity, CBD)). Area-based conservation will likely remain the cornerstone of biodiversity conservation long into the 21st century (Maxwell et al., 2020). The metric of compliance is marine protected area (MPA) coverage. The Banc d'Arguin National Park in Mauritania is Africa's largest marine park, covering 5,600 $km^2$ of the 150,000 $km^2$ EEZ (Binet et al., 2013). Guinea Bissau is a net GHG sink, with MPAs covering 12.6% of the country's land area (INDC, 2015b). Rio Cacheu, considered one of Guinea Bissau's richest fishing regions, is home to the Mangrove National Park (Fernandes, 2012). Protected areas are used as policy instruments to preserve biological resources and are strongly supported by governments. Indeed, close to 13% of the area under national jurisdiction is under conservation to protect biodiversity, including the Bolama-Bijagós islands, a UNESCO Man and Biosphere site, and several other islands, which are RAMSAR sites (NBSAP Guinea Bissau, 2015). The government also promotes local conservation efforts (customary laws). For example, in the coastal communities of Felupe and Bijagós', oysters are only harvested during the dry season, and cutting down mangrove roots is forbidden (NBSAP Guinea Bissau, 2015). Studies of the CCLME countries (Failler et al., 2018, 2020) have found that, although progress has been made, none of the countries has yet reached the 10% Aichi target. Cabo Verde, which has the most MPAs in the region at 29, but only 1% coverage, would need to increase MPA area by 70 times to meet this goal (Failler, 2020), which is understandable given that marine areas constitute up to 90% of its national jurisdiction. For other countries to meet the target, Mauritania, Senegal, The Gambia, Guinea Bissau, and Guinea must increase their MPAs by 3.0, 6.2, 100, 4.7, and 10.0 times, respectively (Failler, 2020).

The bilateral and multilateral fishing agreement protocol of the studied CCLME countries are presented in Figure 4. Although controversial (Nagel et al., 2012), the Fisheries Partnership Agreement (FPA) between the European Union and Mauritania is by far the largest worldwide in terms of financial value (€305 million from 2008 to 2012) (European Commission, 2006 in Binet et al., 2013). Since 2008, a trust fund has been active as part of FPA reforms to ensure the sustainable management of fisheries in the Banc d'Arguin National Park by allocating <1% of total financial compensation for EU-flagged vessels in Mauritanian waters. Per the terms of this payment, it was classified as for ecosystem services (Binet et al., 2013). Details of FPA of EU with other countries are reported in EC (2015).

Cabo Verde is a member of several international and regional organisations including the FAO, the SRFC, and the International Commission for Conservation of Atlantic Tuna (Varela et al., 2011). It also has several cooperative fisheries in place with other West African countries, the European Union, China, and Japan among other countries (Figure 4). The fisheries agreement between Cabo Verde and the European Union between 2014 and 2018 allows a fleet of 71 French, Spanish, and Portuguese vessels to develop tuna fisheries in the country (Lopes et al., 2019; González et al., 2020). However, a new Sustainable Fisheries Partnership Agreement (SFPA) was signed in 2019 (González et al., 2020). Furthermore, Cabo Verde has ratified several international and regional agreements relating to environmental and biodiversity conservation. The fishery sector in Cabo Verde is currently under the authority of the Ministry of Infrastructure and Maritime Economy, but under the administrative responsibility of the Directorate General of Fisheries. The Institute of Maritime Economy and the Captaincies of Ports and the National Coast Guards are in charge of the surveillance of the EEZ and maritime registration supervision, and the National Institute for Fisheries Development (INDP) (Varela et al., 2011). The INDP is now known as Instituto do Mar I.P. (IMar) (González et al., 2020), created through Decree–Law No. 40/2019, of September 24 to promote and coordinate scientific research applied to the sea and its resources, ensuring the implementation of national strategies and policies in its areas of activity, and contributing to scientific, economic, and social development (circular No 1/2019, https://www.facebook.com/INDP.CV/photos/a.199495866805880/2450080691747375/?type=3&theater). The first set of 31 MPAs was created in 2010. According to the Directorate General for the Environment, one of the main drivers of continued biodiversity loss in Cabo Verde is poor management and weak legislative enforcement (Ministério do Ambiente, Habitação e Ordenamento do Território, MAHOT, 2014). Due to financial and human resource constraints, efficient administrative cooperation is a challenge across the country's nine habitable islands. Indeed, environment, tourism, and fishery sectors are not represented on all the islands (MAHOT, 2014). Consequently, there is little cross–sectoral cooperation, and mandates often conflict (MAHOT, 2014); there is a need to minimise sectoral barriers. In the official bulletin for resolution N° 95/2020, fishing nets and gear were regulated: encircling net fishing was approved for tuna, small pelagics (mackerel and whiting) fishing for industrial and semi-industrial longline fishing, and deep-water crawfish fishing for pink lobster, crab, shrimp and shark fishing. For artisanal fisheries, hand line fishing for tuna and demersals have been approved. Encircling nets and gillnets have been approved for small pelagics, and snorkelling is deemed acceptable for coastal lobster, whelk, and demersal fishing. Other approved fishing methods include live bait, sea cucumber, foreign licensed fisheries, amateur fishing, and sport fishing. Fishing effort regulation is enforced by permits, minimum catch size, and minimum mesh size of nets to monitor catches.

Senegal, similar to the other countries, is a party to various regional and international environmental treaties. Senegal was the first African country to sign a fishing agreement with the European Union in 1979 (Belhabib et al., 2013). Since 1982, a reciprocal fishing agreement between Senegal and The Gambia has been in force (United Nations Conference on Trade and development, UNCTAD, 2014). The Ministry of the Environment and Sustainable Development and its directorates are in charge of the conservation of the country's biological resources (NBSAP Senegal, 2015). The country promotes both *in situ* conservation measures, such as MPAs, agroforestry parks and customary laws (sacred forests), and *ex situ* conservation measures, such as private parks and 'totems,' which prohibit the consumption of certain species (NBSAP Senegal, 2015). However, existing barriers to biological resource conservation include a lack of regulatory enforcement by the government and of public environmental awareness, not to mention a lack of synergy between research institutions, human and financial capacity constraints, and a lack of knowledge of resources (especially in relation to marine invertebrates) (NBSAP Senegal, 2015).

The Gambia has adopted a cross-sectoral approach to fisheries management. The institution responsible for the management, development, and conservation of the marine and inland fisheries resources is the Ministry of Fisheries and Water Resources. The policy, legal, and management framework for the fisheries in The Gambia is dictated by the Fisheries Policy 2007, the Fish Act 2007, and its associated 2008 Fisheries Regulation. The Ministry of Fisheries and Water Resources, in collaboration with the Ministry of Trade and Industry, has developed a working fisheries strategy (2012–2015) (Ragusa, 2014). In total, 155 fish landing sites exist across the country, fifteen of which are on the coast with the rest inland. In cooperation with the Gambian Navy, a fisheries MCS unit coordinates all fish landing sites and takes stock of the fisheries. The MCS unit enforces existing management processes and protects the country's resources from IUU fishing (ME and A, 2013). However, there are concerns regarding capacity constraints. Nominal roles of the fisheries department call for 72 technical staff, but 19 of these technical positions remain vacant (Department of Fisheries, 2013 in Ragusa, 2014).

In 2018, Guinea Bissau and the European Commission signed a new Sustainable Fishing Partnership Agreement (EU Directorate-General for Maritime Affairs and Fisheries; https://ec.europa.eu/

oceans-and-fisheries/fisheries/international-agreements/sustainable-fisheries-partnership-agreements-sfpas_en). This agreement, which focuses on catch limits rather than vessel capacity, allows for 50 EU vessels to target tuna, small pelagic species, and demersal such as cephalopods and crustaceans. Institutional instability and weak regulations are the main causes of marine resource overexploitation; the election of a new national government leads to changes in institutional heads and service personnel (NBSAP Guinea Bissau, 2015). Hence, a lack of convergence on fishery catches (artisanal or industrial) has been observed, with the consequent conflicting reports on fish stocks. Guinea fisheries are regulated by various laws based on the FAO Code of Conduct for Responsible Fisheries (CCPR, 1995) and on international conventions for sustainable management of resources, such as Law N° 2015/026/AN on the Code of Maritime Fishing, Law N° 2015/027/AN on the Code of Continental Fishing, and Law N° 2015/028/AN on the Aquaculture Code (SRFC, 2016). The country has a decentralised system of biological resource management (NBSAP Guinea, 2016), and the root causes of fishery decline are IUU fishing, pollution, poverty, demographic growth, institutional/human/financial capacity constraints, poor governance (lack of a fisheries management strategy and collaboration among sectors). and illiteracy, which applies to approximately 55.2% of the population (NBSAP Guinea, 2016).

Governments face the challenge of dovetailing long-term national socioeconomic and sustainability interests with relatively brief political tenures. Good political governance, however, is required for responsible governance of resources (Musah, 2009). To assess national government performance, we focused on two composite governance indicators, reported in standard normal units ranging from −2.5 (low) to 2.5 (high) as proposed by Kaufmann et al. (2010): 1) government effectiveness and 2) regulatory quality. Government effectiveness includes the perception of quality of public and civil services and the degree of independence from political pressures, while regulatory quality refers to the perception of quality of policy formulation and implementation and the credibility of the government's commitment to such policies. Over the last decade (2009–2019), the first indicator improved in four of the CCLME countries (above the 45–degree line, Figure 5), stagnated in The Gambia (close to the line), and deteriorated in Guinea Bissau (below the line). Regulatory quality deteriorated in all countries except Senegal and Guinea.

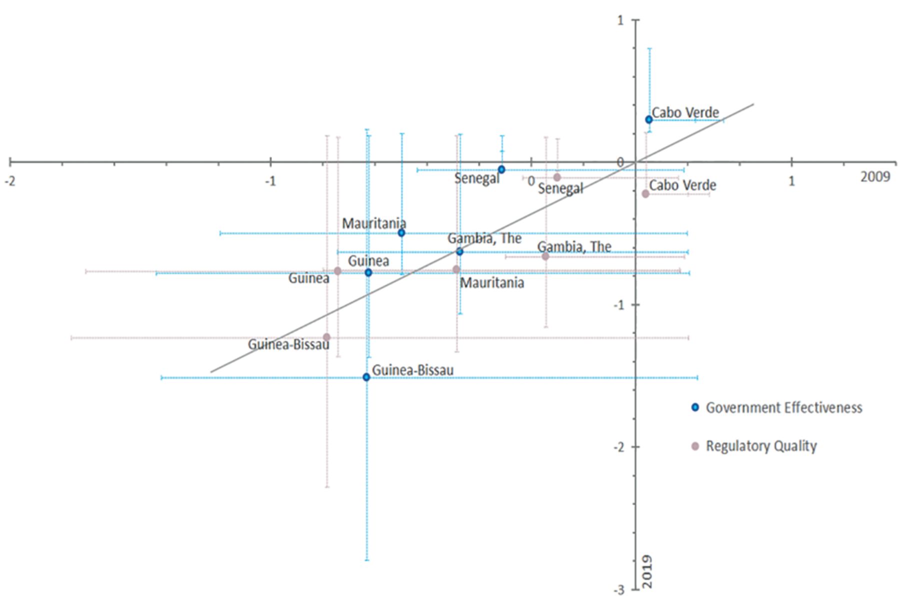



**Figure 5.** Changes over a decade (2009 - 2019) in governance effectiveness and regulatory quality of studied countries. Data source: Kaufmann et al., 2010.

In the wider context of Africa, the blue economy covers both coastal and marine spaces and encompasses a range of productive sectors including fisheries, aquaculture, tourism, maritime transportation, shipbuilding, energy, bioprospecting and underwater mining industries, as well as other related activities (United Nations Economic Commission for Africa, UNECA, 2016). The Africa Blue Economy development strategy, an integral part of the African Agenda 2063, is a blueprint that emphasises cross-sectoral interconnectedness, strong regional cooperation, and support for social considerations such as gender mainstreaming, food and water security, poverty alleviation. and jobs creation. Thus, this strategy could play a major role in the structural transformation, sustainable economic growth, and enduring societal progress of Africa (UNECA, 2016). Furthermore, the implementation of ecosystem-based Marine Spatial Planning (MSP) in the region is needed. MSP is an integrated and coordinated approach to ocean management that aims to balance development objectives and conservation goals (Santos et al., 2019). However, as of 2017, all of the focused CCLME countries except for Mauritania had yet to initiate the MSP (Santos et al., 2019). In 2012, with a view to support the MSP process, spatial maps were developed in line with regulations within the framework of the joint SRFC – IUCN, CARTOREG project for Mauritania, Senegal, and Guinea (Bonnin et al., 2013), and in 2016 for Cabo Verde (Bonnin et al., 2016). During this mapping exercise, issues in the legal texts of protected areas were identified, including typographical errors for geographic coordinates. For example, in Decree No. 2013/037/PRG/SGG creating the Tristao MPA of Guinea, the designated position was in fact in Guinea Bissau. The official park delimitation (Décret n° 76-16 du 9 janvier 1976) for the Langue de Barbarie National Park in Senegal is no longer appropriate due to significant climate change (Le Tixerant et al., 2020). There were also legal inconsistencies in the demarcation of the EEZ borders between Cabo Verde, the Gambia, and Senegal, and between Guinea and Sierra Leone (Le Tixerant et al., 2020). In addition, discrepancies in some legal texts in Mauritania advocated for in-country cross-sectoral collaboration. The Bay of Greyhound, a large marine area and key economic zone located in the northwest of the country, is home to the ports of Nouadhibou (mineral, hydrocarbon, and fishing port) as well as artisanal fishing and aquaculture area (Le Tixerant et al., 2020). Its location between the Cap Blanc reserve, the Bay of Etoile, and the Banc d'Arguin National Park poses a significant conservation challenge (Le Tixerant et al., 2020). The Ministry of Fisheries issued Decree n° 2010-15318 to prohibit fishing within a one-mile radius of the central point of the ore wharf in the port of Nouadhibou, while the Ministry of National Defense (maritime safety) issued Decree n° 2010-01019 to prohibit the navigation of coastal and artisanal fishing boats in a much larger area. Such incoherences in sectoral regulations are systemic barriers to regulatory implementation and compliance (Le Tixerant et al., 2020).

## 4. The levers are required to drive the sustainability of the CCLME: recommended future research directions

The examined literature included many papers that focused on selected themes on the CCLME over the last decade (2009–2020). However, the lack of data, as well as the inconsistency of available data in terms of study time frames, methodological approaches, and geographic coverage provide challenges when assessing the knowledge base of the CCLME, leading to difficulties in making accurate comparisons. The majority of the research was centred on the socioeconomic aspects of the CCLME, whereas pollution and ecosystem health received the least attention. A few academic thesis documents indicated that a small number of ocean scientists were active in the region. In 2017, Mauritania had 68 ocean science researchers (17.86% female), while Guinea had 156 (26.28% female) (IOC-UNESCO, 2020). Data was unavailable for the other focus countries. A 2019/20 survey of university programmes on ocean science in Northwest Africa countries identified up to 20 university programmes in Senegal, as well as a few others in Cabo Verde (including a German Federal Ministry for Education and Research (BMBF)-funded WASCAL Master's Program in Climate Change and Marine Sciences Programme, recently endorsed by United Nations in the framework of the United Nations Decade of Ocean Science for Sustainable Development; https://wascal.org/united-nations-endorses-wascal-cabo-verdes-ocean-science-for-sustainable-development-project/), and Guinea

(IOC-UNESCO, 2020). Thus, the establishment of a fully-equipped (in terms of human capacity and field/ laboratory materials/equipment) marine research institution that can promote ocean research and educate nationals is a recommended course of action. In addition, the research results of new and existing programmes should be made widely available; there is a need for interdisciplinary study reinforcing the scientific outputs of this complex system.

In the CCLME, primary productivity, along with phytoplankton and zooplankton abundances, fluctuates with the seasonal ocean upwelling cycles. In general, productivity has declined, but the primary productivity of the EEZs has not been sufficiently studied nor is well understood. At the sub-LME level, there is a significant knowledge gap between marine organisms and biotic interactions; most of the available are outdated. The majority of published studies have concentrated on specific sections of the EEZ, whereas other studies that are over a decade old no longer represent the current state of this dynamic system. These issues highlight the need for a standardised method of data collection as well as for analyses of the phytoplankton and zooplankton, dominant species, and existing biotic relationships.

In the CCLME, climate change and human factors are inextricably linked as drivers of change. As presented in Figure 6, strong inter-linkages exist between ocean health, sustainable societies, and economy. The key underlying causes of CCLME productivity and fish stocks loss include land-based pollution, coastal habitat degradation, overfishing, and climate change. However, the core causes of these can be linked to poor management, institutional and human capacity constraints, and poverty. This is consistent with the findings of the CCLME project (CCLME, 2016). Although the effects of climate change are already being observed in this marine ecosystem, decoupling anthropogenic influences can help maintain and strengthen the ecosystem's resilience.

Past studies (Tedsen et al., 2014; Watkins et al., 2014) have reported overfishing as the greatest threat to marine biodiversity and continued sustainability of the CCLME. An exponential decline in fish has been reported across multiple trophic levels. Additionally, asymmetry in the access to and exploitation of fishery resources was noted in the CCLME countries. However, there is no comprehensive and up-to-date database or national registry for reporting of the fishery sector, including the post-harvest sector (unloading, processing, and marketing). The post-harvest sector is economically important because it drives the sustainability of the fishery sector and minimises bycatch and post-harvest losses. However, data on the economic contribution of this sector (e.g. the number of people employed) is nearly non-existent (Sambe et al., 2011).

Overall, the present diagnostic study highlights the need to strengthen the capacity for institutions

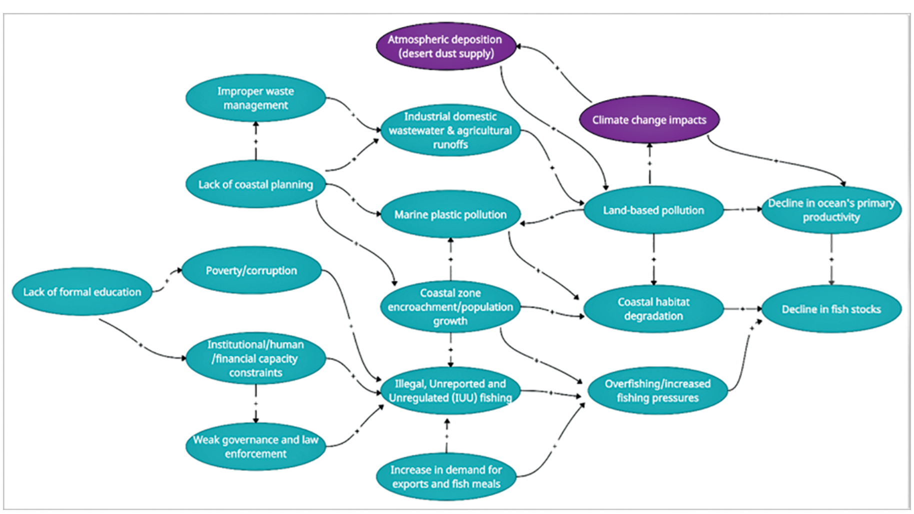



**Figure 6.** Feedback loop (positive) on main stressors on the CCLME. Natural stressors are highlighted in purple while green are anthropogenic stressors. X ⟶ Y indicates that an increase in X leads to an increase in Y.

and individuals to respond to accountability needs in relation to national fishery data. In addition, proper accounting could be strengthened by using standardised methods of catch assessment and by developing the ability of participants to conduct surveys, assessments, and unified approaches to reporting. Overexploitation of fish stocks is already a challenge for most of these countries with strong dependence on small pelagics. The importance of small pelagics to local food security is gradually being compromised by their use as raw materials in the production of fish meal (Palomares et al., 2020). The livelihoods, food security, and nutritional state of local fishing communities, as well as the post-harvest processing subsector largely employing women, are at risk. Fisherfolk are migrating to adapt to declining fish stocks. However, the magnitude of the societal impact of migration remains unclear due to the lack of data, IUU fishing potential arising from these migrations, and conflicts between migrant fishers and local fishers in foreign EEZs (Binet and Failler, 2011; Binet et al., 2012). Therefore, there is an urgent need for increased and effective monitoring and surveillance of EEZs, as well as reductions in fishing efforts in areas where stocks are rapidly declining, until signs of recovery arise.

Currently, there is a clear knowledge gap in the literature in terms of land-based contaminant exports originating from diffuse or point sources to the CCLME. Most of the CCLME countries have inappropriate urban waste disposal mechanisms that are potential sources of ocean fertilisation. To tackle the problem of pollution, these sources must be identified and controlled at the source. Based on available data, coastal land use is unequal across the countries. Between 2009 and 2013, mangrove regeneration was ongoing across the countries, with the highest levels of regeneration occurring in The Gambia. Despite having the highest mangrove regeneration rate, a closer look at local ecological conditions shows that climate-induced hydrological changes have stunted the growth of mangroves in the River Gambia estuary (Ceesay et al., 2017). The small woods, which have a maximum height of 4 m, are of no economic value to the local communities (Ceesay et al., 2017). The degradation and loss of blue forests (mangroves, seagrass beds, and coral reefs) appear to be the shared drivers of both climate change and biodiversity loss, though there is sparse coverage on these issues in the literature. These blue forests provide high value ecosystem services in the CCLME region (Interwies and Görlitz, 2013) as well as carbon sequestration potential, fishery nursery grounds, refugia for migratory marine wildlife species, and coastal protection. Moreover, they are a tourist attraction and provide opportunities for recreational activities such as hiking and boating centred around bird watching and recreational fishing (Spalding and Parrett, 2019). Considering their importance, all aspects of these blue forests, specifically their uses, benefits, carbon sequestration potential, floristic inventory, and ecological conditions, should be priority focus areas for scientific research in the next decade. For mangrove reforestation programmes to be successful, ecological conditions along with the interests and needs of resource users must be taken into account (Osemwegie et al., 2016). Breaking the vicious cycle of decline in coastal and marine biological resources requires effective management, but local realities and human interests must be considered when setting management goals for the long-term survival of the CCLME. This should be top priority. An exemplary win-win initiative for humanity and nature was the 7-year (2013 to 2019) oyster aquaculture project in Casamance, Senegal that benefitted from a USD 44 million World Bank loan (World Bank, 2014). This women-led initiative responded to the community's food security and livelihood support needs, while stimulating mangrove ecosystem conservation.

As EEZs are nested systems within the CCLME, the Atlantic Ocean basin and the interconnected ocean, the effects of a country's activities are not constrained to national boundaries. Therefore, there is the need for cross-sectoral collaboration and consolidation of regional conservation efforts, especially with regards to pollution control, MCS of the EEZ, human and institutional capacity development, and the implementation of the ecosystem-based MSP.

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