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Considering the food environment can help to promote the consumption of aquatic foods for healthy diets

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Aquatic foods ensure food and nutrition security for billions of consumers around the world. As part of food systems, aquatic foods provide nutritious, affordable, convenient options for healthy diets, and can also foster sustainable food production. Within the food system framework, the food environment is the space that connects food procurement to consumption. The food environment influences consumer decisions on which foods to acquire. To date there has been relatively little focus on creating an enabling food environment that supports consumers in decisions to obtain aquatic foods. To fill this gap, we conducted a narrative review of literature from 2000–2020 to document the availability, affordability, convenience, promotion, quality and sustainability of aquatic foods within diverse food environments. Our review highlighted several opportunities that can support development and promotion of convenient, high quality aquatic foods. We also noted several research gaps. For example, some consumers, especially those in high income countries, respond well to labels related to sustainability and also to messaging to consume diverse types of fish, especially lower tropic species like anchovy. However, less is documented on how promotion influences consumers from LMIC. The paper also notes a gap in assessment of the price and affordability of aquatic foods. Most price and affordability assessments do not provide details on which aquatic foods were considered in the costing assessment. In addition, wild or home-harvested aquatic foods are often not accounted for in price and affordability assessments. Using case studies, we demonstrate how considering the food environment in research and implementation strategies can add value to program design. For example, processing tuna frames and underutilized small fish species into powder is one innovation that reduces food waste and also creates a convenient, quality product. These results provide the foundation for deepening our understanding of how key elements of the food environment influence consumers' decision-making and how these elements can be considered in future research, programming and policy efforts.

KEYWORDS

food systems, aquatic foods, healthy diets, nutrition, food environment

1 Introduction

One in three people on the planet suffer from one or more forms of malnutrition, including undernutrition, overweight and obesity, and micronutrient deficiencies. In addition, diet-related non-communicable diseases are increasing, due in part to poor quality diets that include increased consumption of ultra-processed foods (Neri et al., 2022). Healthy diets are not affordable for over one-third of the global population (FAO et al., 2022). Poor quality diets not only lead to human health consequences, but also unsustainable food systems, characterized by resource-depleting food production, lack of diversity of foods produced and consumed, environmentally untenable supply chain practices and inequities throughout the system. Our food systems are responsible for approximately 80% of deforestation (Campbell et al., 2017) and 30% of all greenhouse gas emissions (Crippa et al., 2021). These concerns have led to greater attention to food systems, which can be defined as the activities and actors involved in the ways in which we produce, process, transport, distribute, market, and consume foods.

Food systems research has progressed from a focus on producing sufficient quantities of food, for food security, to ensuring that a broad variety of foods to meet nutrient needs are accessible, affordable, stable, and well-utilized to ensure food and nutrition security, while also considering long- term sustainability and agency of actors within the system as well as the natural environment upon which they depend. While food system frameworks are now well-recognized (High Level Panel of Experts, 2020), research, program and policy interventions in the aquatic foods realm often remain focused on food production and supply chains (UN Nutrition, 2021). Veldhuizen et al. (2020) and Tezzo et al. (2021) found a “missing middle” in fisheries, aquaculture, and aquatic food research in that there was little attention given to factors mediating food provision and acquisition, which largely sit within the “food environment” (High Level Panel of Experts, 2017).

This paper focuses on aquatic foods in the food environment. Aquatic foods are defined by FAO as food for human consumption, grown in or harvested from water. In this paper, aquatic foods refer to fish, crustaceans, mollusks, echinoderms (such as sea cucumbers and urchins), aquatic plants (such as seaweeds and other algae), and other aquatic animals and micro-organisms used for food (FAO, 2022).

The food environment is defined as the consumer interface with the food system that includes wild, cultivated, and built spaces (Downs et al., 2020). Built spaces refer to retail outlets, such as supermarkets and restaurants, as well as open-air food retail and include the formal and informal retail sectors. Fish and other aquatic foods form a unique food group for a food environment study. All three food environment pathways (wild, cultivated and purchased) are important, with the importance of each procurement pathway changing, based on the context.

Aquatic foods, caught or farmed in freshwater and marine ecosystems, play a central role in the food systems across the planet and are a source of food that provides food and nutrition security for billions of people (Khan et al., 2021). The biodiversity of aquatic foods is extraordinarily diverse, encompassing thousands of species and supporting a wide array of cultures and dietary patterns. Aquatic foods are nutritious and healthy food choices that can be sustainably produced or harvested, economically feasible, and acceptable in diets around the world, while also providing livelihoods and social sustainability to small-scale producers (UN Nutrition, 2021). The nutrient density of aquatic foods (especially small fish and bivalves) surpasses that of staple grains and tubers, fruits and vegetables (Koehn et al., 2022). Small fish species, in particular, are rich in calcium, iron, zinc, vitamin A and vitamin B12, as the bones, eyes and viscera which are rich in these nutrients are consumed and are often more affordable than large fish species or terrestrial animal-source foods (Roos et al., 2003). Many aquatic foods are rich sources of omega-3 fatty acids, shown to protect against heart disease (Innes and Calder, 2020,). Several dimensions of the food environment, or the space within food systems where consumer choice is influenced and where consumers procure food are important to consider when promoting aquatic foods for healthy diets.

2 Methods

To frame our paper, we adopt the conceptual framework proposed in Downs et al. (2020) which uses six characteristics, or measurable elements, to describe the food environment: availability, affordability, convenience, promotion, quality, and sustainability (Figure 1). This conceptual framework was selected above others (High Level Panel of Experts, 2017; Turner et al., 2018) for several reasons. First, the approach is grounded in holistic, systems thinking. The framework situates the food environment as an influencing factor of individual choice and dietary intakes, that is also embedded in larger spheres of influence within the socio-ecological framework. This includes sectors of influence such as production, trade, and distribution. A higher layer of the framework includes governance, culture and religion, and finally, this framework includes a unique layer of ecosystem influences such as geography, climate, natural resources, and biodiversity. Second, this framework recognizes sustainability as a characteristic of food environments. The authors of this framework acknowledge that sustainability of a food or product often begins upstream from the food environment, at for example, the sector of influence on production decisions. However, consumers may be influenced by sustainable practices and products at the level of the food environment, when taking decisions on which foods to acquire and ultimately consume. A good example of this is packaging, whereby, a consumer who desires to purchase more sustainably may opt for foods with less plastic packaging or food products sold in recyclable materials.

Third, this framework is well-suited for research that is intended to be multi-disciplinary and designed to achieve multiple sectoral outcomes due to the breadth of food environment elements it contains. Finally, we aim to highlight how thinking holistically during program design is helpful in designing interventions that cut across the multiple, diverse, and simultaneous food environment elements that influence consumers. For example, affordability is often cited as a top priority for consumers, however, we wanted a framework that also allows for consideration of additional elements of importance to consumers such as quality, sustainability, and convenience.

In this paper, we first review unique considerations of fish and other aquatic foods, using the six key elements of the food environment lens. We then demonstrate through the use of case studies, how different projects or initiatives have intentionally considered elements of the food environment in their design and

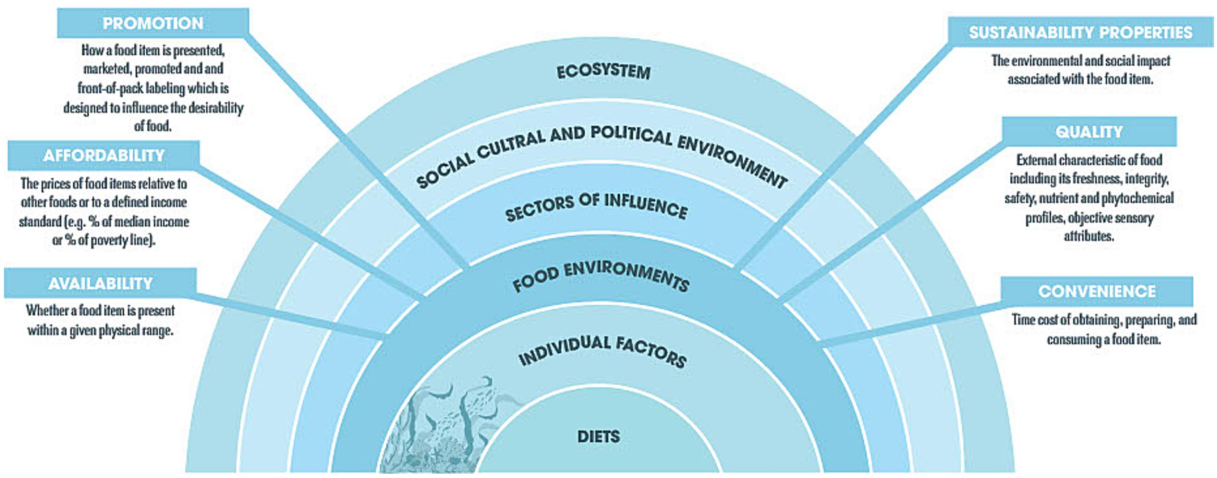

FIGURE 1
Food environment framework, adapted from Downs et al. (2020).

implementation. In our selection of case study examples, our aim is to highlight holistic rather than narrow, single discipline thinking, meaning, that we intentionally chose case study examples with multiple, cross-cutting objectives (e.g., sustainable harvest and promotion).

A narrative review covering an evaluation of published literature (2000–2022) was conducted in order to enable a holistic evaluation of the influence of the food environment on aquatic foods. The narrative review method allows for a structured appraisal of a topic of interest that has received significant development in recent years and allows for a description of this area of interest. Narrative reviews have no predetermined research question or specified search strategy, only a topic of interest. They are different from systematic reviews and do not follow a systematic review protocol. We used Google scholar to search key terms that included aquatic foods, fish, nutrition, food environment and each of the six elements of our framework; availability, affordability, convenience, promotion, quality and sustainability. We used peer-reviewed academic journal articles and global United Nations reports, such as those published by FAO, UN Nutrition and the High Level Panel of Experts.

We reviewed the literature for salient evidence on the availability, affordability, convenience, promotion, quality and sustainability of fish and other aquatic foods, within diverse food environments across the globe and summarized them according to our chosen framework.

We then used a convenience selection of case studies to highlight how the case study considered one or more elements of the food environment framework. The case studies represent work that one or more co-authors are familiar with. We use case studies to illustrate how diverse food environment characteristics can be considered and integrated into programs and policies focusing on fish and other aquatic foods. We use these examples to provide practical illustrations from actual projects to demonstrate how implementers can plan interventions that are intentionally responsive to elements of the food environment, in order to improve availability, affordability, quality, convenience, promotion or sustainability properties of aquatic foods, or to promote aquatic foods for nutrition and health.

3 Results

3.1 Availability

Aquatic ecosystems are incredibly diverse. Only considering fish, there are more than 35,000 species (greater than the total of all other vertebrate species combined) described (Froese and Pauly, 2023). Those consumed by humans (here referred to as aquatic foods) represent a small percentage of this diversity, and include 2,981 species from capture fisheries and 622 species from aquaculture of fish, crustaceans, mollusks, echinoderms (such as sea cucumbers and urchins) and aquatic plants (such as seaweeds and other algae) and other aquatic animals used for food (FAO, 2022). Aquatic food diversity is greater than that of land-based animals, however, it is largely dominated by finfish, accounting for 76% of species from aquatic environments used for human food (FAO, 2022). Three main types of seaweed, brown, red and green are harvested or cultivated, with brown and red seaweeds accounting for the majority of harvest and cultivation, in part due to diversity of uses within food and feed industries (Cai et al., 2021; Webb et al., 2023) Despite this vast diversity and richness of aquatic species, a small number of farmed species dominate in kitchens in high-income countries, while the diverse range of aquatic foods important for nutrition and public health in other regions receive less attention (UN Nutrition, 2021).

Consumption of aquatic foods has been steadily increasing in past decades, from 9.9 kg *per capita* per year in the 1960s to 20.5 kg *per capita* per year (FAO, 2022), in part, due to the growing contribution of aquaculture, which has now surpassed capture fisheries in terms of total production (about 56% of current aquatic animal production is from aquaculture) (FAO, 2022). This growth in aquatic food consumption has outpaced that of all terrestrial animal-source foods (FAO, 2020), although growth in aquaculture has been uneven and lacking diversity in relation to the diversity of capture fisheries. This has raised concerns over availability of aquatic foods and nutrients, as wild small fish have been evidenced for being more nutrient-rich than large, farmed fish (Bogard et al., 2017).

An additional concern in relation to availability of aquatic foods is their perishability. Loss and waste in aquatic food supply chains is estimated at approximately 35% globally, while it may be much greater in some regions which lack cold storage and experience seasonal climatic conditions such as heavy rains which lead to spoilage of fish processed using traditional methods (for example, sun-drying) (UN Nutrition, 2021; FAO, 2022). In addition, as little as 30% of the live weight of a fish may be consumed (FAO, 2022). Consumer preferences in western countries tend to prioritize the fillet of large species (the most protein-rich part) while the micronutrient-rich bones, eyes, and viscera are not consumed. These by-products include heads (accounting for 9–12 percent of fish weight), viscera (12–18 percent), skin (1–3 percent), bones (9–15 percent), and scales (5 percent), which are good sources of long-chain omega-3 polyunsaturated fatty acids, vitamins A, D, and B12, and minerals such as iron, zinc, calcium, phosphorous and selenium which can be available for human consumption, if processed and stored (FAO, 2022). There are positive examples of increased market availability of aquatic foods through simple and low-cost investments in technologies for loss and waste reduction such as raised rack drying, improvements in sanitation and hygiene practices at retail level (as well as upstream, from the point of harvest and while on-board), innovative products which capitalize on the use of previously-wasted by-products (for example, tuna frame powder), and trade of parts which are not consumed in some places (such as export of salted cod heads from Nordic countries, where they are not consumed, to Nigeria, where they are preferred for consumption; Salaudeen, 2014; Abbey et al., 2017; Kimani et al., 2022). Similarly, many cultures consume small fish species whole, a practice which is nutritionally beneficial and does not lead to food waste (Kawarazuka and Béné, 2011; de Bruyn et al., 2021).

Relatively, fish consumption has shifted, with Europe, Japan and the United States of America (USA) accounting for nearly half of the world's total fish consumption in the early 1960s, while in 2017, Europe, Japan and the USA only accounted for 19% of consumption (FAO, 2020). While fish consumption has grown in Asia, there is a concerning downward trend in aquatic food consumption in sub-Saharan Africa, where *per capita* fish consumption is nearly half the global average (9.9 kg *per capita*, in 2017) (FAO, 2021). This decline is largely attributed to population growth, coupled with slow (or complete lack of) development of the aquaculture sector. Additionally, there is concern over the use of fish (specifically pelagic small fish) for non-food uses, such as animal feeds, particularly West Africa (FAO, 2022; Thiao and Bunting, 2022). In countries such as Ghana, the Gambia and Sierra Leone, fish accounts for more than 50% of all animal protein consumed (FAO, 2021). However, in many countries in West Africa where pelagic small fish are important for food and nutrition security, there are concerns over the growing competition over resources. Although a greater percentage of aquatic foods captured or cultured globally is now consumed by humans (89%, an increase from approximately 50% in the 1960s) (FAO, 2022), this competition over fish for food or feed is particularly concerning in some regions such as West Africa (Deme and Failler, 2022; Thiao and Bunting, 2022; Deme et al., 2023), and when coupled with lack of development in the aquaculture sector in Africa, raise concerns over the availability of aquatic foods for meeting the nutritional needs of vulnerable populations (Golden et al., 2017).

The macro-level supply and diversity of fish and other aquatic foods at a national or regional level play a role in availability in food environments, however, distribution of these products within a region, country, community or even household may differ (UN Nutrition, 2021). *Per capita* consumption of aquatic foods ranges between countries from 0 to 100 kg *per capita*, annually (FAO, 2022), and is affected by multiple factors such as differences in cultural norms and perceptions, consumer preferences, and difficulties in distribution of perishable foods (UN Nutrition, 2021). Within countries, availability and consumption of aquatic foods may vary greatly, depending on proximity to water bodies and income status (Simmance et al., 2022a). For example, O'Meara et al. (2021), found that children in Malawi and Zambia were more likely to consume fish if they lived close to inland fisheries and far from urban market centers (O'Meara et al., 2021). Similarly, markets play a role in the availability of fish to consumers. For example, traditional markets, mobile vendors, and food stands were the most frequent access point for aquatic foods in Indonesia, although access through minimarkets and supermarkets increased slightly during the pandemic (Partelow et al., 2023). While physical access to markets plays an important role in the availability of fish across spaces, economic access and affordability of aquatic foods are integral components of the food environment, which will be discussed in the next section.

3.2 Affordability

Analysis of the price of fish and other aquatic foods as well as the contributions that aquatic foods make to affordable, healthy diets are complicated by several factors. Fish and other aquatic foods are a very diverse food group, making it difficult to gather accurate data on price and affordability (Deb et al., 2022). In literature, price comparisons are often made between "fish" and other food groups of interest, such as "cereals," "fruits," or "vegetables." Large errors can occur in estimating price and ultimately the cost of a healthy diet, when the analytical method used homogenizes the vast diversity of fish and other aquatic foods into the food group "fish" (Robinson et al., 2022). The price of fish and other aquatic foods offered through retail can differ due to numerous factors, including, the species, the processing type (fresh, frozen, dried, canned) and the type of retail outlet (specialty fish shop, supermarket or informal open-air market). Not only does the price of fish in retail outlets significantly vary, but many species are harvested either from the wild for subsistence or from homestead production, where no monetary exchange is required to procure the food. There has been very little attention given to these price considerations when assessing the cost of fish and other aquatic foods in relation to the affordability of a healthy diet.

In grouping fish and other aquatic foods from marine waters all together as "fish" as is commonly done, the price per unit quantity, relative to other foods, especially cereals and oils is high. However, to respond to malnutrition in all its forms, affordability must include nutrient density and not only price per quantity. When foods are ranked by cost/nutrient density, the affordability of fresh fish was ranked next to that of eggs and milk in Asia (Bai et al., 2021) and, depending on the context, is more affordable than other animal-source foods (Bennett et al., 2021). A recent study on cost of the diet in Bangladesh, found the species: pool barb (*Puntius sophore*), catfish (*Sulireformes* spp.) and silver carp (*Hypophthalmichthys molitrix*) to be among the most affordable sources of food in the food group "meat, fish and eggs," in seven out of eight divisions of Bangladesh (Islam et al., 2023). This also highlights that, the species of fish chosen also has a large bearing on price.

Many studies demonstrate that pelagic small fish species are not only the most nutrient-dense species types, but often are lower in price compared to large species. A study in 39 low- and middle-income countries (LMIC) found that pelagic small fish such as herring (*Culpea* spp.), sardine (*Culpea* spp.) and anchovy (*Engraulis* spp.) were comparatively affordable in relation to other fish species (Robinson et al., 2022). Fish and other aquatic foods are often some of the least expensive sources of animal protein and micronutrients available, especially in coastal communities and in those areas with a traditional practice of consuming small fish species. Pelagic small fish consumed whole are more affordable and accessible to low- income populations (Kawarazuka and Béné, 2011) than other animal-source foods, as they can be purchased in small quantities. Small fish species, such as mola (*Amblypharyngodon mola*), Indian glassy perch (*Parambassis ranga*), sardine (*Sardina pilchardus*), kapenta (*Limnothrissa miodon*) and numerous others are more nutrient-dense than large fish species, and make significant dietary contributions to protein and micronutrient intakes (Roos et al., 2003). Similarly, some species of seaweeds are more affordable than others. A comparative pricing of seaweed found green seaweed to be more costly (USD 0.79/kg) (wet weight) than the price for either brown (USD 0.47/kg) or red (USD 0.39/kg) seaweed (Cai et al., 2021).

There are some important additional challenges related to assessing the "true affordability" of fish and other aquatic foods in diets. Recent studies show large amounts of fish and other aquatic foods are harvested from the wild or from food production activities at the homestead (e.g., backyard ponds). A study based on 42 LMIC found a large amount of "hidden harvest," especially from inland rivers and lakes, and concluded that this level of under-reporting, obscures the true impact that fish and other aquatic foods have on global food and nutrition security (Fluet-Chouinard et al., 2018). While the contribution of fish and other aquatic foods can be observed in dietary intake and household food consumption surveys, the contribution of fish in terms of the most affordable, least costly healthy diet is often undervalued. Allison and Mills comment that, "fish caught from the myriad smaller lakes, reservoirs, floodplain forests, and river tributaries escape being recorded because they are consumed directly by those who catch them or sold in informal markets in remote areas," and therefore, escape reporting as food resources, especially for the rural poor (Allison and Mills, 2018).

Measures to increase affordability of nutrient-dense foods include electrification and connectivity, especially in rural areas (Bai et al., 2021), promotion and support of small fish species [e.g., bonga *(Ethmalosa fimbriata),* daaga (*Rastrineobola argentea*), herring (*Culpea* spp), kapenta (*Limnothrissa miodon*)], as well as locally based small and medium enterprises, capacity development and training in research for development (Khan et al., 2021).

3.3 Promotion

How food is presented, marketed, and advertised has an influence on consumer purchasing and consumption behaviors (High Level Panel of Experts, 2017). Promotion of aquatic foods and food products is done at multiple levels and through various outlets. Retailers use front of package labelling designed to influence the desirability, and formal and informal markets use point-of-sale advertisements. These efforts can be supported by national food-based dietary guidelines and public sector programs such as school feeding programs (see case study 1). Promotion of aquatic food can also utilize locally appropriate media such as print, radio, TV, or interpersonal communication by trusted influencers to inform consumers where to find the products and motivate purchase and consumption.

An understanding of consumers' characteristics, preferences, and values that influence purchase behavior is a foundation for effective promotion. In Asia, the perceived quality and safety of aquatic foods influence purchase decisions (Uddin et al., 2019; Budhathoki et al., 2022). How these qualities are assessed can differ by consumer demographics. For example, older, rural consumers in China preferred live aquatic foods from local wet markets which they feel convey freshness, while young and wealthy urban consumers preferred imported and convenient aquatic food products from supermarkets or online (Budhathoki et al., 2022). In wet markets, promotion can focus on point-of-sale, while the formal and online market-based promotional efforts can address safety concerns through labeling and advertising.

To promote aquatic foods for specific segments of the population, such as parents, aspirations for their children can be useful to shape marketing efforts. A multi-country study in Tanzania, Kenya, Bangladesh, and Pakistan found that parents aspired for their children to have long-term success in their lives through education and employment and connected these with good nutrition and care (Robert et al., 2021).

Where attention to sustainability of aquatic foods has increased, promotional efforts intentionally address sustainability considerations. A 2016 survey of over 16,000 consumers in 21 countries showed that sustainability is a key driver for purchase of aquatic foods, and independent labeling (such as the Marine Stewardship Council eco-labeling) increases brand trust (Stewart, 2016). Similarly, two recent studies from Italy showed that consumers (particularly some groups, including women) were willing to pay higher prices for eco-labeled fish products, at times independent of income (Maesano et al., 2020; Vitale et al., 2020), and that eco-labeling of low-trophic species such as anchovy led to greater consumer acceptance (Vitale et al., 2020). Some consumers, particularly those who are younger, have higher education or consider themselves to be environmentally aware, desire more social and ethical considerations to be included on eco-labels (Peiró-Signes et al., 2022).

Promotion of aquatic foods can also integrate sustainability concerns by encouraging consumption of the "catch of the day" and consumption of a broad range of aquatic foods (UN Nutrition, 2021). For example, the National Health Service (NHS) of the United Kingdom advises that "to ensure there are enough fish and shellfish to eat, choose from as wide a range of these foods as possible. If we eat only a few kinds of fish, then numbers of these fish can fall very low due to overfishing of these stocks" (NHS, 2022). This NHS message is designed to be a simple communication to the public to encourage consumption of diverse fish species and is particularly applicable to overfishing in circumstances of unregulated or poorly regulated fish stocks. Messages of this nature, if not carefully monitored and accompanied by sustainable management of underutilized species, could lead to overfishing of unregulated stocks and a reduction in overall fish supply (Farmery et al., 2020). Ideally consumer facing messages intended to encourage sustainable consumption, will emphasize choosing from the abundance of edible aquatic foods, that include many aquatic foods such as seaweeds, bi-valves and diverse small and large species of fish. Similarly, all species that people are relying on for consumption should come from well- managed and sustainably harvested stocks.

In low-income countries or countries where aquatic foods are not featured in traditional diets, promotional efforts may focus on the development of innovative fish products that process underutilized fish or fish by-products into desirable food products. For example, the use of fish powder produced from underutilized small fish species in sauces such as *Shiito* in Ghana is common, and processing is often done by small- and medium-scale women's fish processing organizations and sold at affordable prices. Such products help to reach all types of consumers. In Bangladesh, Cambodia, China, India, Malawi, Myanmar, Uganda, and Zambia, fish powders, fish sausages, fish cakes, fish chutneys, and other fish-based products have been produced from low-economic value fish species or by-products and promoted through nutrition programs, targeting the first 1,000 days of life and schoolchildren through school feeding programs (Bogard et al., 2015; Sigh et al., 2018a,b; Borg et al., 2019; Ahern et al., 2021; Bafana, 2021; Byrd et al., 2021; Chadag, 2022; Kabahenda and Hüsken, n.d.; Rizaldo and Morris, n.d.).

3.4 Quality

Quality refers to nutritional and phytochemical properties as well as freshness and other sensory attributes of food and is often a proxy for consumer perception of food safety. According to the United States Department of Agriculture (USDA), food safety refers to the conditions and practices that preserve the quality of food to prevent contamination and food-borne illnesses (USDA, 2022). Quality is an important food environment consideration for fish and other aquatic foods as they are some of the most likely food products to cause illness, yet also some of the most nutrient dense options. In the USA food safety classification system, fish and other aquatic foods pose some of the most frequent (and most serious) food safety threats to consumers (Painter et al., 2013). Globally, approximately one-third of the burden of food-borne illness is attributed to fish, meat, poultry, and eggs (Hoffmann and Havelaar, 2019). Fish, bivalves, and crustaceans are highly perishable and subject to spoilage. Food safety hazards in fish and other aquatic foods include chemicals and heavy metals, marine toxins, bacteria, viruses, and parasites. Some of these hazards (heavy metal contamination) occur prior to harvest, but most other hazards are exacerbated by poor practices along the supply chain, from harvest to consumption (FDA, 2022).

Consumers are very concerned about the safety and quality of food, especially fish and other aquatic foods purchased in markets. While supermarkets and specialty fish shops confer some level of consumer protection due to higher hygiene standards and implementation of food safety regulations, most consumers in LMIC purchase fish and other aquatic foods from formal and informal open air wet markets. Most consumers are also aware that fish should be kept cool and free from flies (Isanovic et al., 2023). This awareness of improved hygiene practices, however, does not always match reality, due to constraints such as lack of access to cooling facilities along the value chain from post-harvest to point of sale and other market-related constraints such as lack of shade or a temperature controlled market environments, lack of protection from environmental contaminants such as insects and dust and lack of convenient access to a clean water supply in many market environments.

At the market, consumers from many cultures have traditional means of assessing the quality of aquatic foods, including visual inspection of fish eyes and gills, for clarity and color (gills should be pink). In addition to product observation, consumers also notice the practices of vendors, looking for vendors who appear clean, have clean surroundings, use clean water and cover food (Nordhagen et al., 2022). Consumers in LMICs also establish trusted relationships with specific vendors to increase confidence in purchase of safe food (Constantinides et al., 2021).

Vendors also cite personal relationships and reputation with consumers as important elements of successful businesses. Vendors are aware of consumers' concern for good hygiene practices and honest vending practices, in relation to expiry dates and food adulteration (Isanovic et al., 2023). In addition, vendors also felt they had some agency to mitigate food safety risk themselves, through the choice of wholesalers or processors from whom they purchase foods, the foods they sell and the location of their shop. Vendors also expressed concern for consumers' welfare and not wanting to sell food to others that they would not be willing to consume themselves (Isanovic et al., 2023).

Immediate cooling, rapid processing, drying, smoking and salting are techniques to reduce food loss as well as reduce food safety risks. Increasing infrastructure at all stages of the supply chain play a central role in food safety. However, capital intensive infrastructure such as cold chain technologies are not always available or affordable for small- and medium-scale fish processors who serve local markets and often utilize low-cost, simple technologies for drying, smoking or fermenting fish (Johnson et al., 2020). Due to cost constraints, cooling technology at point of sale is often absent in many markets in LMIC and remains an issue to improve the quality as well as reduce loss of aquatic foods. Low-cost techniques such as reusable frozen ice packs were shown to be locally appropriate solutions for open markets in Indonesia, with vendors who adopted the technology reporting reduced spending on ice and improved fish quality that led to increased and more rapid sale of aquatic foods (Yalch et al., 2020).

3.5 Convenience

The convenience element of the food environment framework represents the time and labor costs of obtaining, preparing, and consuming foods. Few studies have examined this aspect of aquatic foods consumption, particularly in LMIC (de Bruyn et al., 2021). *Time scarcity* as related to dietary patterns and human nutrition is a relatively recent concept but has direct relevance to the *convenience* construct. One study carried out in Norway found caregivers of young children reporting medium and high time scarcity, had increased odds of consuming ultra-processed dinner products, fast foods, snacks, and soft drinks compared to those reporting low time scarcity (Djupegot et al., 2017). Similarly, the evidence for time scarcity comes largely from high-income contexts, despite the enormous time-consuming workloads of many in LMIC (obtaining water and firewood for cooking, absence of labor-saving devices in the home and lack of mechanized transportation) (Fernandez et al., 2019; Oostenbach et al., 2022). Time scarcity amongst parents, especially mothers, creates a barrier to feeding their children healthy meals (Storfer-Isser and Musher-Eizenman, 2013). Fish powders can reduce food preparation time burden and when flavored appropriately, can increase a child's fish consumption (Shaviklo et al., 2014). A study of old adults living in the United Kingdom showed convenience and the effort exerted in food preparation and consumption were among the leading factors for increasing consumption of fish and other animal-source foods (Appleton, 2016).

Strategies may be employed to lower the time and labor costs associated with aquatic food production and processing. Across the supply chain of fish processing, there are factors that may influence time and labor costs as well as the quality and nutritional value of fish products (Sampels, 2015). Market accessibility and infrastructure play a role in time and labor, for both vendors and consumers of aquatic foods. The degree of processing (e.g., drying, salting, smoking) in the supply chain can reduce time burden in household preparation, which in turn, may increase demand of consumers for convenient fish products (Bland et al., 2021).

Convenient ready-to-use aquatic food products are increasingly available, with implications for time and labor savings as well as health outcomes in LMIC. A recent randomized controlled trial found fish powder in Zambia improved child growth outcomes, though time saving was not studied (Chipili et al., 2022). Fish-based, ready-to-use supplementary foods have been developed and tested in Cambodia, with evidence of positive growth outcomes in young children (Skau et al., 2015; Borg et al., 2020). Fish powders can be blended with other foods and food-type powders, such as tomato and garlic powder, thereby, also increasing dietary diversity (Rahman et al., 2012). Small fish made into powders as well as tuna frame powders in Ghana were found to be highly concentrated in protein, iron, and other micronutrients (Abbey et al., 2017). This study also demonstrated that food safety was enhanced, together with optimizing meal convenience through use of these products.

Also, seaweed processing shows potential for improving health and increasing access by consumers with positive health benefits (Roohinejad et al., 2017). Brown seaweed is the most commonly used seaweed in food products: jellies, candies (in the form of agar), fruit juices, ice cream, and syrups (in the form of alginate), while some species of red seaweed, such as *Chondracanthus chamissoi* are used directly in preparation of dishes, such as Peruvian ceviche, and green seaweed varieties are often consumed fresh in salads, although consumption remains focused in countries with tradition of consuming seaweed (Alemañ et al., 2019; Cai et al., 2021; Webb et al., 2023).

3.6 Sustainability

According to the United Nations, there are three pillars of sustainability: economic development, social development, and environmental protection (Asche et al., 2018). These pillars can be used to examine the sustainability of food sources, including fish and other aquatic foods. In the last 60 years, *per capita* seafood consumption has doubled, with the largest growth seen in LMIC (Cojocaru et al., 2022). While demand for fish and other aquatic foods has rapidly increased, several concerns exist as to whether the amount of aquatic food needed to meet this demand can be produced sustainably (Zhou et al., 2015). As described in the availability section, total production of aquatic foods from both fisheries and aquaculture has increased substantially in recent years, reaching 240 million tons in 2020 (FAO, 2022). The growth in both fisheries and aquaculture over the past 50 years has contributed favorably to the social and economic dimensions of sustainability, by playing an important role in poverty reduction and food security in LMIC (Bogard et al., 2019; Naylor et al., 2021; Cojocaru et al., 2022; FAO, 2022). Additionally, growth in this sector has increased access to nutrient-dense animal-source foods, thereby improving global diets (Naylor et al., 2021; FAO, 2022).

In terms of environmental sustainability, fish and other aquatic foods are often considered to have a lower environmental impact than terrestrial animal-source foods (Bogard et al., 2019). However, the rapid expansion in both capture fisheries and aquaculture is not without environmental challenges. In capture fisheries, a central sustainability concern is overfishing which negatively impacts the ecosystem and threatens the long-term productivity of fish stocks (FAO, 2022). In 2019, 35% of the world's marine fish stocks were overfished (FAO, 2022). Overfishing often occurs in commercially harvested fish stocks, specifically impacting large fish and high economic-valued fish species which are in high demand (Zhou et al., 2015). Aquaculture also faces environmental sustainability challenges as it continues to grow, including over-intensification, the use of wild fish in feed, and pathogens, parasites, and pests (Naylor et al., 2021).

Despite the view that there are fundamental trade-offs across the three pillars of sustainability, solutions exist to uphold all three while allowing for continued growth in the capture fisheries and aquaculture industries (Asche et al., 2018). First, several NGOs and private companies have created certification and labeling schemes to increase production and demand for sustainable aquatic food products (Naylor et al., 2021). These certifications and labels appear to be successful from the consumer-end, with evidence indicating that consumers are willing to pay more for eco-labeled, sustainable aquatic foods (Cojocaru et al., 2022). Including social, economic, and environmental sustainability dimensions in certification criteria could incentivize broadly sustainable approaches to producing aquatic foods (Tlusty et al., 2019). However, while consumers may state a preference for sustainable aquatic foods, producers usually do not experience a financial benefit to sustainable production, and therefore, consumer demand based on eco-labels or certification is often not enough to create changes in sustainable production, without increasing producer premiums (Naylor et al., 2021; Cojocaru et al., 2022). Additionally, comprehension and visibility of sustainability labels can be low among consumers, so more research is needed in target communities before labels are considered a viable influence on consumers (Annunziata et al., 2019). While there is some evidence that the inclusion of sustainability considerations in food-based dietary guidelines or labeling and certifications can promote consumption of a variety of aquatic foods, the majority of studies focusing on eco-labeling are focused on high-income countries where consumers may be more aware or concerned about sustainability.

Other solutions have been examined for achieving sustainability in capture fisheries and aquaculture production. For example, fishing pressure can be redistributed to catch a broader array of ecosystem components, including underutilized species and species at low trophic levels. Producing a more diverse catch can help maintain ecosystem balance and sustain fish stocks for the future (Zhou et al., 2015). Additionally, research in capture fisheries has shown that utilizing rights-based management encourages fishers across low- and middle-income countries to fish more sustainably because they reap economic benefits, and in the long term, this benefits the broader community (Asche et al., 2018). In Ecuador, a study found that fishery workers engaged in bivalve farming petitioned for sustainability challenges to be addressed, including restoration, and strengthening of custody of mangrove ecosystems, improved sanitation and purification, and institutional investments (Prado-Carpio et al., 2021).

In aquaculture, the production of bivalves (clams, oysters, mussels, and scallops) which have attractive environmental sustainability attributes could be increased to support growing demand for aquatic foods, while improving surrounding ecosystems (Naylor et al., 2021). In practice, the viability of these solutions may be constrained by limited consumer demand for under-used fish species such as mesopelagic fish and bivalves (Zhou et al., 2015; Naylor et al., 2021) and also limited due to the effects of local, national or international demand and trade. The sustainability attributes of these aquatic foods should be properly communicated to consumers in the food environment, through increased promotion and marketing to increase demand and provide economic incentives for production (Zhou et al., 2015).

3.7 Case studies

We highlight through three case studies, how elements of the food environment have been considered in program implementation.

3.7.1 Case study 1: Considering the importance of convenience, sustainability and promotion of aquatic foods when designing interventions for school food environments

This case study from Ghana represents an example of the convenience, sustainability, and promotion elements of the food environment framework. In Ghana, factory remnants of tuna frames and three underutilized small fish species one-man thousand (*Sierathrissa leonensis*), anchovy (*Anchoa guineensis*), and flying gurnard (*Dactylopterus voltans*), were dried and ground into fish powder, then added to local dishes such as okra stew and tested for acceptability, based on a hedonic scale (Glover-Amengor et al., 2012). Acceptability amongst children was high, and nutrient analysis of these powders showed high protein and iron concentrations (Abbey et al., 2017). Fish powders have been evidenced to have a long shelf-life, offering an opportunity to stabilize supply by producing fish powder during high production seasons and storing it for times of low availability (Nowsad et al., 2021; Mahmud et al., n.d.).

Despite fish and other aquatic foods being recognized for their nutritional importance, their inclusion in nutrition programs has generally been limited to initiatives focused on the first 1,000 days of life (from conception to a child's second birthday) (Bogard et al., 2015; Sigh et al., 2018a,b; Borg et al., 2019; Byrd et al., 2021; Chadag, 2022; Rizaldo and Morris, n.d.), overlooking initiatives to improve nutrition during childhood and adolescence. School feeding programs are often implemented to promote educational goals such as increased enrolment, decreased absentee rates, and as a social safety net for low-income households, by providing meals for students. They can also be an opportunity to improve adolescents' nutrition as well as provide livelihood opportunities for local producers when nutritious foods are sourced locally, for example, through programs such as home-grown school feeding (HGSF) (FAO and WFP, 2018). Ahern et al. (2021) reviewed literature on school feeding programs in sub-Saharan Africa in order to identify those that have included fish, with particular focus on those sourcing from local producers, to analyze key challenges and good practices (Ahern et al., 2021). Key challenges in school food environments which have caused barriers for fish and aquatic food products' inclusion in school feeding programs include availability within a physical range, sustainability of the supply, affordability, and food quality and safety. Availability within a physical range is particularly important for HGSF programs, which often require that schools source foods from producer organizations within a given radius, which can limit the sourcing of fish and aquatic food products for HGSF programs to areas close to water. The sustainability of supply was noted as a key challenge as it relates to organizational capacity of producer groups to regularly supply adequate quantities of safe fish products, also relating to seasonality and affordability.

Good practices highlighted in the review were related to convenience, sustainability, and promotion. For example, it is important to ensure engagement of various stakeholders in creating and testing fish products for acceptability by children as well as convenience of preparation for school cooks, who prepare meals for hundreds or thousands of students, with limited kitchen facilities. Products such as fish powders, which can be produced from underutilized species or by-products are more cost-effective and improve upon sustainability concerns by reducing food loss. They were also found to be convenient for preparation in one-pot dishes and to have an extended storage life. Lastly, promotion was noted as good practice in schools, to ensure that students, teachers, school canteen workers, parents and the community are aware of the nutritional importance of fish intake. Promotion of fish as part of a healthy diet can also be done by ensuring that the presentation is desirable, to encourage the consumption of fish as part of a healthy diet, beyond schools.

3.7.2 Case study 2: Samaki Salama: promoting healthy child growth and sustainable fisheries in coastal Kenya

The Samaki Salama ("fish security" in Kiswahili) research project in coastal Kenya represents an example of research targeting the sustainability, promotion, and availability elements of the food environment framework (Blackmore et al., 2022). Food production broadly has been implicated in its contributions to climate change and environmental degradation, though small-scale production of aquatic foods has been only minimally studied (McCauley et al., 2015; Clark et al., 2019). Small-scale fisheries can achieve sustainable production through greater outputs per unit effort, with application of passive gear types (e.g., traps, gill nets, long lines) and minimizing damage to local ecosystems (Kolding et al., 2014). Further, small-scale fisheries generally maintain a wide range of aquatic species, reducing the risk of single species collapse. In Kenya, however, small-scale fisheries are chronically over-exploited and fish stocks are declining, as evidenced by a four-fold decrease in marine catch since the 1980s (Samoilys et al., 2017). Fishing households are among the poorest and most malnourished in the country, often selling nutrient-dense small fish to purchase less nutrient-dense foods such as maize.

Samaki Salama aimed to improve young child nutrition in tandem with sustainable fisheries practices. Building on formative research that described the challenges and opportunities surrounding young child nutrition and fish consumption, a bundled intervention was developed (Cartmill et al., 2022; Kamau-Mbuthia et al., 2023). In one component, a social behavioral change strategy targeted messages to fishing households to encourage retaining some fish for young child consumption. The multi-pronged, tailored set of activities included home visits with counseling, cooking demonstrations, fisher workshops, community health worker messaging, and an array of communications and promotional materials (e.g., flyers, t-shirts). For the second component, modified fishing traps were distributed in communities using basket trap gear. These modified gated traps allowed juvenile fish to escape, thereby, leading to greater catch diversity and improving the economic value of the fish caught (McClanahan et al., 2008).

To evaluate the impacts of the one-year bundled intervention, a cluster-randomized controlled trial was carried out, in 2021–2022. Small fisher households with children under 5 years of age were eligible for participation. Matched communities across five distinct areas in Kilifi County were divided into three groups: (1) control ($n = 200$); (2) multi-component nutrition social marketing intervention ($n = 100$); and (3) multi-component nutrition social marketing intervention plus modified fishing traps and training ($n = 100$). Primary outcomes include child growth, fish consumption and fish yield of mature fish, and secondary outcomes are diet diversity, child diarrheal morbidity, and revenue from fish. A process evaluation was used to monitor and ensure fidelity of intervention delivery. Preliminary results show improved child dietary diversity and fish consumption, as well as increased fish length and biomass yield. Samaki Salama points to the importance of an integrated holistic approach to addressing the food environment challenges to enable improved nutrition, through the consumption and sustainable production of aquatic foods. In this context, the combined effects of addressing sustainable fisheries, aquatic food promotion, and improved availability led to changes in dietary practices and yields, enhancing marine ecosystem health.

3.7.3 Case study 3: Small fish powder offers affordable, convenient and quality aquatic food options in Cambodia's informal markets

Small fish powder in rural Cambodia offered through informal markets shines a light on aquatic foods for young children in the affordable, convenient, and quality elements of the food environment framework. Fish is a major part of the diet in southeast Asia, including Cambodia, accounting for the second most common food, after rice. However, less than half of young children from 6 months of age, those most at risk of malnutrition, are fed fish. This is due to a variety of reasons, including fear of the child choking on bones and preparation time needed to cook separate infant meals. Yet, in many regions of Cambodia, indigenous small fish are naturally present in the seasonally flooded rice paddy areas. Historically, these indigenous small fish are not perceived to be food for people, and left for pigs to eat, however, they are a naturally sustainable food source (Islam et al., 2023). Consumption of whole, small fish, including the head, organs and bones, deliver greater concentrations of vitamins, minerals and omega-3 fatty acids compared to the fillet of large fish (Roos et al., 2003).

WorldFish partnered with women entrepreneurs to find ways to prepare small fish for human consumption. Dry-roasting whole small fish, without using oil or water and crushing the product into a fish powder, resulted in a desirable, quality product. The United States Agency for International Development (USAID)-funded NOURISH project conducted multiple sensory tests with consumers. Families and young children liked the smell, taste, and texture of the dry-roasted powder, preferring this fish product, without addition of seasoning or spices. The Pasteur Institute conducted a series of safety tests on multiple samples of powder, over multiple points in time (after 1, 3, and 6 months), with each test passing international microbiology safety standards. A market assessment gauged consumer interest, whereby they would want to purchase, and at what price, for jars of 50 and 100 g fish powder. Caregivers of young children expressed particular interest in the convenience of the powder, which they could easily add to meals and save time in meal preparation—and at the same time, their children find tasty.

A network of 21 women entrepreneurs in rural communities learned to produce and market the small fish powder in a business accelerator, monitored by trained agriculture extensionists of the Ministry of Agriculture, Forestry and Fisheries, Cambodia. Consumers helped to co-create a strong product brand and promotional message, based on their values, "Small Fish Powder: Power of Growth" with colors green and gold, meaningful to rural farming communities, and a picture of a happy family. Each jar has a label with nutritional content for easy identification. The brand concept is amplified through a TV spot, point-of-sale print materials (leaflets, stickers, key chains), and conversational marketing talking points by the women entrepreneurs in their local, informal markets. Some women also sell through social media.

Surveys showed increased consumption of fish by young children. The proportion of children between 6 to 23 months of age who were fed fish in the past 24 h increased from 46%, at baseline in 2014, to 72%, at endline, in 2019. The increase in fish consumption was greatest among children 9 to 11 months old, a critical time for reducing malnutrition (Save the Children, 2019). Critical for these consumers who are highly concerned about safety of processed foods, they said that they trust the quality because the product is locally sourced and made by trusted market vendors. Many also say they use the powder to make timesaving, tasty family meals (often a soup). The findings show how a sustainable aquatic food product that meets consumers' need for quality and convenience can be effectively promoted through informal markets.

3.8 Limitations

There are some potential limitations to the methods used in this review. Review papers are commonly used to describe and summarize an emerging topic and do not follow a method of systematic review. There is the possibility of bias of the authors, including the influence of the authors' personal viewpoints when selecting literature. There may be omissions of relevant literature that could lead to incomplete descriptions of the topic. To mitigate these issues, our review was prepared by six co-authors. We collectively discussed interpretations and made suggestions on additional literature to be consulted for the review. Our methodologic approach was to use a comprehensive conceptual framework and narrate the state of knowledge over the past decade for each food environment element. Future studies with the aim of conducting a systematic review, could consider narrowing the scope to only one or two elements of the food environment framework or could consider conducting the review on selected aquatic species of interest such as seaweeds or pelagic small fish. We also used a convenience selection method for case studies to illustrate how aspects of the food environment were considered in recent projects focused on aquatic foods. Case studies are illustrative examples and are not program or project evaluations, therefore cannot be used as evidence of impact. The case studies identified all had some focus on interventions in food environments to improve child nutrition, including interventions in school food environments or development of aquatic food products targeting young consumers and their families. While these case studies were selected based on convenience, they may reflect the broader body of literature, as past studies which focused on food environment interventions to promote aquatic foods for public health and nutrition similarly focused on food environments that shape young children and their households access to, and choices made about food consumption (Bogard et al., 2021; de Bruyn et al., 2021; Simmance et al., 2022b). Future food environment interventions for improving aquatic food consumption may benefit from a broader perspective to target the general population. Future research could systematically review and summarize the impact of projects on different dimensions of the food environment. This would provide a stronger indication of the impact of food environment interventions on outcomes of interest such as dietary intake and nutritional status.

4 Conclusion

The food environment is the most proximal space to the consumer within food systems, and understanding aspects of the food environment that influence consumer behavior is critical to guide policies and programs to promote healthier diets. Aquatic foods provide consumers with a diverse range of nutritious food choices that can contribute to alleviating all forms of malnutrition while also reorienting our food systems toward greater sustainability and equity. This paper reviewed six food environment characteristics that are each important to consider for reorienting food systems to deliver on the goal of safe, nutritious food, for all, produced within planetary boundaries.

The availability of aquatic foods has been increasing globally, particularly in Asia, in large part, due to increases in aquaculture. However, concern has been expressed over lower availability of aquatic foods in sub-Saharan Africa, where increased availability could help boost food and nutrition security. There is also an opportunity to better utilize aquatic foods for food and nutrition security through attention to the benefits of aquatic foods for food rather than feed and by utilizing more of what has been traditionally consider by-products. Our understanding of the affordability of aquatic foods is hampered by the lack of granularity when collecting information on price. Mechanisms to collect price by species rather than by food group (e.g., Fish and Seafood) are needed in order to illuminate important differences in price across species and orient consumers toward this information. In addition, greater attention to aquatic foods obtained from wild and cultivated food environments that do not enter formal retail is to account for the real contribution of aquatic foods to food and nutrition security and the cost of a healthy diet. The promotion of aquatic foods takes various forms, ranging from providing information on nutrition or sustainability properties to innovating diverse products that make aquatic foods attractive to consumers. Many consumers are motivated in part to purchase sustainably produced aquatic foods. This aspect of promotion can be enhanced and intentionally focused on consumption of lower-trophic or underutilized species as a strategy to pull the sector toward the sustainability aspect that consumers desire. Convenience of aquatic foods, especially in relation to time scarcity of consumers in LMIC is understudied. Additional research on time scarcity and the role that more convenient and healthy aquatic foods could play when incentivizing consumers toward aquatic foods needs more attention.

Food safety was a key theme in our review of quality. Technologies such as immediate and continued cooling and increasing market-level infrastructure (e.g., shading and covering products) should be considered at all stages of the supply chain and especially in open and wet market settings. In our review we found convenience to be most often measured in terms of time to obtain, process and prepare food. Place-based strategies that engage vendors and consumers can be used to co-create convenience and time savings strategies.

In this review, we highlight the importance of recognizing opportunities for interactions and synergies between food environment element. For example, the sustainability of the offering is used as a means of promotion. The quality of aquatic foods within the retail food environment is dominated by consumer preferences for freshness and safety. Processing techniques, such as using small fish and fish frames to produce fish powder are promising avenues to increase both quality and convenience. Evidence of consumer and vendor responses to sustainability of aquatic foods seems limited to small-scale studies, with labeling and certification schemes in specific contexts having some impact on consumer decision making but understudied in LMIC contexts.

Our review demonstrates the importance of using a holistic approach toward food environments. By reviewing all six elements together, we are able to consider synergies within the food environment space. Using case studies, this paper also highlights how a deeper understanding of the intersections within the food environment can be integrated at the beginning of project design. For example, the Samaki Salama project in Kenya highlights the intersection of sustainable harvest and promotion, while the case studies from Cambodia and Ghana highlight the importance of considering diverse food environment characteristics such as convenience, quality, and sustainability, when designing programs that ultimately seek to influence consumer behavior. Future research, interventions, and policies that aim to encourage the consumption of diverse aquatic foods should include food environment considerations, to continue to build the body of knowledge and understanding on how the food environment shapes and influences consumer choice.

Author's note

The views expressed in this publication are those of the author(s) and do not necessarily reflect the views or policies of the Food and Agriculture Organization of the United Nations.

Author contributions

ST and GK conceived the idea for the manuscript. GK, MA, LI, SV, and LS conducted the review and wrote the manuscript. All authors reviewed, edited and approved the final version.

Conflict of interest

LS was employed by the company The Manoff Group, Inc.

The remaining 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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