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The role of aquatic foods in combating malnutrition and food insecurity: An integrative review

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Abstract

Malnutrition and food insecurity pose significant challenges in developing countries, especially in Africa, where many people lack essential nutrients. Aquatic foods are valuable sources of nutrients and have the potential to address these issues. Global policymakers and funders are increasingly recognizing the significance of aquatic foods in tackling malnutrition and food insecurity. They are boosting their production, processing, and trading investments to strengthen the global food system. This is particularly crucial as the world's population is expected to surpass 9 billion by 2050. The current integrative review indicates substantial potential for using aquatic foods to control food insecurity and malnutrition in low- and middle-income developing countries. By involving funders, policymakers, and researchers in promoting sustainable aquaculture and other aquatic practices, we can improve food security and nutrition outcomes in vulnerable populations. Stakeholders must collaborate and implement targeted or necessary interventions to capitalize on the benefits and advocate the use of aquatic resources in enhancing health and well-being in these regions.

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Introduction

Food insecurity is a critical issue that affects individuals and communities worldwide. It occurs when people don't have reliable access to enough nutritious food to live a healthy life (FAO, IFAD, 2013; Saint Ville *et al.,* 2019). This can be due to various reasons such as poverty, political instability, natural disasters, and environmental degradation. The consequences of food insecurity are serious and can lead to malnutrition, poor health, and reduced productivity (Mandela, 2016; Liese, 2018). Certain regions are particularly vulnerable to food insecurity due to factors such as sub-Saharan Africa, for example, faces significant challenges, with countries like South Sudan, Somalia, and Nigeria struggling to access enough nutritious food due to conflict, climate change, and poverty (Clover, 2003; Bjornlund *et al.,* 2022; Wudil *et al.,* 2022). Yemen, Haiti, and Venezuela also face high levels of food insecurity due to civil unrest, natural disasters, and economic and political crises (Dureab *et al.,* 2019; Kabbani and Wehelie, 2004; Felima, 2009; Viceisza *et al.,* 2020; John, 2019; Doocy *et al.,* 2019; Herrera-Cuenca *et al.,* 2021). These examples underscore the complex and interconnected factors contributing to food insecurity. Addressing this issue requires a comprehensive approach that includes improving access to education, healthcare, and employment, investing in sustainable agricultural practices, and addressing the root causes of poverty and inequality.

Malnutrition is a serious issue that affects millions of people around the world, particularly in underprivileged populations. It can be caused by undernutrition, overnutrition, or macro-and micro nutrient deficiency (Chopra *et al.,* 2023; Tarasuk *et al.,* 2019). Undernutrition occurs when an individual does not consume enough essential nutrients, leading to deficiencies in vitamins, minerals, and other important substances. This can result in a range of health problems, including stunted growth, weakened immune systems, and impaired cognitive development. Overnutrition is caused by excessive intake of nutrients, often in the form of unhealthy or high-calorie foods, leading to obesity, which is a major risk factor for chronic diseases such as heart disease, diabetes, and certain types of cancer. Malnutrition can also be caused by micronutrient deficiency when an individual lacks specific vitamins and minerals that are essential for proper bodily function, resulting from poor dietary intake, malabsorption issues, or other factors (Pancheva-Dimitrova *et al.,* 2018). Common deficiencies include iron, vitamin A, vitamin D, and iodine, which can lead to various health problems if left untreated (Pancheva-Dimitrova *et al.,* 2018). In regions where access to nutritious food is limited, such as in some developing countries, malnutrition in the form of undernutrition and macro or micro nutrient deficiency is more prevalent. The burden of undernutrition is significant, as it not only affects an individual's health but also puts them at a higher risk of morbidity and mortality. A study by Ahmed *et al.* (2013) reported that child malnutrition was responsible for 54% of child mortality for children under five in developing countries. This is why it is crucial to address the root causes of malnutrition, such as inadequate diet and poor living conditions, to improve the overall health and well-being of populations worldwide.

Consuming aquatic foods is crucial in addressing food insecurity and malnutrition. Aquatic foods are rich sources of essential nutrients, such as protein, omega-3 fatty acids, and various vitamins and minerals (Pradeepkiran, 2019; Maulu *et al.,* 2021). Access to fish can improve the overall nutritional quality of a diet and reduce the risk of malnutrition. In areas where fish is readily available and affordable, higher fish consumption is associated with lower levels of food insecurity and malnutrition (Béné *et al.,* 2005; Beveridge *et al.,* 2013; Obiero *et al.,* 2019). Conversely, in areas where fish is scarce or expensive, food insecurity and malnutrition rates tend to be higher (Belton *et al.,* 2014; Hasselberg *et al.,* 2020). Promoting aquatic food consumption can be an effective strategy for addressing food insecurity and malnutrition, especially in vulnerable populations with limited access to nutritious foods.

This review aims to examine the potential of consuming aquatic foods to address food insecurity and malnutrition in low and middle-income developing countries. By exploring the perspectives of funders and policymakers on the role of aquaculture in addressing these critical issues, we aim to provide insights into how sustainable aquatic food production and consumption practices can contribute to improving food security and nutrition outcomes in these regions. By highlighting the potential benefits of utilizing aquatic resources, we aim to promote increased aquatic food consumption and encourage researchers to implement interventions for hunger and malnutrition alleviation in vulnerable populations.

The status of malnutrition in Africa

Malnutrition remains a significant challenge in developing countries particularly African countries, where a large portion of the population experiences undernourishment and lacks essential nutrients. According to a report by FAO *et al.* (2023), the global number of undernourished individuals between 2021 and 2023 was approximately 735 million. The 2018 report by the Food and Agriculture Organization of the United Nations estimated that there were 821 million malnourished individuals in 2017 (FAO *et al.,* 2018) representing a 10.5% reduction in malnutrition when comparing 2017 to the years 2022-2023. The FAO *et al.* (2018) further reported that an estimated 120 million people worldwide faced acute food insecurity in 2017, requiring immediate action to safeguard their well-being. The issue of undernourishment and food insecurity is worsening in Africa, with the Eastern Africa region having a higher prevalence compared to Northern Africa, which has the lowest prevalence of undernourishment, refer to Table 1. Country-wise, Nigeria is the most malnourished country in Africa, despite being the second in aquaculture production behind Egypt, with approximately 25 million malnourished people ((Adeyeye *et al.,* 2023; Obada *et al.,* 2021). Moreover, despite Asia being the leading continent in aquaculture production, Asian countries like India have reported a high prevalence of malnutrition. This may be attributed to socio-economic factors. In 2022, Asia and Latin America ranked second and third in the prevalence of malnutrition, with 8.5% and 6.5% respectively. North America and Europe continue to report a low prevalence of malnutrition, with less than 2.5% (FAO *et al.,* 2023).

Table 1. Prevalence (%) of malnutrition in Africa, 2005 – 2022

Year/Area	2005	2010	2012	2014	2015	2016	2017	2018	2019	2020	2021	2022
Global	12.1	8.6	11.3	10.7	7.9	7.8	7.5	7.6	7.9	8.9	9.3	9.2
Africa	19.2	15.1	18.6	18.3	15.8	16.6	16.5	16.6	17.0	18.7	19.4	19.7
Northern Africa	6.2	4.7	4.8	4.6	5.4	5.7	6.0	6.0	5.8	6.0	6.9	7.5
Sub-Saharan Africa	22.5	17.6	21.0	20.7	18.2	19.1	18.9	19.1	19.5	21.6	22.2	22.5
Eastern Africa	31.7	23.8	30.9	30.2	24.6	26.2	26.2	26.0	26.7	28.1	28.4	28.5
Central Africa	31.9	22.5	26.0	24.2	23.3	24.7	23.7	24.4	24.8	27.6	28.5	29.1
Sourthern Africa	5.1	7.2	6.9	7.4	9.3	8.3	7.8	7.7	8.3	9.5	10.0	11.1
Western Africa	12.2	10.8	10.4	10.4	10.6	10.7	10.6	11.1	11.0	13.7	14.5	14.6

Source: (FAO *et al.,* 2023; FAO *et al.,* 2018)

Health, economic, and social impacts of food insecurity and malnutrition

Food insecurity and malnutrition negatively affect our society, including social, economic, cognitive, behavioral, and health impacts. These issues can lead to poor growth and development in children (Chilton *et al.,* 2007; Alaimo *et al.,* 2020; Kaiser and Townsend, 2005; Cook *et al.,* 2004), increased risk of chronic diseases such as diabetes and heart disease, and a weakened immune system that makes people more susceptible to infections and illnesses (Fernandes *et al.,* 2018; Carruth and Mendenhall 2019; Nagata *et al.,* 2019).

Food insecurity and malnutrition can harm cognitive and behavioral development, particularly

in children whose brains are still maturing and adapting to their surroundings. Insufficient food intake can impact cognitive function and behavioral outcomes, potentially resulting in learning difficulties, memory issues, and impaired decision-making skills (Wainwright and Colombo 2006; Royer *et al.,* 2021; Liu *et al.,* 2003; Olness 2003; Puri *et al.,* 2023).

From an economic point of view, food insecurity and malnutrition can lead to decreased productivity in the workforce. When individuals and families struggle to afford enough nutritious food to maintain their health and well-being, it can result in lower productivity, increased healthcare costs, and reduced ability to fully participate in the economy. Ultimately, this places an economic burden on society and the affected country's government. Studies by Sansón-Rosas *et al.* (2021), Gubert *et al.* (2017), and Nugent *et al.* (2020) have discussed the economic effects of malnutrition in food-insecure families.

Food insecurity has social implications. People facing food insecurity may feel ashamed and socially isolated due to their inability to access adequate food. This can harm their mental health, well-being, and community relationships. Additionally, the lack of access to nutritious food can lead to environmental consequences, such as unsustainable farming practices, resource overconsumption, deforestation, soil degradation, and water pollution to secure enough food (Falvey 2004; Conway 2012; Swaminathan, 2016; Chitondo *et al.,* 2024).

Hence, food insecurity and malnutrition have had detrimental effects on our communities, making it crucial to tackle these challenges in order to enhance the welfare of everyone. Aquatic foods offer a promising solution to these issues as they are abundant in vital nutrients like omega-3 fatty acids, proteins, vitamins, and minerals that are essential for cognitive development, immune function, and overall health and well-being.

Different categories of commonly consumed Aquatic foods

Aquatic foods have a high diversity in food systems and can supply critical nutrients to improve overall health. According to Lala-Pritchard & Johnstone (2020), aquatic foods refer to animals, plants, microorganisms, cells, and plant-based food of aquatic origin emerging from new technologies. Aquatic foods can be farmed or wild-caught and are sourced from inland waters like lakes, rivers, and wetlands; coastal areas like estuaries, mangroves, or near-shore; and marine or ocean waters (Garcia & Rosenberg, 2010; Reid *et al.,* 2013; Aasim *et al.,* 2018). They include: (i) Finfish: Small pelagic fish like herring, sardines, anchovies; medium pelagic fish like bonito, mahi-mahi; large pelagic fish like tuna, swordfish; salmonids like salmon, trout; carps; cichlids like tilapia; cods like cod, haddock, pollock; and demersal fish such as flounder (Venugopal, 2005). (ii) Crustaceans: Shrimps, prawns, crabs, lobsters, and crayfish; seed shrimp, branchiopods, fish lice, krill, remipedes, isopods, barnacles, copepods, opossum shrimps, amphipods, and mantis shrimp (Klaoudatos & Klaoudatos, 2008; Poore, 2004). (iii) Cephalopods: Octopus and squids (Hunsicker *et al.,* 2010). (iv) Molluscs: Clams, cockles, and sea snails (Sonak & Sonak, 2017). (v) Aquatic plants: Water spinach, Ipomoea aquatica. (vi) Algae: Seaweeds. These aquatic foods also include other aquatic animals such as mammals, insects, and sea cucumbers.

Sustainable Aquatic food supply

Aquatic foods are central to the livelihoods, food, and nutrition security of more than 800 million people in developing countries – particularly those vulnerable to climate change, poverty, conflict, and humanitarian emergencies (Elvevoll, and James 2000; Barange *et al.,* 2014; Ellis *et al.,* 2015). Aquatic food production has to be ecologically sustainable to keep the ecosystems and resources on which production relies. Whereas the supply has to be socially and economically sustained so that the industries and supply chains that harvest and process the food and make it available to

consumers continue to operate (Jennings *et al.,* 2016; Marinda *et al.,* 2018).

A sustainable aquatic food supply involves meeting current and future aquatic food demands in a way that does not deplete or harm the ecosystems of oceans, rivers, and other bodies of water. This includes practices that ensure the long-term health and productivity of marine life, while also taking into account environmental, social, and economic factors (Pounds *et al.,* 2022; Tigchelaar *et al.,* 2021; Jennings *et al.,* 2016). Sustainable aquatic food supply can involve responsible fishing and aquaculture practices, conservation of marine habitats, and consideration of the impacts of food production on local communities and economies (Subasinghe *et al.,* 2009; Bunting 2023; Sumaila *et al.,* 2016). The goal is to provide a continuous and reliable source of food from aquatic resources without compromising the health of the environment.

It is important to practice responsible fishing and aquaculture. Fish stocks should be managed and harvested sustainably to prevent overfishing and protect the long-term health of aquatic ecosystems. This involves setting catch limits, monitoring fishing activities, and minimizing bycatch. Additionally, aquaculture or fish farming should be conducted in an environmentally sustainable manner by using sustainable feed sources, reducing pollution, and preventing the spread of diseases. For example, effluents from aquatic farms have been found to cause eutrophication in large water bodies by leaching nutrients that fertilize the water and overgrow macroalgae, ultimately disrupting the aquatic ecosystem (Porrello *et al.,* 2003; Herbeck, *et al.,* 2013; Saikku and Asmala, 2010; Milhazes-Cunha and Otero 2017; Zhang *et al.,* 2006). By taking these responsible measures, we can preserve our water bodies for future generations. Preserving aquatic habitats is also crucial for ensuring a sustainable supply of aquatic food. This includes safeguarding and rejuvenating aquatic ecosystems like coral reefs, mangroves, and wetlands that are vital for supporting fish populations. Moreover, it's important to educate the public to raise awareness about the significance of sustainable aquatic food sources and to promote responsible consumption habits that contribute to a more sustainable food supply.

Aquatic food systems

The world is rapidly changing. Increasing food consumption by a growing population, together with changing dietary habits, poses an immense challenge for the global food system. On that ground it's now time to see how to meet the increasing demand for food and provide healthy diets for all for the time to come without undermining the compromising the resources and crossing planetary boundaries, beyond which the prospects for humanity may be threatened (Godfray *et al.,* 2010; Steffen *et al.,* 2015).

The Sustainable Development Goals (SDGs) aim to guarantee that "all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life" in addition to eradicating poverty and hunger by 2030 (UN, 2015b). This promotes appropriate and sustainable food systems while focusing on all facets of malnutrition and the food system. Aquatic food systems are sustainable when they support food security without compromising social, economic, or environmental aspects (Koehn *et al.,* 2023).

Ecological sustainability, economic viability and social equity of aquatic foods

Ensuring the sustainability of aquatic food systems requires minimizing environmental impacts and maintaining biodiversity (Meybeck and Gitz2017; Elisabat *et al.,* 2018). Overfishing, habitat destruction, and pollution are significant threats. Sustainable practices include regulated fishing, marine protected areas, and eco-friendly aquaculture techniques. These methods help in preserving aquatic ecosystems while ensuring a continuous supply of food (Elisabat *et al.,* 2018). For sustainability, aquatic food systems must be economically viable. This involves creating profitable and resilient business models for fishers and fish farmers. Investment in infrastructure, access to markets,

and fair-trade practices are essential. Economic policies should support small-scale fishers and aquaculture producers, enabling them to compete in the global market (Meybeck and Gitz 2017).

The contribution of aquaculture in supplying animal protein for human consumption

Over the past few decades, aquaculture has experienced rapid growth and has become a significant contributor to the global animal protein supply. According to the Food and Agriculture Organization of the United Nations (FAO), aquaculture has been the fastest-growing animal food production sector worldwide for over three decades (Naylor *et al.,* 2021). It also accounts for over half of the global seafood supply (FAO, 2020). In 2018, global aquaculture production reached 114.5 million metric tons, showing a 28% increase compared to 2000 when production was 32.4 million metric tons. The report also revealed that the number of cultured species has increased from 250 in 2000 to 600 in 2018. In 2018, aquaculture also contributed to approximately 15% of the global animal protein supply (Fig. 1) (Boyd *et al.,* 2022). Future projections indicate that the contribution of aquaculture to the global animal protein supply will continue to grow in the coming years to meet the demands of the rapidly growing population (Hua *et al.,* 2019; Gephart *et al.,* 2020). The consistent increase in the contribution of aquaculture to the global animal protein supply over the past few decades is expected to play a crucial role in meeting the protein needs of a growing global population.

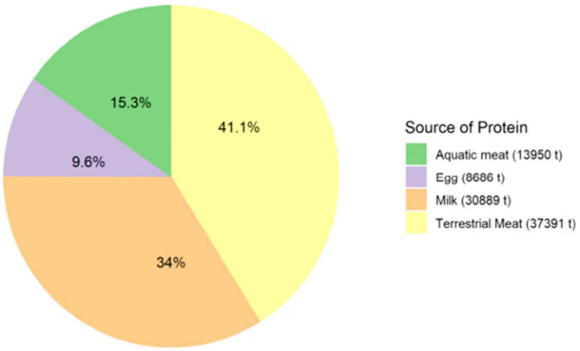

Fig. 1. The comparison between aquatic protein and other animal protein sources
(Source: Boyd *et al.,* 2022)

The contributions of aquatic foods in managing malnutrition and food insecurity

Aquatic foods, such as fish, shellfish, and seaweed, play a significant role in combating malnutrition and addressing food insecurity challenges in our communities, especially in low and middle-income countries where access to nutritious food is minimal (Thompson and Subasinghe, 2011; Norman *et al.,* 2019; Calder, 2021). First, aquatic foods are high in nutrients such as protein, omega-3 fatty acids, vitamins, and minerals. These nutrients are important for overall health and development, especially in children and pregnant women.

For instance, consuming omega-3 fatty acids in biologically active forms such as docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA) accelerates fetal brain development during the second trimester of pregnancy. Yaktine and Nesheim (2007) reported that deficiency of omega-3 fatty acids during pregnancy is associated with visual and behavioral abnormalities that cannot be reversed with post-natal supplementation. Due to these health and nutritional benefits of omega-3 fatty acids, different guidelines recommend at least a daily minimum intake of about 200 mg DHA, equivalent to one fatty fish from the sea per week for pregnant women (Koletzko *et al.,* 2018; Jaclyn *et al.,* 2010). These recommendations align with the US Food and Drug Administration (FDA) and Environmental Protection Agency (EPA) (Groth, 2017).

Second, aquatic foods are cost-effective animal protein sources for human consumption compared to land-based sources such as beef, pork, or poultry. These foods are easily accessible in most parts of the world, not only for communities living near rivers, lakes, and oceans but also for people living in urban areas. This makes them a cost-effective and sustainable source of nutrition for many people where access to affordable and nutritious food can be challenging. A study by Fisher *et al.* (2017) on integrating fisheries and agricultural programs for food security in 12 low-income countries such as Cambodia, Ethiopia, Mozambique, Zambia, Haiti,

Malawi, Rwanda, Senegal, Uganda, Bangladesh, Ghana, and Nepal found that between 10 to 45% of their population rely on fish as a main part of their daily diet. The study also found that fish-reliant households were poorer compared to their counterparts. In addition, a report by the WorldFish Center highlighted the importance of fish in the diets of people in low to middle-income countries, particularly in Africa and Asia. The report found that fish is a highly affordable source of protein for many people in these regions, with higher consumption rates among lower-income households (Hall and Andrew 2011). Aquaculture has significantly increased the availability and affordability of fish in many low to middle-income countries. By farming fish and other aquatic species, countries can produce a more sustainable source of animal protein that is accessible to a larger portion of the population. Overall, aquatic foods are a cost-effective and sustainable source of animal protein for people in low to middle-income countries, providing essential nutrients to support healthy diets and food security.

Third, aquaculture offers a wide variety of foods to choose from, including different types of finfish, shellfish, and seaweed. This diversity helps to ensure a well-rounded and balanced diet that offers various nutritional benefits essential for preventing malnutrition. For example, salmon is rich in omega-3 fatty acids, which are important for brain health (Koletzko *et al.,* 2018). Tuna is high in protein and a good source of vitamin D (Edouard Bourre & Marc Paquotte, 2008; Kamel *et al.,* 2022). Sardines are packed with calcium and vitamin B12 (Öhrvik *et al.,* 2012). Shellfish such as shrimp, crab, and mussels are also excellent sources of protein, vitamins, and minerals (Venugopal and Gopakumar, 2017). Shrimp is low in calories and high in protein, while crab is rich in copper and selenium, both essential minerals for the body. Mussels are a great source of iron and vitamin B12 (Azra *et al.,* 2021; Abdel-Salam, 2013). Seaweed is a unique aquatic food rich in vitamins, minerals, and antioxidants. It is a good source of iodine, essential for thyroid function, and also contains fiber, which can promote gut health. Different types of seaweed, such as nori, kelp, and dulse, can be incorporated into soups, salads, and stir-fries to add a nutritional boost to the meal (Peng *et al.,* 2015; Kim *et al.,* 2013). Therefore, aquaculture offers a variety of foods that can provide a diverse range of nutrients to support overall health and combat malnutrition (see Table 2).

Table 2. Reported proximate and nutritional compositions of selected fish species per 100 g

Food item	Calories (Kcal)	Protein (g)	Fat (g)	Ca (mg)	Fe (mg)	Mg (mg	P (mg)	K (mg)	Na (mg)	Zn (mg)	Cu (mg)	Mn (mg)	I (ug)	Se (ug)	Cholesterol (mg)
Tilapia (farmed)	100	19	2.48	9	<0.25	24.3	159	342	94	0.3	<0.025	0.005	4.1	20.5	48
Shrimp (farmed)	76	15.6	0.8	65	0.52	22.5	191	146	475	0.94	0.208	0.029	13.6	19.5	136
Salmon (farmed)	203	20.3	13.1	9	0.26	25.4	230	398	49	0.34	0.025	<0.0125	0.32	22.8	62
Salmon (wild)	136	22.3	4.94	15	0.4	26.2	226	330	53	0.42	0.062	<0.0125	18.4	30.2	59
Catfish	134	16.5	7.31	8	<0.25	20.6	166	292	61	0.47	<0.025	0.002	1.9	9.3	66

Source: US Department of Agriculture (USDA)

Through sustainable practices and proper management of aquatic foods, we can ensure a reliable source of nutrition for billions of people worldwide. Implementing science-based regulations on fishing quotas, regulating the use of fishing gear to minimize bycatch and habitat damage, and establishing protected marine areas are essential steps in achieving this goal. For example, countries like New Zealand and Iceland use Individual Transferable Quotas (ITQs) to allocate a specific portion of the total allowable catch to individual fishers or fishing companies, encouraging responsible fishing and preventing overexploitation of fish stocks (Squires *et al.,* 1995; Sumaila, 2010; Pálsson and

Helgason, 1995). Additionally, fish farming has the potential to reduce pressure on wild fish populations, but it must be carried out sustainably, minimizing waste and pollution and ensuring the health and welfare of farmed fish. Furthermore, promoting the consumption of underutilized and low-trophic level species, such as seaweed, mussels, and small fish, can help relieve pressure on overexploited species and provide a more diverse and sustainable source of aquatic foods. By implementing sustainable management and harvesting practices, we can ensure a reliable source of nutrition for future generations and contribute to the health and well-being of communities around the world.

Community adaptability to the consumption of aquatic foods

The consumption of aquatic foods and food products has been on the rise in recent years due to a variety of factors. Growing health awareness has led many consumers to seek out seafood as a healthy protein option. Technological advancements in fishing and aquaculture have made it easier to harvest and produce aquatic foods. Changes in the environment, such as overfishing and pollution, have also led to a shift towards more sustainable seafood options. Additionally, shifting cultural attitudes toward seafood consumption have made seafood more popular in many cultures around the world. Combined, these factors have all contributed to the increase in the consumption of aquatic foods.

The increasing awareness of the health benefits of consuming seafood is driving communities to incorporate more aquatic foods into their diets. Seafood has always been a staple in many coastal communities around the world. However, as researchers continue to uncover the health advantages of consuming aquatic foods, there has been a resurgence in incorporating more seafood into diets for its health outcomes. Numerous studies have shown that fish and other seafood are rich in essential nutrients such as omega-3 fatty acids, proteins, minerals, and vitamins (Khalili-Tilami and Sampels, 2018; Balami *et al.,* 2019; Durmuş, 2018; Jayasekara *et al.,* 2020). For example, in Japan, seafood is a dietary mainstay, and the population has one of the longest life expectancies in the world (Smil and Kobayashi, 2012; Tsugane, 2021). The Japanese diet includes a variety of fish, seaweed, and other seafood, which are thought to contribute to their overall health and well-being (Smil and Kobayashi, 2012; Tsutsui, 2023). The high consumption of Omega-3 fatty acids in seafood can help reduce the risks of cardiovascular diseases, improve brain function, and lower inflammation in the body (Mozaffarian and Wu, 2011; Lorente-Cebrián *et al.,* 2013). In addition, a book titled 'The Omega 3 Miracle' revealed that the Icelandic population has a lower prevalence of heart diseases and obesity compared to countries with lower seafood consumption, which is attributed to the consumption of abundant seafood such as salmon, cod, and herring (Gordon and Herb Joiner-Bey, 2010; Steingrímsdóttir *et al.,* 2018). Efforts should be made to promote seafood consumption in our communities and encourage aquaculture practices to increase aquatic food availability. For example, in Africa, where malnutrition is a major concern, programs have been implemented at school levels to educate communities on the benefits of incorporating more fish and seafood into their diet to improve overall health and nutrition (Hasselberg *et al.,* 2020; Ahern *et al.,* 2021; Hunter *et al.,* 2017; Anena, 2023). Recognizing the health benefits of consuming aquatic foods will drive our communities to become more adaptable in their dietary practices, leading to better health outcomes and improved well-being for populations around the globe.

Advancements in technology have played a key role in enhancing the accessibility and appeal of aquatic foods. Improved fish farming practices and transportation methods have made a wider variety of seafood options available to consumers, including those living in landlocked areas. Aquaculture techniques have significantly increased the availability of aquatic foods. Through advancements in aquaculture, it is now possible to raise a wide variety of aquatic species in controlled environments, such as fish ponds, raceways, tanks, Recirculatory

Aquaculture Systems (RAS), and cages (Ahmed and Turchini, 2021; Angel *et al.,* 2019; Das *et al.,* 2022). These environments allow for the monitoring and control of water quality, temperature, feeding, and disease prevention, resulting in improved growth rates and fish health. They have also allowed for the production of seafood that meets specific consumer preferences, such as organic or locally sourced options (Chauhan and Mishra, 2022; Ramesh *et al.,* 2022). Innovations in processing and packaging, ranging from high-pressure processing to edible coating, have also had a significant impact on the quality, shelf life, and safety of aquatic foods. For example, vacuum sealing, high-pressure processing (HPP), plasma technologies, purified condensed smoke, microwave heating, and freezing technologies have extended the shelf life of seafood products, allowing them to be stored for longer periods without compromising their quality and safety (Russo *et al.,* 2024). This has made seafood more convenient and cost-effective for consumers, as they can now purchase seafood in bulk and store it for future use. Furthermore, transportation methods have improved, allowing seafood to be transported across long distances quickly and efficiently. This means that consumers living in landlocked areas can access a wider variety of seafood options that were previously unavailable to them. For example, advances in refrigerated shipping containers have made it possible to transport seafood from coastal areas to inland markets while maintaining the quality and freshness of the product (Mercier *et al.,* 2017). Advancements in biotechnology have also led to the genetic modification of farmed fish species that grow faster and are disease-resistant. For example, the Genetically Improved Farmed Tilapia Fish (GIFT) developed by WorldFish in the 1980s has already benefited millions of Africans (Hilsdorf *et al.,* 2017; Gjedrem, 2012). Therefore, technological advancements have not only significantly increased the accessibility and appeal of aquatic foods, but have also expanded the availability, quality, sustainability, and convenience of aquatic foods for consumers around the world.

Cultural attitudes towards aquatic food consumption have evolved in recent years, with many communities embracing a more diverse and adventurous approach to aquatic food. This shift has also promoted adaptability to aquatic food consumption. Globalization has facilitated the exchange of culinary traditions and ingredients, leading to the incorporation of exotic aquatic food options that were previously considered hard to find into mainstream diets. For example, sushi, once considered a food specific to Western countries, is now a popular and widely available dish that many people can access and afford (Feng, 2012; Freedman, 2016). The rise of food tourism has also played a vital role in expanding people's culinary horizons when it comes to aquatic foods (Berno *et al.,* 2022; Mair and Sumner, 2017). Tourists are increasingly seeking out authentic and unique food experiences when visiting new destinations, encouraging them to try new dishes. Furthermore, social media has also had a major impact on changing cultural attitudes towards aquatic food consumption. Platforms like Instagram, Facebook, WhatsApp, and TikTok allow people to share visually appealing images and videos of their meals, including seafood dishes from around the world. This exposure to different culinary traditions can inspire people to be more adventurous and open-minded when it comes to trying new seafood (Leer and Kjær, 2015; Szakály *et al.,* 2021; Yen *et al.,* 2018). Therefore, the combination of globalization, food tourism, and social media has led to a more diverse and adventurous approach to aquatic food consumption in many cultures and communities. People are increasingly eager to explore new flavors and culinary experiences, and aquatic foods are often at the forefront of this exploration. As a result, cultural attitudes towards aquatic foods are evolving with greater appreciation for the vast array of delicious and unique aquatic foods available around the world.

The economic aspect is an important factor to consider when it comes to consumers' adaptability to aquatic foods in communities. The availability and cost of aquatic foods significantly influence

consumption patterns (Oken *et al.,* 2012; Golden *et al.,* 2021). High prices can limit access to aquatic foods for low-income households, while a strong economy can lead to increased consumption of higher-priced aquatic food items. In many low and middle-income countries, seafood is a crucial source of protein and essential nutrients for a large portion of the population. Economic fluctuations can impact the availability and affordability of seafood, thus affecting consumption patterns. However, the recent growth in fish farming has helped bridge the gap between fish supply and community adaptability to seafood consumption in several ways. First, it has increased overall fish production, meeting the demand for seafood and ensuring consistent availability for consumers (Anderson *et al.,* 2017; Kobayashi *et al.,* 2015). Second, fish farming has improved the accessibility of aquatic foods (Anderson *et al.,* 2017). Fish farming has made seafood more accessible to communities that may not have easy access to fresh fish from natural bodies of water. Therefore, fish farming has played a crucial role in bridging the economic gap and increasing community adaptability to seafood consumption by boosting production and improving accessibility.

The environmental impact of seafood production, including concerns about sustainability and overfishing, can influence consumer attitudes towards seafood consumption. As awareness of these issues grows, there is a shift towards more sustainable and responsibly sourced options. For instance, certifications like the Marine Stewardship Council (MSC) label have influenced consumer choices and consumption patterns (Maesano *et al.,* 2020; Van Putten *et al.,* 2020; Arton *et al.,* 2020). The MSC label has contributed to increased consumer adaptability for aquatic food consumption in several ways. Firstly, it has enhanced trust and credibility. The label is widely recognized as a trustworthy and credible certification for sustainable seafood, ensuring that products bearing the MSC label meet strict environmental and social standards. Secondly, it promotes awareness and education about sustainable fishing practices and the impact of seafood consumption on marine ecosystems. This empowers consumers to make informed choices about the seafood they purchase and consume. Lastly, it provides transparency and traceability in the seafood supply chain, allowing consumers to easily identify MSC-certified products and trace their journey from ocean to plate (Roheim *et al.,* 2018; Roheim, 2009; Jaffry *et al.,* 2004; Lim *et al.,* 2018). As a result, the MSC label has played a significant role in promoting sustainable seafood consumption and encouraging consumers to make more environmentally friendly choices when it comes to aquatic food.

Global policy makers and funders agenda on aquatic food and food security

Aquatic foods have been increasingly recognized by global policymakers and funders as an essential resource in addressing malnutrition and food insecurity in recent years. In 2021, the United Nations (UN) Food Systems Summit initiated a dedicated Action Track on Nutrition, highlighting the significance of aquatic foods in improving health and human nutrition. The State of Food Security and Nutrition in the World report by the Food and Agriculture Organization (FAO) echoed this stance, emphasizing the urgent need for increased investments in the production, processing, and trade of aquatic foods to strengthen global food security and nutrition (FAO, 2021). Here are some of the key agendas identified by global funders and policymakers regarding aquaculture and food security:

1. Implementing sustainable fisheries management practices to ensure the long-term availability of aquatic food resources for human consumption. These practices involve setting limits on fishing activities, protecting critical habitats, monitoring fish populations, and promoting responsible fishing practices. Successful examples of sustainable fisheries management include implementing catch limits and quotas in the Gulf of Maine to prevent overfishing of Atlantic cod and American lobster (Zhang *et al.,* 2011; Boenish, 2018), establishing

marine protected areas in the Great Barrier Reef Marine Park in Australia (Day, 2016), and adopting responsible fishing practices by small-scale fishers in the Philippines (Barboza *et al.,* 2024). These efforts have led to the recovery of fish populations, improved ecosystem health, and increased biodiversity while supporting the livelihoods of local fishing communities.

2. Investing in aquaculture research and development is crucial to increasing the production of nutritious aquatic foods. As aquaculture becomes a major source of sustainable and nutritious protein for millions worldwide, there is a growing need to meet the increasing demand for aquaculture products. Continued investment in research and development is essential to improve production efficiency, sustainability, and nutritional quality. Government agencies, non-profit organizations, and private investors are key in supporting aquaculture research and development initiatives. These funders can provide financial resources for research projects, infrastructure development, and training programs to enhance aquaculture systems' productivity and sustainability (Little *et al.*. 2016; Golden *et al.,* 2021). For example, the World Bank's funding for capture fisheries and aquaculture averaged about 1.8% from 1968 to 2018, but it increased to approximately 2.6 to 5.4% in 2018 (Bennett *et al.,* 2021).
3. Regional development banks have also allocated even higher funds to capture fisheries and aquaculture practices than the World Bank (Hamilton *et al.,* 2021). These figures are expected to continue increasing due to the recognition of fish as an important food source, as reported in the study by Bennett *et al.* (2021) titled "Recognizing Fish as Food in Policy Discourse and Development Funding." Policymakers also play a crucial role in supporting aquaculture research and development efforts by creating enabling policies that encourage innovation, investment, and sustainable practices in aquaculture to improve food security. Additionally, policymakers can support research initiatives that focus on enhancing the nutritional quality of aquaculture products, such as the development of feeds, high-quality fingerlings, and probiotics to promote fish health and growth.
4. Promoting equitable access to aquatic food resources for all populations, especially vulnerable and marginalized communities. This is because access to nutritious and sustainable aquatic food is crucial for the overall health and well-being of individuals, and disparities in access can worsen existing inequalities in food security and nutrition. One approach to promoting fair access to aquatic food resources is by investing in initiatives that support small-scale fishers and farmers. For example, the Norwegian Agency for Development Cooperation (NORAD) donated 5 million US dollars to provide training, technical assistance, and access to markets for small-scale fishers and aquaculture producers. This support can empower these communities to enhance their livelihoods and improve their access to aquatic food resources in Kenya, Mozambique, and Tanzania (https://www.ifad.org/en/web/latest/-/norway-commits-funds-to-ifad-to-lift-aquaculture-communities-out-of-poverty-and-lower-malnutrition-in-kenya-mozambique-and-tanzania).
5. In terms of policy, governments are now working to promote fair access to aquatic food resources by implementing regulations and policies that support small-scale fishers and fish farmers. This includes removing barriers to access faced by vulnerable and marginalized communities, providing incentives for sustainable aquaculture production, regulating aquatic resources to ensure long-term sustainability, and supporting the development of local markets to increase access to aquatic food resources for all populations.
6. Supporting efforts to mitigate the impacts of climate change on aquatic food systems, including ocean acidification and sea level rise. Climate change is affecting aquatic food systems through phenomena such as ocean acidification and sea level rise (Alava *et al.,* 2017; Reid *et al.,* 2019). This is a significant concern for funders and policymakers who are increasingly recognizing the importance of protecting aquatic food systems for food security and biodiversity. To address these

impacts, funders and policymakers are considering funding research on the effects of ocean acidification and sea level rise, as well as supporting adaptation strategies for vulnerable communities and ecosystems. By investing in research, adaptation strategies, and policy interventions, funders and policymakers can contribute to safeguarding aquatic food systems for future generations.

7. Other important funders and policymakers' agenda on aquaculture and food security include: Encouraging the adoption of innovative technologies and practices to improve the efficiency and sustainability of aquatic food production (Kumar *et al.,* 2018; Henriksson *et al.,* 2021). Enhancing food safety and quality standards for aquatic foods to protect consumers and prevent foodborne illnesses. Strengthening international cooperation and partnerships to address global challenges in aquatic food security (Schwarz *et al.,* 2021; Kumar and George, 2019; Smithrithee *et al.,* 2020; Obiero *et al.,* 2020). Promoting education and awareness of the importance of aquatic foods for nutrition and food security (Stead, 2019). Providing financial support and incentives for small-scale fishers and aquaculture farmers to improve their livelihoods and resilience. Monitoring and evaluating progress towards achieving global goals and targets for aquatic food security, and adjusting policies and funding priorities accordingly (Pingault *et al.,* 2018).

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