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Aquatic food resources in tropical Africa: a comprehensive analysis

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Aquatic food production holds great promise as a viable solution to tackle the pressing issue of meeting the protein requirements of the African populace. It plays a crucial role in food security and economic growth, especially in tropical Africa. With a fast-expanding population, there is a growing need for aquatic food sources to provide inexpensive protein and essential nutrients. Despite Africa's vast aquatic food source supplies and the importance of aquatic food in healthy and sustainable diets, several challenges hinder its full exploitation in the tropical African environment. This study, therefore, aims to assess the existing state of aquatic food resources in Africa, examine the nutritional advantages associated with these foods, and identify the problems that hinder their maximal utilization. The findings highlight the differences in aquatic protein consumption across various countries, emphasizing the importance of considering local factors when formulating nutritional interventions and policies. The comparison between the supply of protein from aquatic sources and land animals across African nations revealed a consistent trend of lower availability of aquatic protein. Africa, in particular, had relatively lower *per capita* consumption values of animal protein. The continent's average quantity of land animal food significantly surpassed the average aquatic food supply. This suggests a predominant reliance on land animal sources in African countries to meet dietary protein needs. This finding holds significant importance for policymakers, nutritionists, and stakeholders, highlighting the need for targeted strategies to improve protein accessibility in African countries. Moreover, it calls for attention to address any existing imbalances between the utilization of land and aquatic protein sources in the region.

KEYWORDS

aquatic food, aquaculture, fisheries, fish consumption, sustainability, tropical Africa

1 Introduction

With a global population exceeding 8 billion, tropical Africa accommodates about 1.4 billion individuals (Worldometer, 2023). However, the region is confronted with high poverty levels, signifying the need for alternative strategies to fulfill the protein demands of its residents (Schönfeldt and Hall, 2012). Recent data obtained in early 2023 indicates that Africa persists in facing substantial difficulties, with undernourishment reaching 20.15% in 2013 (Abegaz, 2018). These statistics highlight the pressing need for sustainable and inventive measures to tackle the nutritional necessities of the African populace and enhance their general welfare.

The United Nations' 2021 State of Food Security and Nutrition shows that about 282 million people lack regular access to sufficient, safe, and nourishing food to meet their dietary needs and sustain a healthy lifestyle. This scenario highlights the challenge of undernourishment in tropical Africa, influenced by several factors, such as constrained agricultural productivity, pervasive poverty and inequality, challenging climate and weather conditions, ongoing political instability and conflict, and inadequate infrastructure (Gashu et al., 2019). Given these complexities, exploring alternative sources of nutrition, such as aquatic foods, becomes imperative to address food insecurity in these regions.

Aquatic foods are plants and animals sourced from aquatic environments, including fish, shellfish, seaweed, and aquatic plants, for human consumption. There are abundant water resources in Africa, and aquatic food production presents a promising and feasible solution to address the urgent challenge of fulfilling the protein demands of the African populace (Chan et al., 2019; Belton et al., 2021). This solution assumes even greater significance when considering that more than 30% of the African population relies on fish as their primary source of animal protein [Food and Agriculture Organization (FAO), 2022b] and contributes over 20% of animal protein intake (Hollinger and Staatz, 2015; Chan et al., 2019). This highlights that the importance of fish, comprising both finfish and shellfish, cannot be overemphasized, as they serve as pivotal sources of nutrition (Chan et al., 2021). It further contributes 17% of animal protein and 7% of all proteins, thereby playing a vital role in providing essential nourishment to over three billion individuals in developing countries (Boyd et al., 2022). As the demand for aquatic foods, particularly fish, continues to rise, sustainable management practices are paramount to ensuring the long-term viability of aquaculture and fisheries and the livelihoods they support.

The African governments, regional organizations, and local communities are investing in sustainable fish production systems to meet the increasing demand and reduce dependence on imported fish (Naylor et al., 2021). Moreover, Africa possesses a vast untapped potential for the advancement of aquaculture. The continent's abundant freshwater resources and favorable climatic conditions offer an ideal environment for fish cultivation (Adeleke et al., 2020). Aquaculture can generate more avenues for income in rural communities, alleviate strain on wild fish populations, and enhance overall food production (Gephart et al., 2020). Therefore, prioritizing investments in research, development, infrastructure, and capacity-building initiatives can effectively harness the potential of aquaculture to meet the escalating demands for fish, reduce poverty and stimulate economic growth in African countries (Adeleke et al., 2020). However, realizing this full potential in Africa necessitates unified efforts and collaboration among governments, stakeholders, and international organizations (Jolly et al., 2023). Hence, there is a need to actively promote sustainable practices, enhance infrastructure, facilitate market access, and fortify institutional frameworks to strengthen the expansion of fish and other aquatic food production (Rahman, 2021).

Fish production in tropical Africa varies significantly across the countries and regions. Africa collectively produced 16.7 million metric tons of fish, with approximately 25% originating from aquaculture [Food and Agriculture Organization (FAO), 2018]. Egypt, Nigeria, and Uganda have emerged as the leading aquaculture producers in the continent, leveraging their geographical advantages, government backing, and technological

advancements to excel in fish farming (Adeleke et al., 2020). Over the years, these countries have improved their aquaculture production potential to address food security, generate employment opportunities, and contribute to overall economic growth (Adeleke et al., 2020; Muringai et al., 2022). Specifically, Egypt has become a key player by substantially producing Nile tilapia and African catfish (Mansour et al., 2021). Similarly, Nigeria has made significant strides in catfish and tilapia farming (Kaleem and Sabi, 2021), while Uganda has positioned itself through its Nile perch cultivation (Cowx and Ogutu-Owhayo, 2019).

In other countries, Mauritania, Senegal, and Angola have established their prominence as notable traditional fisheries producers, capitalizing on their extensive coastlines and abundant marine resources (Deme et al., 2023). These countries possess a rich fishing heritage, where artisanal and small-scale fishing activities are vital in providing livelihoods for coastal communities. Their traditional fisheries sector has sustained local economies and preserved cultural practices while meeting the demands of both domestic and international markets with exceptional seafood of the highest quality (Deme et al., 2023; GlobeFish, 2023). However, Mozambique, Ghana, the Democratic Republic of Congo, Madagascar, and Tanzania are confronted with significant deficiencies in their fish production. These countries encounter a range of obstacles that impede their ability to meet the growing demand for fish (GlobeFish, 2023). Factors such as limited infrastructure, insufficient investment in the fisheries sector, ineffective governance, overfishing, and environmental degradation contribute to these deficits (Akegbejo-Samsons, 2022). For instance, Mozambique, situated along an extensive coastline and endowed with abundant marine resources, contends with illegal fishing practices and a lack of suitable management strategies (Zeller et al., 2021). Conversely, despite its long-standing fishing industry, Ghana faces challenges with depleted fish stocks caused by unsustainable fishing practices and inadequate regulatory frameworks (Okyere et al., 2023). Moreover, the Democratic Republic of Congo, Madagascar, and Tanzania encounter similar problems, including restricted access to modern fishing technologies, inadequate storage and processing facilities, and weak governance in fisheries management (Eyayu et al., 2023).

Despite the vast aquatic food source resources and the role of aquatic food in healthy and sustainable diets, several factors limit its full utilization in the tropical African context. Therefore, this study examines the current state of aquatic food resources in the region, analyses the nutritional benefits of aquatic food, the factors that could affect aquatic protein consumption, including their relationships, and identifies the barriers limiting their utilization. This study further explores the environmental implications of maximizing aquatic food utilization and the policy interventions in promoting sustainable aquatic food systems in tropical Africa. Finally, this study proposes strategies for promoting the utilization of aquatic food resources, thereby contributing to the development of sustainable and healthy diets for the population. This study is organized thus: next, Section 2 explains the methodology. Section 3 highlights the nutritional benefits and aquatic food consumption in tropical Africa. Then, section 4 discusses the barriers to adequate consumption and section 5 reports on sustainability and its health implications. Section 6 reports the recent aquatic policies for more accessible aquatic foods. Finally, sections 7 and 8 highlight the study's limitations and the conclusion.

TABLE 1 Distribution of aquatic species mostly consumed across African countries.

Country	Aquatic species consumption	References
Egypt, Nigeria, Ghana	River and marine fish such as catfish and mackerel, herring, sardines	Bradley et al. (2020), Food and Agriculture Organization (FAO) (2021), and Hinrichsen et al. (2022)
South Africa	Prepared and preserved fish, molluscs, and crustaceans	Mbaka et al. (2022)
Benin, Burundi, Malawi, Rwanda, Uganda, Zambia	Tilapia	Food and Agriculture Organization (FAO) (2021)
Tanzania	Fish from the African Great Lakes region	Mbaka et al. (2022)
Congo, Botswana, Mauritius, Algeria, Central African Republic, Burkina Faso, Cameroon, Niger, Seychelles, Côte d'Ivoire, Democratic Republic of the Congo, Djibouti, Mali, Guinea, Guinea-Bissau, Lesotho, Liberia, Libya, Mauritania, Sao Tome and Principe, Sierra Leone, South Sudan, Togo, Angola, Cabo Verde, Chad, Comoros,	No specific information was found.	

2 Methodology

This review used the Web of Science, Scopus, and Google Scholar databases to extract data records on aquatic food resources in tropical Africa. The search period was set at “All years” to capture all possible articles with no language restriction. The search terms included “Aquaculture” OR “Fisheries” AND “Tropical Africa,” “Aquatic Food Resources” AND “Tropical Africa,” “Fish Farming” OR “Sustainable Fisheries” AND “Tropical Africa,” “Fish Species” AND “Aquatic Biodiversity” AND “Tropical Africa.” A manual screening was conducted by reading all the retrieved documents and screening relevant studies. Relevant information related to the review topic was extracted to evaluate the existing information on this subject.

This study further explored the typical intricate relationship between aquatic protein consumption and critical factors such as population, annual gross domestic product (GDP), land protein intake, aquatic food imports, and aquatic food export. Data for population and GDP across the African countries were sourced from the World Bank,¹ while aquatic food import and export data were from the FAOSTAT statistical database.²

3 Nutritional benefits of aquatic food and consumption in tropical Africa

Studies have documented the nutritional benefits of aquatic food consumption, including proteins, essential amino acids, vitamins, minerals, and heart-healthy omega-3 fatty acids (Golden et al., 2021; Tacon, 2023). Their consumption is linked to numerous health benefits, including enhancing brain and eye health and providing a healthier alternative to red and processed meats, which can negatively impact well-being (Qian et al., 2020; Golden et al., 2021). However, the nutrient composition varies among aquatic species, primarily influenced by their fat content. For instance, carp species such as *Amblypharyngodon mola* and *Puntius sophore* contain high amounts of vitamin K, ranging between 402.9 and 786.9 IU per 100 g of flesh, highlighting their significance in human nutrition (Bianchi et al., 2022). Mackerel provides high-quality protein, vitamins D and B12,

minerals like selenium and phosphorus, and is a good source of omega-3 fatty acids (Ahern et al., 2021; Golden et al., 2021; Tacon, 2023). Shellfish such as mussels, clams, and oysters are rich in protein, iron, zinc, and vitamin B12 and are a good source of antioxidants and omega-3 fatty acids (Venugopal and Gopakumar, 2017; Arshad et al., 2022). The human body relies on dietary sources to obtain two crucial omega-3 fatty acids [eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA)], emphasizing their essentiality (Shahidi and Ambigaipalan, 2018). Furthermore, regular consumption of aquatic foods lowers the risk of stroke, depression, Alzheimer's disease, and other chronic conditions, supporting a healthy heart (Awuchi et al., 2022). Thus, aquatic foods, mainly fatty species like African Mackerel (*Scomber scombrus*) and Sardines (*Sardinella* spp.), are healthy options as they are abundant in these fatty acids (Calder, 2013; Calder, 2021).

Furthermore, aquatic foods offer more than omega-3 fatty acids; they serve as an exceptional reservoir of high-quality protein, crucial for constructing and mending body tissues. They play a vital role in maintaining a robust immune system and facilitating the production of enzymes and hormones (Gutiérrez et al., 2019; Tacon et al., 2020). Moreover, they encompass all the essential amino acids the body cannot synthesize independently, making them excellent protein sources for plant-based alternatives. In contrast to land-based animals and plant-based substitutes, aquatic foods are especially rich sources of vitamin D and iodine (Craig et al., 2021). Additionally, the minimal levels of saturated fat in aquatic foods make them a healthier substitute for land-based animals, which often contain substantial amounts of saturated fat associated with an elevated risk of heart disease (Aldaya et al., 2021). Consequently, choosing sustainably sourced aquatic foods, particularly shellfish, is environmentally friendly and requires fewer resources and less energy for production than land-based animals (Ahern et al., 2021; Laso et al., 2022). Given Africa's diverse ecosystems and cultural practices, it is important to consider the regional diversity in consumption patterns.

The consumption patterns of African aquatic foods show considerable heterogeneity across the continent (Table 1). In West Africa, along the coastal countries, and across numerous small island states, fish can contribute about 60% or even more of the overall dietary protein intake (for instance, in countries like Gambia, Sierra Leone, and Ghana) [Food and Agriculture Organization (FAO), 2018]. While the overall average consumption of aquatic foods in Africa

1 www.data.worldbank.org

2 <https://www.fao.org/faostat/en/#data/FBS>

remains relatively low, it is noteworthy that eleven countries have surpassed the global average (Chan et al., 2021). These countries encompass some small island developing states (SIDS) and Gabon, Congo, the Gambia, Sierra Leone, Ghana, Egypt, and Côte d'Ivoire, indicating their relatively higher aquatic food consumption rates. Conversely, most African countries contend with relatively low levels of aquatic food consumption due to several factors, such as geographical, economic, and social factors (Rocha et al., 2022). However, despite these challenges, there is a growing recognition of the nutritional benefits and economic potential of increasing aquatic food consumption in many African nations.

The demand for fish has experienced a substantial and rapid surge in recent years (Iversen et al., 2020). This upward trajectory can be primarily attributed to the simultaneous growth in population and income levels (Oreggioni et al., 2021). Furthermore, increased awareness of the myriad health benefits of fish consumption has further propelled this trend (Thurstan and Roberts, 2014). Additionally, the ever-evolving dynamics of urbanization and globalization have significantly shaped consumer preferences and lifestyle choices, thus contributing to the increasing demand for fish. The *per capita* fish consumption in Africa is reported to gradually decrease from 10.0 kg/person/year (about half the global and Asian fish intake) in 2015 to 7.7 kg/person/year in 2050 as population growth will outpace growth in the fish sector (Obiero et al., 2019). Also, the aquaculture sector in Africa remains relatively underdeveloped, resulting in limited production capacity and constrained availability of farmed aquatic products (Naylor et al., 2023). The restricted expansion of aquaculture operations contributes to the prevailing low consumption levels, as the sector fails to bridge the gap between demand and supply (Adeleke et al., 2020).

Likewise, inadequate landing facilities, substandard road networks, and poor market infrastructure pose formidable challenges (Narayan and Petesch, 2002). These deficiencies hinder the efficient movement of high-quality aquatic products across national borders within the continent, making the accessibility of diverse and nutritious aquatic foods harder and worsening the overall low consumption rates (Mindjimba et al., 2019). Furthermore, the high prevalence of post-harvest losses significantly undermines the availability of safe and fresh aquatic foods in the market (Rajapaksha et al., 2021). The absence of well-developed cold chain systems intensifies this issue, resulting in the spoilage and deterioration of aquatic products during storage and transportation (Sohrabpour et al., 2012). The resultant losses in quality and quantity further limit the potential for increased consumption relative to distribution patterns.

The distribution of aquatic food varies across African countries, with coastal regions often having greater access to diverse seafood options (Figure 1). The leading five countries in terms of *per capita* daily aquatic protein supply, measured in grams, are Uganda, Egypt, Seychelles, Benin, and Mozambique, with quantities of 4.25, 3.66, 3.55, 3.55, and 3.47 grams per person per day, respectively (FAOSTAT, 2023). This highlights significant disparities in the total supply of aquatic protein among the selected countries. Uganda stands out with the highest value of 4.25 grams per person per day, indicating a comparatively higher consumption of aquatic protein sources within its population. This could be attributed to Uganda's favorable geographical location, providing abundant access to freshwater resources such as the Nile River and Lake Victoria (Yitayew and Melesse, 2011).

On the other hand, Egypt, Seychelles, Benin, and Mozambique show relatively similar levels of *per capita* aquatic protein supply, ranging from 3.47 to 3.66 grams per person per day. Despite their diverse geographical characteristics and varying proximity to marine resources, these countries display comparable consumption of aquatic protein individually. Other factors like cultural preferences, availability of alternative protein sources, and financial status may contribute to the observed similarities (Arrieta et al., 2021).

Countries that experienced relatively low food supply values (kg/capita/yr) in 2020 include Egypt (14.98), Uganda (14.2), Malawi (9.68), Zambia (8.04), Togo (5.67), Nigeria (1.28), Djibouti (0.02), Libya (0.04), Guinea-Bissau (0.09), and São Tomé and Príncipe (0.00). These figures reveal the challenges these nations face in ensuring an adequate and sustainable supply of fish as a vital source of nutrition. Egypt, with a value of 14.98 kg/capita/yr., is one of the countries on the list with a higher food supply of freshwater fish. This can be attributed to the country's strategic location along the Nile River, which provides good opportunities for fishing activities and a consistent source of fish for its population (Abila, 2003). Uganda follows closely with a value of 14.2 kg/capita/yr. Given its large freshwater bodies, including Lake Victoria, Uganda has significant potential for fish production. However, despite the favorable conditions, the value of the food supply remains lower than expected, suggesting potential challenges in aquatic resource management (Troell et al., 2014). Malawi and Zambia, with values of 9.68 kg/capita/yr. and 8.04 kg/capita/yr., respectively, also encounter limitations in achieving optimal freshwater fish supply. Both countries have access to various lakes and rivers, such as Lake Malawi and the Zambezi River, which are known for their rich fish populations. However, factors such as poor infrastructure, inadequate fishing techniques, or socio-economic issues hinder these resources's utilization to their full potential (Mittal et al., 2010).

Countries with lower value for freshwater fish food supply include Togo, Nigeria, Djibouti, Libya, Guinea-Bissau, and São Tomé and Príncipe. Nigeria, with a value of 1.28 kg/capita/yr., is one of the most populous countries on the list. Despite its vast coastline and numerous inland waterways, Nigeria fails to fulfill its rising population's fish demand due to overfishing, insufficient processing facilities, and poor infrastructure (Ajani and Osho, 2019). Djibouti, Libya, Guinea-Bissau, São Tomé and Príncipe have considerable freshwater fish availability constraints, with values ranging from 0.02 kg/capita/yr. to 0.00 kg/capita/yr. Due to limited water supplies, unfavorable environmental conditions, or economic restraints, some countries face challenges obtaining freshwater fish. These highlight the critical need for coordinated efforts in aquatic resource management, infrastructure development, and promoting sustainable practices. This also indicates the necessity to address the underlying issues and push for ethical and sustainable practices, greater food security, increased aquatic source food nutrition and general well-being for the people.

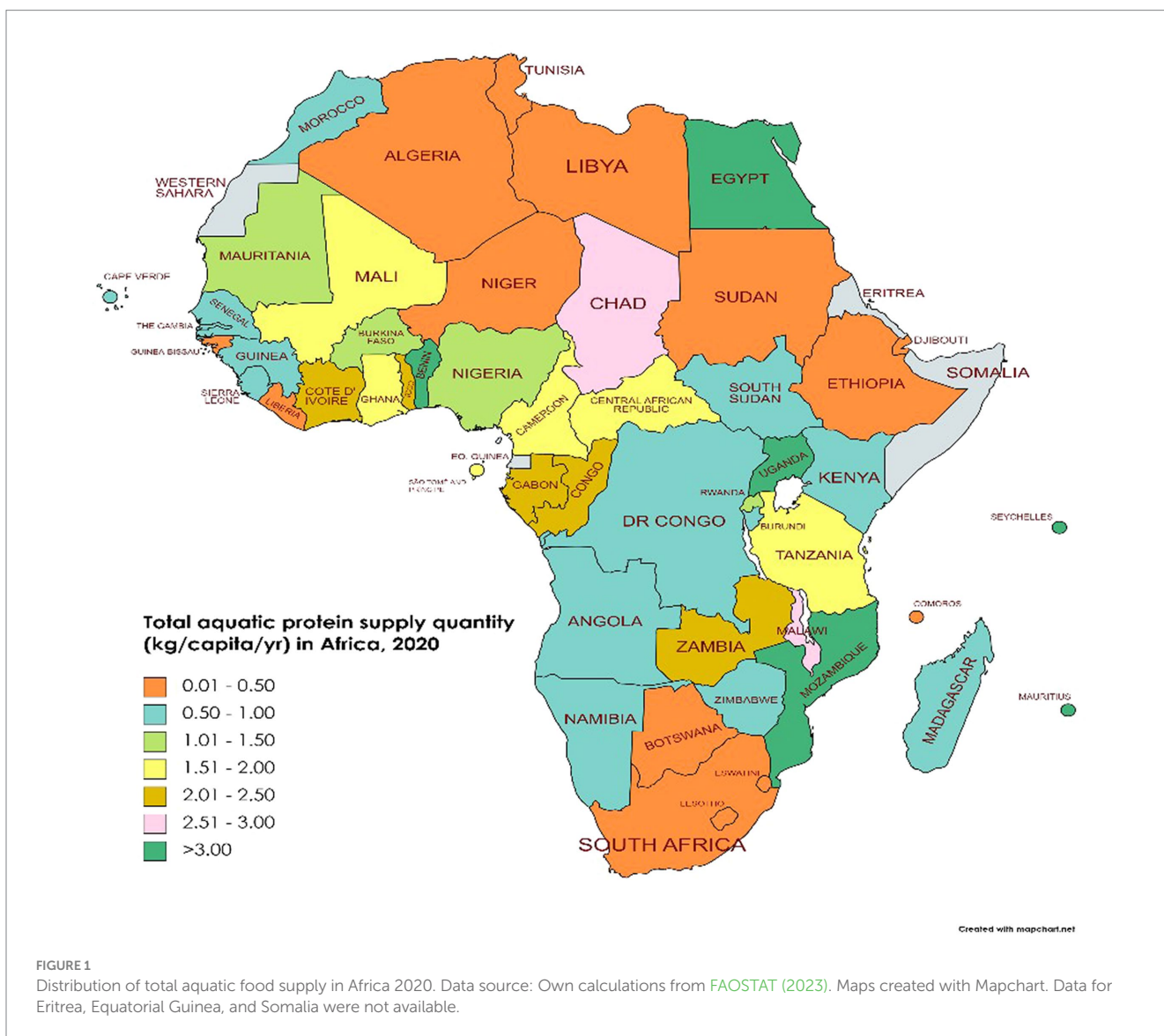
For marine fish food supply, Mozambique (7.18), Benin (5.73), Côte d'Ivoire (3.26), Cameroon (2.92), Gabon (2.17), and Burkina Faso (2.02) led in terms of values (kg/capita/yr). While South Sudan (0.00), Ethiopia (0.00), Chad (0.01), Zimbabwe (0.01), Guinea-Bissau (0.02), Democratic Republic of Congo (0.04), and Botswana (0.05) had relatively lower (kg/capita/yr) values (FAOSTAT, 2023). With a long fishing history and a large stretch of coastline in the Indian Ocean, Mozambique has a wealth of fisheries resources (McClanahan et al., 2011; Ollivier and Giraud, 2011). Its high consumption quantity

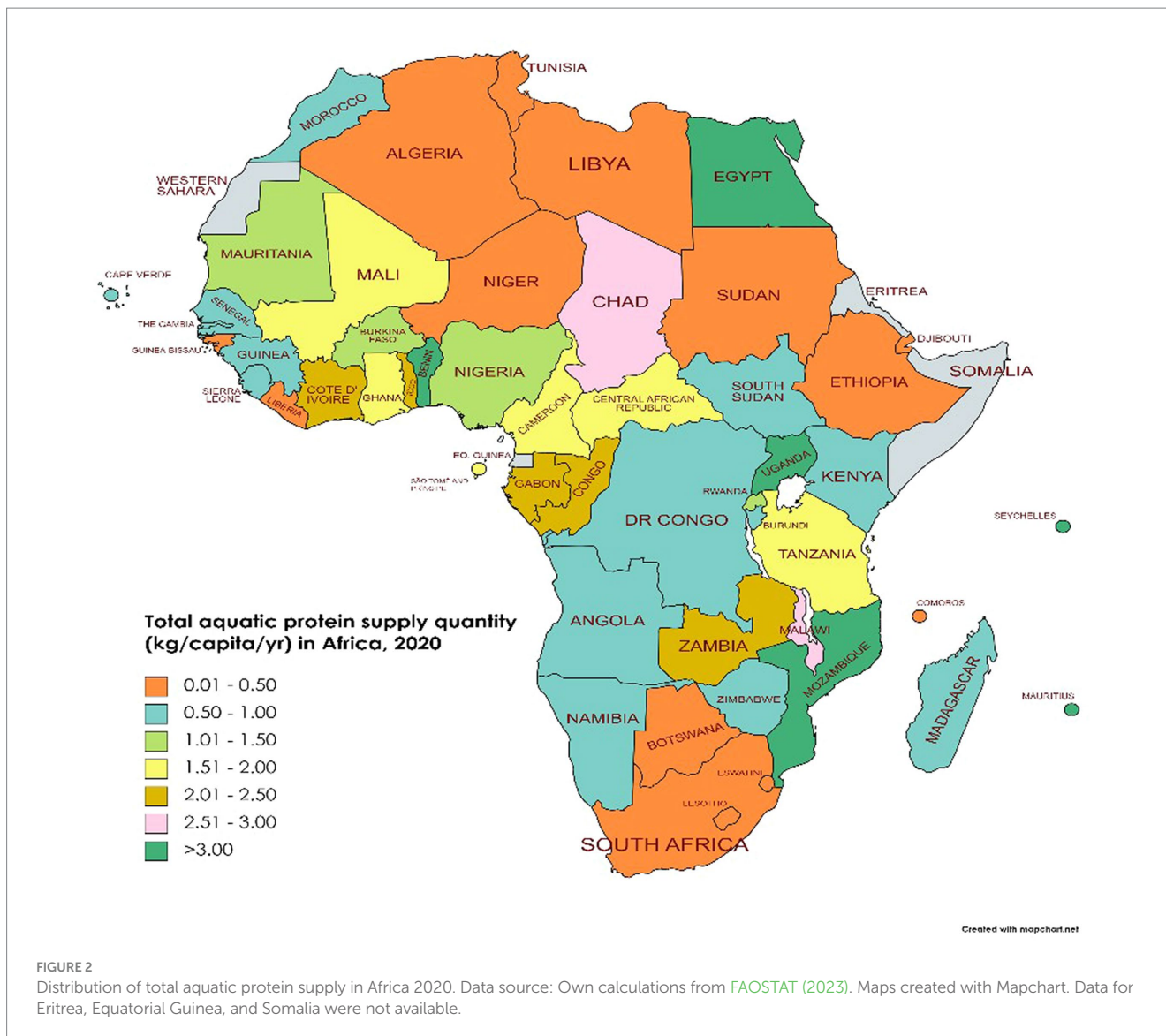
demonstrates how much the country depends on marine fish as a source of protein. Similarly, the Benin Republic's location along the Gulf of Guinea offers the country a coastline edge, enabling the utilization of a thriving marine habitat.

Côte d'Ivoire, located on the West African coast, has a well-developed fishing sector and many coastal fish farmers, resulting in a comparatively high consumption of marine fish. Cameroon, another coastal country within the area, has comparable qualities and benefits from a vast range of fish species along its coastlines. Gabon, recognized for its substantial marine reserves and protected areas, consumes significant amounts of marine fish due to its natural richness (Spalding et al., 2008). Burkina Faso appears surprisingly on the list as a landlocked country. However, this value reflects a large consumption of imported marine seafood, indicating the desire for aquatic resources even in countries without direct sea access. Many countries had considerably lower numbers (kg/capita/year) for marine fish consumption. Both South Sudan and Ethiopia are landlocked countries with limited access to coastal resources, restricting their intake of marine seafood. Similarly, Chad and Zimbabwe face geographical limits that hinder

seafood consumption. Despite its proximity to the sea, Guinea-Bissau faces infrastructural, governance, and economic issues that may lead to lower consumption values (Temudo and Abrantes, 2014).

The quantity of land animal protein supply surpasses aquatic protein supply across all African countries (Figure 2). The provision of protein from land animals, such as livestock, cattle, goats, sheep, and poultry, plays a significantly more prominent role in meeting the population's protein requirements when compared to aquatic sources like fish and seafood. The higher supply of land animal protein in African countries can be attributed to various factors. The long-standing integration of animal husbandry and agriculture into many African societies has contributed to domestic animal rearing and food production (McClure, 2015). Cultural and dietary preferences, as well as factors like land availability and agricultural practices, have influenced the prominence of land animals as a source of protein (Beveridge et al., 2013). Moreover, the relatively lower supply of aquatic protein may be influenced by limited access to coastal areas or freshwater bodies, lower fish production and availability, and challenges in fishery management and infrastructure development



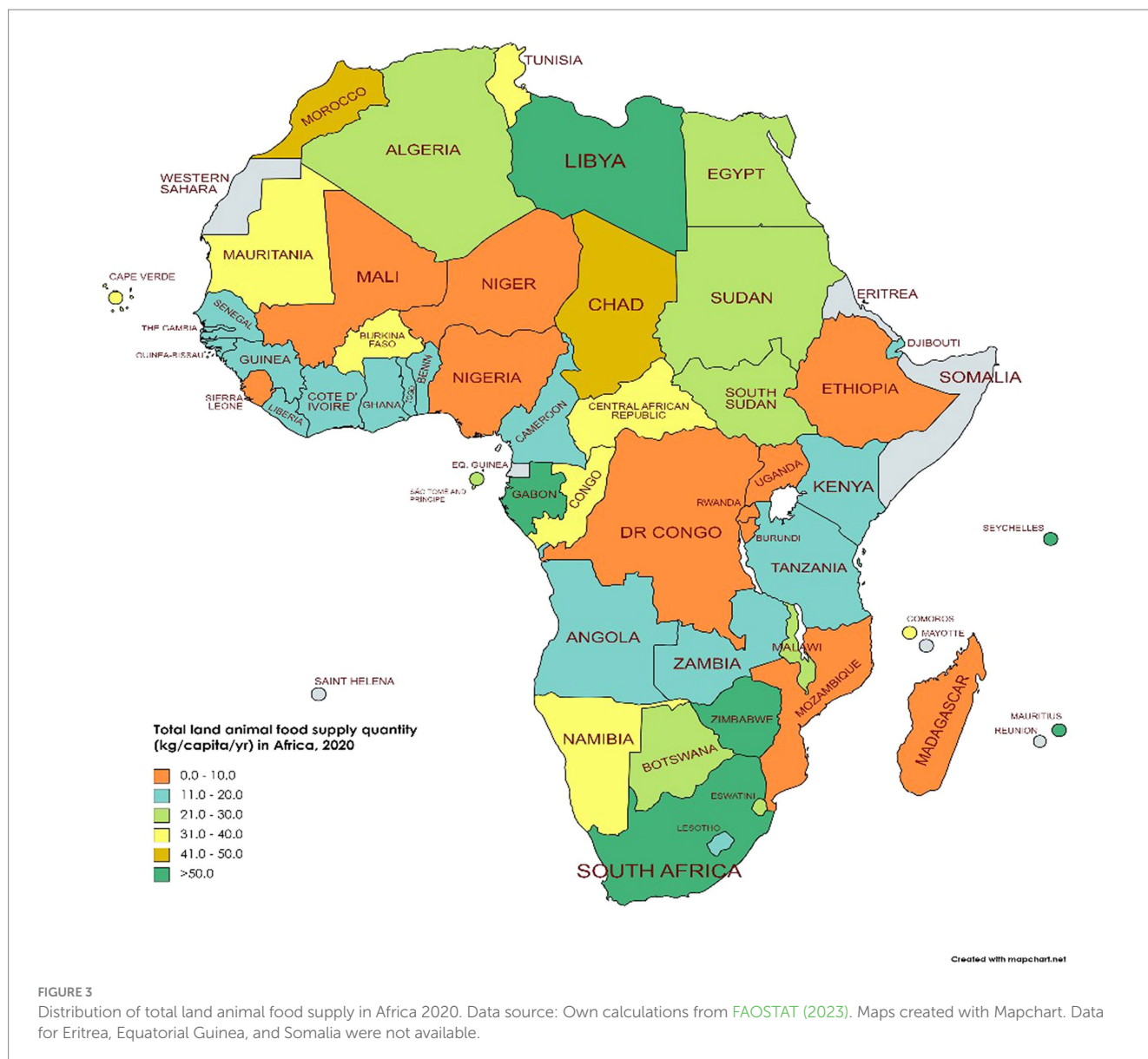


(Reid et al., 2019). Consequently, this affects the *per capita* consumption of animal protein across the African continent.

Africa, in particular, had relatively lower *per capita* animal protein consumption values than other regions (Latino et al., 2020). In 2020, the United States consumed 75 g of animal protein per day, of which fish and seafood were 5.4 g. Spain consumed 68 g of animal protein, of which 12 g were fish and seafood. The United Kingdom consumed 59 g of animal protein, including 5.7 g from fish and seafood, while China consumed 39 g of animal protein, including 9.4 g from fish and seafood (FAOSTAT, 2023). Generally, low-income countries had low *per capita* availability of animal protein, averaging 13.8 grams per person per day in 2018–20. Within Africa, Southern Africa had comparatively higher values of *per capita* consumption of animal protein than other regions (FAOSTAT, 2023). In recent years, the evaluation of *per capita* intake has become more critical for understanding the nutritional profiles of different locations (Popkin, 1994). It becomes clear that, on average, people in Southern Africa prefer to consume more animal protein than their counterparts in other regions despite the diversity and variation within this region (Du Toit and Cumming, 1999).

The quantities of land animal food supply consistently exceeded aquatic food supply across all African countries (Figure 3). The continent’s average quantity of land animal food significantly surpassed the average aquatic food supply. This pattern suggests a predominant reliance on land animal sources to meet dietary needs in African countries. Among the countries, Egypt stood out with the highest aquatic food supply quantity value, reaching 15.96 kg *per capita* per year. This indicates Egypt’s reliance on aquatic food to fulfill its population’s nutritional needs more than other African countries, underscoring the significance of fish production and distribution value chains.

Value chains play a crucial role in aquatic food consumption in tropical Africa by enhancing sustainability, economic growth through local and international trade and food security. It is vital in meeting the nutritional needs of the people, particularly in countries with a substantial reliance on aquatic sources (Belton et al., 2021). However, the volatility in aquatic food value chains has resulted in short- and long-term consequences regarding the availability and desire for aquatic foods. Hence, several components of these value chains need to be enhanced to guarantee the long-term supply and accessibility of



aquatic foods. In tropical Africa, the challenges of these value chains, intensified by the COVID-19 crisis, include risks related to economic resilience, social and environmental sustainability, changing global investment landscapes, Africa's digital transformation, and the global drive for sustainability (Feyaerts et al., 2020). Furthermore, insufficient investments in infrastructure, tropical deforestation due to economic incentives, significant rural poverty, and a lack of prioritization of tropical agriculture by governments contribute to the challenges faced by stakeholders in recent years (Belton et al., 2021). Addressing these problems requires improvements in storage, processing, and transportation infrastructure, enforcing regulations, facilitating access to finance and credit, building capacity, and providing training and technical assistance to improve production techniques and market access.

Considering the recent trends highlighted above, aquatic protein consumption is essential in the nutritional landscape, particularly in tropical Africa. To better understand this scenario, this study explored a typical relationship between aquatic protein consumption and key

factors such as population, annual gross domestic product (GDP), land protein intake, aquatic food imports, and aquatic food export (Table 2). Understanding the dynamics between these variables is essential for elucidating the complex interplay of dietary habits, economic development, and trade dynamics in the context of aquatic protein consumption. The results of a multiple linear regression of total protein intake (highlighted here as a representative view) in Africa for 2020 with these factors showed that only "Import" was significant at the 10% level ($p=0.080$). Increasing aquatic food imports was associated with a proportional rise in aquatic protein intake by 0.267%, suggesting a potential relationship with total protein intake. This implies explicitly that import volume may influence the consumption of aquatic protein across African countries (considering the different landlocked countries). Hence, trade dynamics may influence regional protein availability and access. Addressing this requires further studies to provide insight into the specific nature of imports and their impact on aquatic protein consumption in the region. Also, further insights from trade economics of aquatic foods

TABLE 2 Multiple linear regression for aquatic protein intake in Africa with some key factors for 2020.

Total protein intake	Coefficient	Standard error	t	P > t	[95% Conf. Interval]	
GDP	0.0004	0.0019	0.23	0.819	-0.0034	0.0043
Import	0.0027	0.0015	1.80	0.080	-0.0003	0.0057
Export	-0.0007	0.0009	-0.81	0.422	-0.0025	0.0011
Land protein intake	0.02789	0.0306	0.91	0.367	-0.0339	0.0898
Population	-6.40e-06	6.68e-06	-0.96	0.344	-0.00002	7.10e-06

across the continent would help stakeholders and policymakers to develop targeted strategies to enhance aquatic protein access and utilization in Africa.

Other variables such as land protein intake, export, GDP, and population showed a non-significant relationship. This indicates that these factors may have limited direct influence on total protein, at least for the year under study. Given the non-significant relationships observed in the regression analysis, there is a need for more comprehensive research to identify additional factors that may influence aquatic protein consumption in Africa. Specifically, it is essential to consider the time course dynamics of these factors and their influence on aquatic protein consumption, as other non-significant factors for 2020 may be significant in the future. Thus, a holistic and time-course approach is required to draw valid conclusions.

Generally, understanding seafood demand patterns is of significant importance in research. However, existing literature has primarily concentrated on developed nations and commercially important fish species, resulting in a dearth of information regarding consumer preferences for fish in many African countries (Obiero et al., 2019). While previous investigations have considered consumer preferences and future demand changes, there are limited details, particularly concerning the African context [Food and Agriculture Organization (FAO), 2017a,b]. Of particular note is the dearth of studies that have effectively integrated the complex relationship between urbanization, income growth, and accurate future fish demand estimations (Béné et al., 2015). Thus, studies have relied on assumptions of constant consumption rates in the future (Barange et al., 2014) or fixed nutritional targets (Rice and Garcia, 2011) without considering the dynamic nature of dietary needs and evolving nutritional requirements over time. Addressing these multifaceted challenges requires comprehensive and strategic interventions (Adelman and Taylor, 2002). Enhancing capture fisheries management practices, such as implementing sustainable fishing methods and ensuring responsible resource utilization, can help mitigate the supply-demand imbalance (Gutierrez, 2015). Simultaneously, fostering the growth of the aquaculture sector through investments in research, technology, and infrastructure is imperative to bolster production and expand availability (Nguyen, 2016; Elegbeleye et al., 2024). Furthermore, addressing the deficiencies in landing, road, and market infrastructures necessitates substantial investments in improving logistics and transportation networks [Food and Agriculture Organization (FAO), 2022a].

This strategy would enable the seamless movement of aquatic products across borders, facilitating greater access to diverse markets and enhancing consumption opportunities. Also, prioritizing the development of robust cold chain systems is vital for minimizing

post-harvest losses. Investments in storage facilities, refrigeration technologies, and efficient distribution networks would ensure the preservation of product quality and enhance consumer confidence, leading to increased consumption (Sugri et al., 2021). In relation to this, it is imperative to develop all-encompassing policy frameworks to foster sustainable and nourishing consumption of aquatic food in Africa. Such policy frameworks entail integrating fisheries and aquaculture management strategies with broader food security, nutrition, and socio-economic development initiatives (Béné et al., 2016). By fostering an enabling environment that encourages innovation, research, and collaboration among stakeholders, Africa can unlock the full potential of its aquatic resources and achieve improved consumption patterns in the future (Tigchelaar et al., 2022).

4 Barriers/challenges to adequate consumption of aquatic foods in tropical Africa

Aquaculture, a burgeoning industry in tropical Africa, holds tremendous promise as an alternative protein source and a complement to traditional fisheries [Food and Agriculture Organization (FAO), 2018]. However, significant obstacles to expansion exist within the industry, including restricted access to finance, poor infrastructure, and a lack of technical experience (George et al., 2016). Despite the potential benefits of aquatic food production, many local communities encounter significant barriers to accessing and consuming aquatic foods. These challenges take several forms due to economic, social, and cultural variables (Baumgartner et al., 2021).

Economically, limited access to financial resources and market possibilities has hindered aquatic food production and distribution, particularly for small-scale farmers (Béné et al., 2019). Socially and culturally, a preference for land-based animal products or a lack of awareness regarding the nutritional benefits of aquatic foods has contributed to low consumption levels (Cochrane et al., 2016). Furthermore, environmental factors such as water pollution, habitat destruction, and climate change have adversely affected the availability and quality of aquatic food sources (Khan et al., 2021). Poverty further limits the sufficient consumption of aquatic foods, and many communities in the region have been economically marginalized, with limited access to resources like income, education, and healthcare.

Consequently, they struggle to afford nutritious foods, including aquatic foods, which are costlier than other protein sources (FAO and ECA, 2018). Besides, insufficient infrastructure, characterized by inadequate transport networks, storage facilities, and processing facilities, has significantly constrained the availability and quality of

aquatic foods across various regions (Rolle, 2006). Therefore, communities encounter difficulties in accessing and consuming these foods. Inadequate water and sanitation systems further worsen the issue by compromising the safety and quality of aquatic foods. Such foods sometimes become contaminated with bacteria and other harmful substances, thus undermining their suitability for consumption (Jennings et al., 2016). These social obstacles can be linked to many factors arising from complex interactions among socio-economic elements, gender gaps, cultural norms, and restricted availability of resources. Socio-economic disparities, gender inequalities, limited access to quality water sources, and a lack of awareness regarding the nutritional value of fish are examples of these challenges. For instance, lack of access to improved water services, reliance on poor energy sources like biomass, and access to quality water impact the population's health and contribute to food insecurity (Nwozor et al., 2019; Fayad, 2023).

Cultural factors also limit the consumption of aquatic foods in tropical Africa. For example, a lack of awareness regarding the nutritional significance of fish, particularly within specific societal groups, can hinder the incorporation of aquatic foods into regular diets. Also, traditional beliefs or practices may influence dietary choices and limit fish consumption and other aquatic foods. Notably, specific communities prefer terrestrial protein sources, such as beef or chicken, due to deeply ingrained cultural or religious beliefs (Looy et al., 2014). Additionally, social norms governing food preparation and consumption may discourage the utilization of aquatic foods, particularly among women who commonly assume the responsibility for food preparation in many communities (Meyer-Rochow, 2009).

Climate change is another significant barrier to adequate consumption of aquatic foods in tropical Africa. The escalating sea temperatures and shifting weather patterns have deleterious effects on the productivity and distribution of fish stocks, thus impeding communities' access to and consumption of these vital food sources (Barange et al., 2018). Consequently, effectively addressing the complex challenges associated with aquatic food consumption necessitates concerted efforts and comprehensive solutions that acknowledge the multifaceted nature of the barriers hindering access to and consumption of aquatic foods (Elkin and Katz, 2019). Thus, harnessing the vast potential of aquatic food production in tropical Africa can benefit the region's people, economies, and environment.

A notable endeavor in the field involves implementing various initiatives to foster responsible aquaculture practices. For instance, the Aquaculture Stewardship Council (ASC) has emerged as a significant organization offering certification to ensure adherence to responsible aquaculture methods (Kruk and Peters, 2018). The ASC certification is pivotal in promoting responsible aquaculture practices, ensuring sustainability and environmental stewardship within the industry. However, the low ASC certification rates, particularly in the Global South and Africa, present significant challenges that must be addressed to foster widespread adoption of responsible aquaculture methods (Bush et al., 2013). This underscores the importance of understanding and addressing the barriers hindering certification uptake in these underrepresented areas. One key barrier identified is the lack of awareness and understanding of ASC certification standards and benefits among African aquaculture stakeholders. Limited access to information and insufficient outreach efforts contribute to this challenge, inhibiting the widespread adoption of certification practices. Moreover, high certification costs are challenging for

aquaculture producers in these regions, where financial resources may be limited. This calls for targeted interventions, including financial support mechanisms, capacity-building programs, infrastructure development projects, and policy initiatives incentivizing certification to address these challenges and improve African ASC certification rates (Bush et al., 2013).

Such interventions could be spearheaded by organizations such as the Aquaculture Network for Africa (ANAF), which has been established to facilitate technical assistance and promote the exchange of information among stakeholders within the sector (Nath et al., 2000). Also, the African Union's Policy Framework and Reform Strategy for Fisheries and Aquaculture in Africa, along with the Sustainable Fisheries Management Project, supported by the World Bank, contribute substantially to the comprehensive development of the sector (AUC-NEPAD, 2014). These initiatives emphasize the enhancement of governance structures, the implementation of responsible fishing techniques, and the augmentation of investments in the sector (Franz et al., 2019). Collectively, these efforts can enhance fishery management in the region by bolstering legal and institutional frameworks, promoting sustainable fishing practices, and improving the livelihoods of individuals engaged in the fishing industry.

5 Sustainability of aquatic food production in Africa and implications on health

Sustainable aquatic food production is critical in ensuring food security, fostering economic development, and promoting environmental conservation in Africa (El Bilali et al., 2019). The African continent boasts an extensive water resource base comprising rivers, lakes, and coastal areas, which present abundant opportunities to produce diverse aquatic foods, including fish, crustaceans, and molluscs (Zilhão et al., 2020). However, several factors pose significant threats to the sustainability of aquatic food production in Africa, including overfishing, weak governance, climate change, and pollution (Ahern et al., 2021).

Overfishing is one of the most pressing concerns among these challenges, jeopardizing the sustainability of aquatic food production in Africa (Lucrezi, 2022). Unsustainable fishing practices have severely depleted numerous regional fish stocks (Haque et al., 2021). This depletion threatens the viability of fish stocks and the livelihoods of millions of individuals who rely on them for sustenance and income (Bi et al., 2022). In tropical Africa, overfishing, characterized by unsustainable fishing techniques like using destructive gear and targeting immature fish, has depleted various fish stocks (Srinivasan et al., 2012). The depletion of fish stocks due to overfishing represents a critical challenge to the sustainability of aquatic food production in Africa, with far-reaching consequences for local communities (Ikram et al., 2023). This situation directly impacts the availability and affordability of fish, limiting their access to vital sources of nutrition (Ansari et al., 2021). Fish is a good source of omega-3 fatty acids essential for cardiovascular health, brain growth, and cognitive function (Sanjay Panda and Diwan, 2023). A decrease in fish supply may raise the risk of malnutrition, cardiovascular diseases, and other conditions linked to omega-3 deficiency. Several countries in tropical Africa lack the key institutional and legal frameworks for aquatic

resources management (DiNicolantonio and O'Keefe, 2020). Specifically, poor governance poses a significant barrier to successfully managing fisheries and the sustainability of aquaculture food production in Africa (Wilson and McCay, 2019). Many countries within the region face the absence of necessary legal and institutional structures, resulting in inadequate enforcement of regulations, the prevalence of illegal fishing practices, and conflicts among various user groups (Begum et al., 2022). This dearth of governance also extends to aquaculture management, wherein deficient monitoring and regulation exacerbate pollution and the spread of diseases (Edokpayi et al., 2017).

Moreover, the impact of climate change intensifies the issues mentioned above. The increasing sea temperatures, ocean acidification, and shifting weather patterns affect the productivity and distribution of fish stocks (Maulu et al., 2021; Lubembe et al., 2022). Extreme weather events, including floods and droughts, cause infrastructure damage and disrupt production systems. Also, the rising sea levels threaten the viability of coastal aquaculture (Gitz et al., 2016), consequently impacting the availability and affordability of fish resources (Katikiro and Macusi, 2012). Water temperature and salinity changes also affect the quality and safety of aquatic foods, as warmer waters facilitate the growth of harmful bacteria and toxins (Gomez-Zavaglia et al., 2020). Furthermore, climate change-induced extreme weather events, such as floods and droughts, directly affect the accessibility and safety of aquatic foods, thereby contributing to malnutrition and various health issues (Duchenne-Moutien and Neetoo, 2021).

Besides climate change, aquatic pollution significantly threatens the sustainability of aquatic food production in Africa (Mpumi et al., 2020). The contamination of water bodies resulting from industrial and agricultural activities, as well as untreated sewage and waste disposal, has detrimental effects on the safety and nutritional quality of aquatic foods (Mateo-Sagasta et al., 2017). Consequently, aquatic pollution has led to the accumulation of harmful substances, including antibiotics and heavy metals, in fish and other aquatic organisms, posing potential risks to human health (Okocha et al., 2018; Qadri and Faiq, 2020; Okon et al., 2022). In this regard, consuming fish contaminated with mercury can result in neurological damage and developmental disorders. Similarly, exposure to polycyclic aromatic hydrocarbons (PAHs) may elevate the risk of cancer (Mitra et al., 2022) and require a more proactive approach to tackle aquatic organisms and human exposure.

Various initiatives have been implemented to address these challenges and promote the sustainability of aquatic food production in Africa. These efforts encompass improvements in governance, exemplified by the African Union's Policy Framework and Reform Strategy for Fisheries and Aquaculture in Africa. This framework provides a comprehensive structure for the sector's sustainable development, focusing on enhanced governance, responsible fishing practices, and increased investments (NEPAD Planning and Coordinating Agency, 2016). Other initiatives concentrate on advancing sustainable fishing practices. For example, the Sustainable Fisheries Management Project, backed by the World Bank, strengthens legal and institutional frameworks, encourages sustainable fishing practices, and enhances fishers' livelihoods (Guenard, 2021). These initiatives generally work toward a shared objective of maximizing the potential of aquatic resources in the region.

Africa has vast untapped potential for advancing aquatic food production (De Angelis et al., 2021). The continent's copious

freshwater resources and favorable climatic conditions establish an ideal setting for cultivating different aquatic species. For instance, aquaculture can generate income in rural communities, alleviate strain on wild fish populations, and enhance food production (Odeno et al., 2022). By prioritizing investments in research, development, infrastructure, and capacity-building initiatives, African countries can effectively harness the potential of aquatic food production to meet their increasing demands, concurrently addressing poverty reduction and stimulating economic growth (Ali et al., 2021). However, realizing the full potential of aquatic food resources in Africa necessitates unified efforts and collaboration among governments, stakeholders, and international organizations (Zhao et al., 2022). It, therefore, becomes imperative to actively promote more sustainable practices, enhance infrastructure, facilitate market access, and fortify institutional frameworks to bolster the expansion of these sectors.

The Aquaculture Network for Africa (ANAF), one of such institutional frameworks, is essential in advancing sustainable aquaculture in Africa. The ANAF functions as a collaborative platform that facilitates technical assistance and information exchange among stakeholders within the aquaculture industry (Capobianco et al., 2021). Through the promotion of knowledge sharing, the ANAF empowers farmers, researchers, policymakers, and other crucial participants to gain access to valuable insights, adopt best practices, and explore innovative solutions (Vermunt et al., 2022). This network-based approach fosters the adoption of sustainable aquaculture methods, expedites technological progress, and facilitates sharing of resources and expertise across different African regions (Reddy et al., 2021). Apart from the Aquaculture Stewardship Council (ASC) and the Asian Aquaculture Network (AAN), numerous other organizations, governmental bodies, and research institutions contribute to developing and expanding sustainable aquaculture in Africa. These efforts encompass various activities, including promoting capacity-building, encouraging infrastructure investment, researching local species and ecosystems, and facilitating market access for aquatic foods. By addressing these diverse aspects, the collective initiatives aim to establish a flourishing and sustainable aquaculture sector that effectively complements traditional fisheries and provides a sustainable source of protein for communities throughout the region (Brears, 2021).

The sustainability of aquatic food production in Africa plays a significant role in determining the price, consumption patterns, and dietary intake of aquatic foods, thereby impacting human health (Golden et al., 2021). The availability and affordability of fish and other aquatic foods are threatened by unsustainable fishing methods, pollution, and climate change, which leads to an increase in price (Agostoni et al., 2023). This increase in price makes it challenging for low-income communities to access nutritious aquatic foods, leading to reduced consumption and a shift toward more affordable but less nutritious food options (Belton et al., 2020). The accessibility and cost of fish and other aquatic foods directly impact consumer intake and human health outcomes (Fiorella et al., 2021). Fish availability declines due to overfishing or pollution, decreasing fish consumption and resulting in insufficient vital nutrients like omega-3 fatty acids (Gormaz et al., 2014).

Moreover, the price of aquatic foods might discourage intake, especially for low-income groups that frequently have trouble accessing other proteins and minerals (Maulu et al., 2021). Access to and availability of aquatic foods is also critical for the health and well-being of millions of people in Africa. Promoting and emphasizing

sustainable practices could ensure fish supplies' long-term safety and nutritional value (Khan et al., 2021). This can be accomplished by enacting rules and regulations that promote sustainable fishing practices, such as quotas and gear limits.

Furthermore, efforts are required to reduce the adverse effects of climate change on aquatic ecosystems and regulate pollution (Odeku and Paulos, 2017). Aquatic ecosystems can be challenged by overfishing, pollution, and climate change while still gaining access to the advantages of aquatic foods (Zhang et al., 2023). Implementing appropriate management measures will eventually improve the health and well-being of millions of Africans (Andrews et al., 2021). These actions will require raising more awareness among local communities about the importance of the safe and healthy consumption of aquatic foods. Furthermore, supporting research on these foods' nutritional quality and safety can guarantee meeting the necessary standards (Khan et al., 2021), while creating more opportunities.

Aquatic food production opportunities and sustainability differ among coastal and landlocked African countries. Coastal countries have the advantage of access to the ocean, allowing them to utilize various marine resources such as fish and shellfish (Bennett et al., 2020). Coastal African countries typically have access to the marine biodiversity that offers valuable fish species. The ocean environment provides high protein content, important fatty acids and essential micronutrients, making seafood an integral part of their diets (Aakre et al., 2020). On the other hand, landlocked countries rely on rivers, lakes and inland fisheries for their food needs (Kolding et al., 2019).

Moreover, coastal regions are usually better positioned for seafood trade as they can export and generate income through this industry. At the same time, landlocked African countries face the challenge of being geographically distant from the coast (Ferguson, 2021). These inland resources can be equally rich; however, their sustainability depends on water quality management, effective fisheries management practices, transportation infrastructure availability, and storage purposes (Anselem Tengecha and Zhang, 2020). Coastal countries naturally have an advantage regarding fisheries-based industries and tourism related to resources. They can quickly develop their aquaculture production and processing sector for export purposes (Uddin et al., 2021). The preferences and dietary traditions also vary as coastal communities tend to have an affinity for seafood, while landlocked communities may have practices centered around other food sources (Cooke et al., 2018; Ferguson, 2021).

For landlocked countries to thrive, they must diversify their economies by engaging in activities such as aquaculture, utilizing irrigation techniques and adopting agricultural practices incorporating aquatic resources (Das and Mandal, 2022). Thus, a collaboration between landlocked countries can be mutually beneficial when harnessing the full potential of aquatic food resources. In essence, coastal countries can focus on implementing fishing practices, while landlocked countries can explore partnerships and agreements to access shared water bodies. Taking these aspects into account is crucial when formulating policies and managing resources.

6 Recent aquatic policies to make aquatic foods more accessible

Policy interventions are crucial in promoting sustainable aquatic food systems by addressing environmental, social, and

economic challenges (Ahern et al., 2021). The International Food Policy Research Institute (IFPRI) discussed policy issues and options in the Aquatic Food System (Ragasa and Loison, 2023). Some policy interventions in aquatic food systems highlighted include implementing community-based fisheries management for increased fish stocks and improved livelihoods for fishing communities. Also, establishing a national aquaculture development plan and introducing a fishery co-management system, directed by comprehensive guidelines can increase investment and growth in the aquaculture sector and improve fishery resource conservation and sustainable use, respectively (Kyvelou et al., 2023).

Given this, the Food and Agriculture Organization (FAO) (2021) has developed guidelines for sustainable aquaculture, which provide a framework for responsible and sustainable aquaculture practices. One such intervention prioritizes aquatic foods for domestic consumption over export, particularly in areas with high malnutrition rates (Farmery et al., 2020). This can be achieved through policies that support local production and distribution of aquatic foods and measures to reduce trade barriers and increase market access for small-scale producers (Wood et al., 2021). Another intervention is to improve the food safety of aquatic foods through improved governance at all levels, as well as behavioral and systemic changes, such as enabling a better circular economy framework and more sustainable production and consumption patterns (Cooney et al., 2023). Prioritizing the revision of existing regulatory frameworks, institutional arrangements, and other instruments related to marine litter and their enforcement can also help identify synergies, gaps and potential solutions globally and regionally, thus reducing and avoiding impacts on aquatic food systems and consumers (Graham, 2023). Finally, policies that support research and development of new technologies for sustainable aquaculture practices can also help increase the availability of aquatic foods (Gephart et al., 2021).

7 Limitations of the study

The broad scope of this study has both strengths and limitations. On the one hand, it allows for an overview of aquatic food resources in tropical Africa, which serves as a basis for more localized studies in the future. However, this broad nature is limited when making recommendations and policy implications for countries or regions. Therefore, exploring research directions focusing on localized and context-specific investigations to address this limitation is vital. This will offer tailor-made solutions, focused policy recommendations, and strategies directly impacting the regions or communities involved.

Besides, tropical African countries have diverse aquatic ecosystems and communities, each with distinct cultures, characteristics and challenges. Given the nature of this study, there is a possibility that it may not fully capture these differences. Therefore, future research should consider the sociocultural variations within these regions, as these factors can influence the applicability of recommendations and policies. Another approach is to promote collaborative research endeavors by combining the expertise of ecologists, economists, anthropologists and policymakers to devise solutions that tackle the dynamics of aquatic food resources in tropical Africa based on specific contexts.

8 Conclusion and future directions

In conclusion, this research offers significant insights into the quantities of aquatic protein supplied across tropical African countries. It provides valuable insights into these countries' aquatic source food consumption patterns. The results underscore the differences in aquatic protein consumption among the countries, fostering the need to consider local factors when developing nutrition interventions and policies. This study showed the dynamics of local culture, socio-economic status, environmental conditions, and individual dietary behaviors, offering actionable recommendations for tailoring interventions to optimize effectiveness within diverse African communities. In this regard, future research is recommended to investigate the specific origins of aquatic protein and its role in the overall dietary landscape of these nations, thereby facilitating targeted approaches to enhance food security and public health outcomes.

This research further demonstrates the pattern of an aquatic protein supply, which showed lower values than land animal protein supply across African countries. These findings highlight the significance of land-based animal sources in meeting the population's protein needs. Specifically, aquatic food imports significantly influenced their consumption across the region for the year under study, suggesting the influence of trade economics on aquatic food intake. In this regard, a clearer understanding of these factors influencing the differences and their dynamics is essential for policymakers, nutritionists, and stakeholders in devising targeted strategies to enhance protein availability and address imbalances between land and aquatic protein sources in African countries. Therefore, further research is required to investigate the underlying factors contributing to these gaps and explore potential solutions for sustainable aquatic source food production and consumption in the region.

Furthermore, the production of aquatic food in tropical Africa is an intricate and diversified sector of the economy that supports

millions of people. The sector involves a variety of fishing, aquaculture, and fish farming techniques. However, the sector has experienced challenges and barriers, including poor infrastructure, inadequate legislation, and restricted access to finance. Diverse approaches have been proposed to address these issues, such as increased financial accessibility and environmentally friendly aquaculture practices. However, implementing these approaches requires more practical efforts and ongoing monitoring to ensure effective outcomes for a healthier African population.

Author contributions

EO: conceptualization, formal analysis, and writing – original draft preparation. RO: formal analysis and writing – reviewing and editing. DF, PO, and BF: writing – original draft preparation. All authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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