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The vital roles of blue foods in the global food system

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ABSTRACT

Blue foods play a central role in food and nutrition security for billions of people and are a cornerstone of the livelihoods, economies, and cultures of many coastal and riparian communities. Blue foods are extraordinarily diverse, are often rich in essential micronutrients and fatty acids, and can often be produced in ways that are more environmentally sustainable than terrestrial animal-source foods. Capture fisheries constitute the largest wild-food resource for human extraction that would be challenging to replace. Yet, despite their unique value, blue foods have often been left out of food system analyses, policies, and investments. Here, we focus on three imperatives for realizing the potential of blue foods: (1) Bring blue foods into the heart of food system decision-making; (2) Protect and develop the potential of blue foods to help end malnutrition; and (3) Support the central

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role of small-scale actors in fisheries and aquaculture. Recognition of the importance of blue foods for food and nutrition security constitutes a critical justification to preserve the integrity and diversity of aquatic species and ecosystems.

1. Introduction

Debates and decisions about food systems are predominantly focused on agriculture and livestock. In contrast, blue (also known as aquatic) foods – fish, invertebrates, algae and aquatic plants captured or cultured in freshwater and marine ecosystems – are often neglected (Bennett et al., 2021). Yet blue foods play a central role in food and nutrition security for billions of people and may become even more important as the world seeks to create just food systems that support the health of people and the planet (HLPE, 2014; Bennett et al., 2018; FAO, 2020; Hicks et al.; Golden et al., 2021).

To ensure blue foods continue to make a significant contribution to global food systems, governments need to incorporate them in their food-related decision-making. In 2020, the UN Committee of World Food Security High Level Panel of Experts called for a transformation of the food system, moving "from a singular focus on increasing the global food supply through specialized production and export to making fundamental changes that diversify food systems, empower vulnerable and marginalized groups, and promote sustainability across all aspects of food supply chains, from production to consumption" (HLPE, 2020). As we argue in this paper, evidence is growing that when properly understood and managed, many blue foods are profoundly suited to these food system transformations.

To make a case for integrating blue foods into global food system

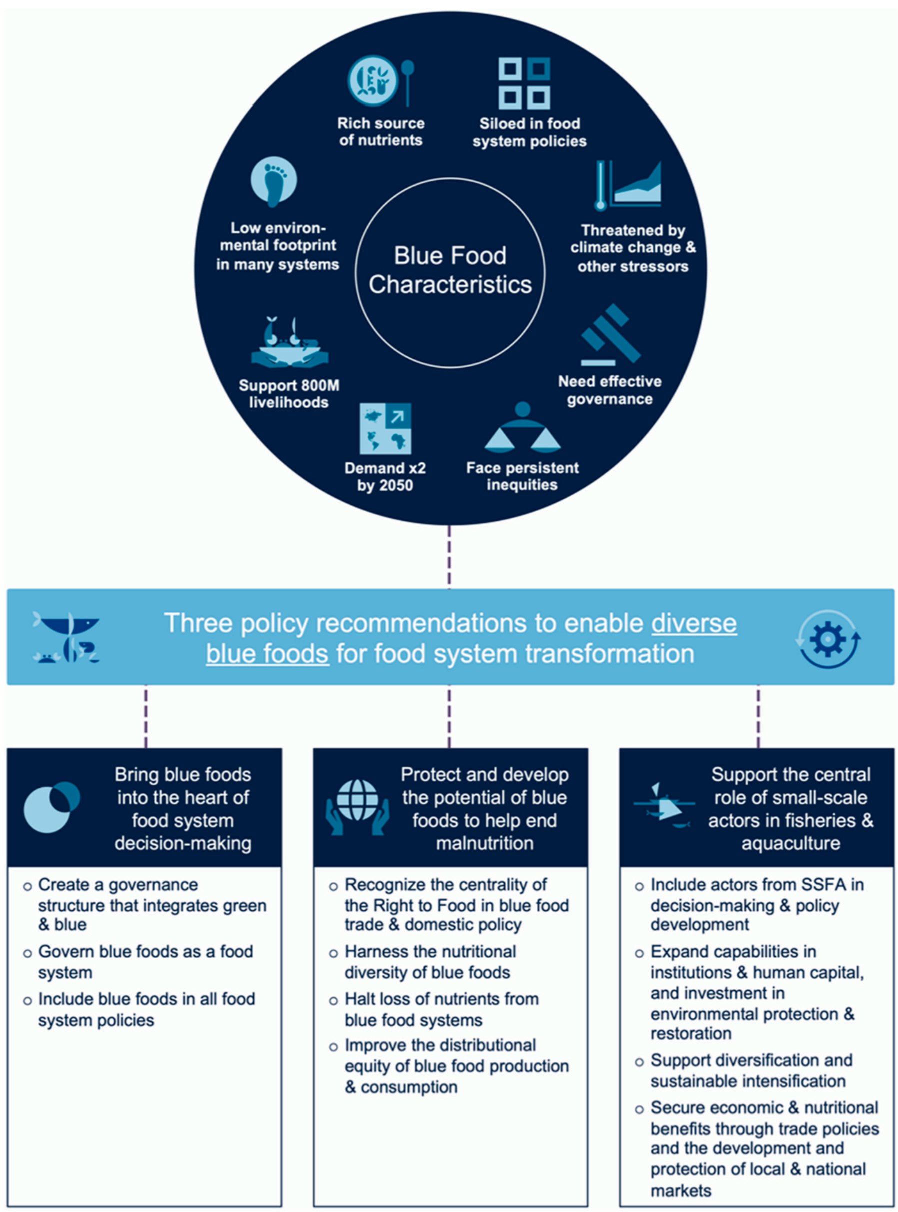

Fig. 1. Overview of blue food benefits and challenges and the three areas of policy action identified in this paper that would help realize the potential of blue foods to contribute to sustainable, healthy, and just food system outcomes. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

decision-making, we draw on the findings of the Blue Food Assessment (BFA; http://bluefood.earth) and related work. The BFA was the first global assessment of the benefits of and challenges facing blue food systems based on the work of over 100 scientists from more than 25 institutions. Its first five (out of nine) papers and a summary report were published in September of 2021. In February 2021, the BFA authors were invited to submit a policy brief to the Scientific Group supporting preparations for the 2021 U.N. Food Systems Summit (UNFSS). Here we present three policy action domains to assist national-level government decision-makers to realize the potential of blue foods in improving food system outcomes (see Fig. 1). These policy recommendations should not be seen as all-encompassing. Instead, they are an entry point into making blue foods part of food system transformations.

2. Blue food benefits and challenges

The blue food portfolio is highly diverse. More than 2500 species of marine and freshwater animals, plants, and algae are found in human diets (Golden et al., 2021; Thilsted et al., 2016). Blue food systems are supported by a wide range of ecosystems, cultural practices and production modalities – from large-scale trawlers on the high-seas to small-scale fishponds integrated within agricultural systems – supporting access to nutritious food for communities through global and local markets alike (Short et al., 2021). This diversity supports resilience that can help local food systems withstand shocks (Troell et al., 2014; Béné, 2020; Love et al., 2021; Hertel et al., 2021), as exemplified during economic transitions in fishing communities (Cline et al., 2017) as well as in COVID-19 pandemic responses (Stoll et al., 2021; Ferguson et al., 2022). Blue food diversity offers many possibilities for governments and communities seeking to build food systems that are healthy, sustainable, just, and locally adapted.

Blue foods are a cornerstone of good nutrition and health. Many of them are rich in bioavailable micronutrients that help prevent maternal and infant mortality, stunting, and cognitive deficits. Blue foods can also be a healthier animal-source protein than terrestrial livestock: they are rich in healthy fats and can help reduce obesity and non-communicable diseases (Golden et al., 2021; Thilsted et al., 2016). In many parts of the world, blue foods are more accessible and affordable than other animal-source foods and offer benefits beyond health alone (Ryckman et al., 2021a, 2021b). For example, aquatic plants, including seaweeds, commonly found in the diets throughout the Asia-Pacific region hold the potential to provide both a nutritious and low-carbon source of food.

Blue foods often have smaller environmental footprints than many other animal-source foods (Gephart et al., 2021a). However, across a diverse sector, the details matter: greenhouse gas emissions and wildlife and biodiversity impacts can be quite high for some blue food systems, such as bottom trawling or aquaculture systems that are poorly sited or poorly managed (Gephart et al., 2021a; Naylor et al., 2021a). For example, many fisheries, especially those targeting small pelagics, and aquaculture systems, like bivalves, carp, and tilapia, offer climate footprints comparable to or smaller than that of chicken, the most efficient terrestrial animal-sourced food, with the potential to be improved further (Gephart et al., 2021a). Unfed aquaculture (such as seaweeds and filter-feeding shellfish) also has the potential to improve water quality and create habitat for biodiversity (Naylor et al., 2021a).

Blue foods are important to livelihoods in many vulnerable communities. The FAO estimates that the livelihoods of about 800 million people – directly and indirectly – depend on blue food systems (FAO, 2012), mostly in small-scale fisheries and aquaculture. These systems produce a wide variety of blue foods, supporting healthy diets and resilience in the face of climate change and market fluctuations. Blue foods can also be an essential part of cultural heritage and socio-economic practices (Johannes, 1981; Ban et al., 2019). Coastal and riparian Indigenous Peoples, from the Arctic to the Amazon, have traditionally had the highest per capita aquatic food consumption rates in the world (Bayley, 1981; Cisneros-Montemayor et al., 2016).

To capitalize on the potential of blue foods, decision-makers must address significant challenges. Wild capture fisheries, both marine and freshwater, need to be better valued (Sumaila, 2021), managed (Hilborn et al., 2020; Melnychuk et al., 2021) and rebuilt (Sumaila et al., 2012; World Bank, 2017) as many fish stocks have become severely depleted and some technologies have high environmental footprints. Although the aquaculture sector works towards more sustainable practices, increasing feed demand is putting pressure on the environment and resource systems through overfishing, deforestation for feed crops and intensification of agricultural production (Gephart et al., 2021a; Naylor et al., 2021a; Cottrell et al., 2018). Intensification of some types of aquaculture can concentrate nutrient pollution and exacerbate risks associated with pathogens and high dependence on antibiotics (Naylor et al., 2021a; Henriksson et al., 2018).

Environmental stressors limit blue food production and climate change will increasingly affect the health and productivity of fish stocks and aquatic ecosystems (FAO, 2018) with implications for food security, livelihoods and economies worldwide and especially in wild-capture fisheries in Africa, East and South Asia, and Small Island Developing States (Tigchelaar et al., 2021; Golden et al., 2016). Aquaculture growth will also be directly and indirectly affected by climate change (Ahmed et al., 2019). Other kinds of pollution, from agricultural nutrient runoff to plastics, further threaten productivity and the safety of foods harvested from polluted waters (Bank et al., 2020; Garrido Gamarro et al., 2020).

Like all food systems, blue food systems are beset by inequities. Wealth-generating activities are often favored over those critical to nutrition and health, livelihoods, and culture (Hicks et al.; Österblom et al., 2020; Cohen et al., 2019; Brugere et al., 2021; Zhang et al., 2022). The aquatic resource management systems, knowledge, and rights of Indigenous Peoples and traditional small-scale fisherfolk have often been undermined or overlooked in fisheries, water management and ocean governance (Ratner et al., 2014). Although men and women participate in blue food value chains in roughly equal numbers (FAO, 2020), their roles, influence over value chains, and benefits can be highly unequal (Wabnitz et al., 2021). Progress toward gender equality is critical for development of more equitable and efficient blue food systems (Hicks et al.; Lawless et al., 2021).

Blue foods are globally the most traded food products – for developing countries, net revenues from trade of blue foods exceed those of all agricultural commodities combined (Gephart and Pace, 2015; Sumaila et al., 2016; FAO, 2018). However, global supply chains are complex and often opaque, making it difficult or impossible for buyers to ascertain environmental impacts and human rights abuses in production (LeBaron, 2021). In some places harvesting and trade of fish for high monetary-value global markets have undermined production that is important for local food security and livelihoods (Hicks et al., 2019).

3. Policy recommendations

There is every reason to expect that total demand for blue foods will grow substantially in the years ahead – nearly doubling by 2050 as population and incomes increase, and as attention toward healthy and sustainable food expands (Naylor et al., 2021b) – with growth in supply primarily expected to come from aquaculture (Ratner et al., 2014). If produced responsibly, blue foods have essential roles in ending malnutrition and in building healthy, nature-positive and resilient food systems, including for people living on lands marginal for agricultural production (particularly forests, wetlands and small islands), many of whom are Indigenous (Azam-Ali et al., 2021). Realizing that potential, however, will require that governments are thoughtful about how to develop those roles. Here, we focus on three central imperatives for policymakers:

1. Integrate blue foods into decision-making about food system policies, programs, and investments, to enable effective management of

production, consumption and trade, and the interconnections with terrestrial food production;
2. Understand, protect and develop the potential of blue foods for ending malnutrition, fostering production of accessible, affordable nutritious foods; and
3. Support the central role of small-scale actors, with governance and finance that are responsive to their diverse needs, circumstances and opportunities.

3.1. Bring blue foods into the heart of food system decision-making

Blue foods are deeply interconnected with the rest of the food system – in diets, in supply chains, and in the environment (Cottrell et al., 2018). Aquatic and terrestrial foods appear on the same plate and are often substitutes for each other in household food choices. Capture fisheries provide feed inputs for aquaculture and livestock; terrestrial crops provide feed inputs for aquaculture. Excess nutrients from agriculture and aquaculture can pollute rivers and cause coastal dead zones, undermining fisheries; cultivation of filter-feeding fish and seaweeds imply removal of nutrients and, if properly managed and scaled, can help protect ecosystem health. Genetic advances in crops and livestock have had positive spillover effects on aquaculture through selection and breeding and through improvements in nutritional performance and feed efficiency (Naylor et al., 2021a).

Yet blue foods are generally ignored in food system discussions and decision-making (Bennett et al., 2021). Compared to terrestrial agriculture systems, blue foods receive limited attention in development assistance outside of Asia – with the consequence that the potential role of fish, shellfish and aquatic plants in human nutrition and health in many developing regions remains underfunded. Blue foods also tend to be left out of food system policymaking at the national level (Koehn et al., 2021). Ministries or agencies dedicated to capture fisheries and aquaculture tend to manage them as a natural resource, with a focus on economic interests – production and trade (Bennett et al., 2021). In many countries, the result is that both fisheries and aquaculture are managed with an emphasis on high monetary value, export-oriented production. That orientation is reinforced by the market and naturally favors investments in innovations and enterprises that offer the highest financial return. Critical welfare functions are often neglected; indeed, fisheries agencies often lack the mandate to address the potential contributions of blue foods to food security and public health, to livelihoods and communities, and to cultural traditions and diets (Hicks et al.; Österblom et al., 2020; Cohen et al., 2019).

When fisheries and aquaculture are siloed and managed primarily to maximize revenue or rent within sustainable limits, policymakers overlook opportunities for advancing nutrition, sustainability, resilience, and livelihood goals. They also, often unwittingly, create new trade-offs among these goals. For instance, fisheries that have sustained communities for generations are in many developing countries exposed to overexploitation by distant water fleets or out-competed in the market by large volumes of inexpensive farmed fish. Farming of species that could reduce nutrient deficiencies often remains undeveloped because management and investment are directed to high-revenue products, often for export markets. Evidence also shows that small-scale fishers and fish farmers who are central to local diets, livelihoods and community resilience often lose access to key land and water resources to large commercial concessions (Cohen et al., 2019). Bringing blue foods into food system decision-making thus requires integrated governance, systematic inclusion in policy, and a fundamental change in the way we think about blue foods. Specifically, governments could:

3.1.1. Create a governance structure that integrates green and blue

Governments could create organizational structures – such as a food policy council, a national food strategy or even a ministry of food – that can govern, or align governance, across the entire food system, managing synergies and trade-offs in production, consumption and trade (Candel and Pereira, 2017; FAO, 2014; Meijers and Stead, 2004) (see Box 1). Ministries of agriculture and of fisheries typically focus on production – generally on increasing volume – and revenue, and often are captured by entrenched interests. Integrated food policy-making across inter-connected terrestrial and aquatic food systems could manage the disparate interests of producers, consumers, and other stakeholders for improved nutritional, environmental, economic, and social outcomes. It could, for example, manage production and consumption to encourage markets for more nutritious species (see Section 3.2). It could also expand the capabilities of small-scale producers, through investment and allocation of resource rights to support livelihoods and community resilience (see Section 3.3). More broadly, it enables policy to make blue food governance actions within the frame of food system outcomes, and to ensure blue foods are fully included in all food system policies. It is worth noting that experiences with implementing coordinative food structures and procedures in several countries have shown that doing so is important but not necessarily sufficient for achieving improved food system outcomes (Candel and Pereira, 2017; Farmery et al., 2020): development of a resonating policy frame (see next recommendation) and sustained political leadership are key (Candel and Pereira, 2017; Meijers and Stead, 2004).

3.1.2. Govern blue foods as a food system

At the most basic level, integrating blue foods into food system decision-making recognizes that fisheries and aquaculture should themselves be managed as food systems – they should be managed to deliver society's goals for nutrition, health and equity, as well as for economics and sustainability. Government policy and management should embrace all aspects of the blue food sector – including fisheries and aquaculture production, distribution, exports and imports, and consumption.

Promoting a systems approach – as emphasized in the food and nutrition strategy of the Pacific Community amongst others (Davila, 2020) – means that governments can ensure nutrient-rich aquatic foods are available and affordable to those for whom they are most important, both nutritionally and culturally. A food systems approach will allow policy-makers to work across the value chain to identify and address the many threats to blue food supplies, from overfishing to pollution to waste and loss in harvesting, processing and distribution (see Section 3.2). It can build a system that is just, ensuring equitable participation in production, accessibility for consumption, and broad representation in decision-making. By managing blue foods as a system, governments can create policies and incentives across the value chain to shift both production and consumption to species and technologies that have lighter footprints and to foster diversity in production systems (Sections 3.2 & 3.3).

Looking at the whole system also enables governments to make public investments where markets fail. Private investment often goes to blue food systems and enterprises that offer high short-term financial returns. Governments can allocate public funds to help develop innovations and investments in fisheries and aquaculture enterprises that may offer lower returns or higher short-term risk, but have long-term nutrition, livelihoods, and sustainability benefits, with a stronger focus on creating the right business environment for small and medium-sized enterprises that can take those innovations to the scale needed (Box 3).

To realize this vision, governments would need to collect data that enable good decisions – including data that permit monitoring of fisheries and supply chains, that capture the vital diversity of species that are produced and consumed, that survey the demographic diversity of participants in the sector, and that reflect the frequently profound heterogeneity in consumption across different regions of the country and between different socio-cultural groups (Bennett et al., 2021; Needham and Funge-Smith, 2014). They would also need to redesign policies to enable and incentivize the capabilities of key actors – from producers to consumers – to adopt transformative practices in the food system as a

Box 1
Blue Food Integration in the African Great Lakes

The small pelagic fisheries of the African Great Lakes region illustrate the opportunities of bringing blue foods into food system policymaking. These fisheries produce large volumes of affordable, micronutrient-rich food traded throughout the region, but they have traditionally been given low priority for investment and management because they are seen as having low economic value. However, scientific and policy dialogues on food and fisheries are starting to include these species. For example, the Malawi Department of Fisheries recently developed a Management Plan for usipa (Usipa, 2018) (*Engraulicypris sardella*), a small pelagic species harvested in large volumes from Lake Malawi. The plan recognizes its importance to Malawi's food and nutrition security as its first guiding principle, and includes objectives not only to sustainably manage the resource but also to research post-harvest dynamics to reduce loss and improve handling and storage. The inclusion of fisheries in Malawi's National Agriculture Investment Plan (Malawi Government. Nation, 2018) provides the political framework for developing fisheries policy in step with broader food systems policy, across issues of climate change, gender, food safety, and strategic investment. Future research could assess how specific fisheries and aquaculture production systems (such as usipa fisheries) contribute to food and nutrition security for vulnerable populations, so that specific investments and policies can effectively protect and enhance those contributions.

Box 2
Blue Foods in School Meal Programs

School meal programs offer a powerful means of improving nutritional outcomes, cognitive development, and educational performance of school-going children and adolescents, particularly when they incorporate nutrient-dense animal-sourced foods (Ahern et al., 2021). Additionally, they offer opportunities to create co-benefits by generating local livelihoods, promoting gender equity, and enhancing sustainable production practices when they include culturally appropriate, locally produced and processed ingredients. Several examples from around the world – including Odisha State in India (USAID Advancing Nutrition, 2021), multiple countries in sub-Saharan Africa (Ahern et al., 2021), and California in the United States (Koehn et al., 2020) – have shown that fish and fish by-products (processed into fish powder) can be an affordable and acceptable way to increase the nutritiousness of school meals. In Odisha, India, introduction of fish products in school meals has been paired with development of local aquaculture and fish drying facilities, creating economic opportunities for the women's cooperatives that run them (USAID Advancing Nutrition, 2021). In Cabo Verde, quotas for the supply of local products from small-scale fishers and support for fishing and fish farming organizations have strengthened the capacity of local supply chains to sustainably supply safe fish products for school meal programs (Ahern et al., 2021). The emergence of a global School Meals Coalition (https://schoolmealscoalition.org/) following the UN Food Systems Summit – with commitments from over 50 countries – offers an opportunity to further promote inclusion of blue foods in school meals in context-specific and culturally appropriate ways.

Box 3
Dynamic Blue Food Actors in Bangladesh

The proliferation of diverse, freshwater aquaculture supply chains in Bangladesh in recent decades illustrates the potential for blue foods to meet domestic demand, improve food and nutrition security, and reduce rural poverty (Golden et al., 2016). This "hidden aquaculture revolution" has involved hundreds of thousands of small-to medium-scale actors along the supply chain, acting independently and in response to urbanization, growing incomes, and rising fish demand. Approximately 94% of the fish produced in freshwater aquaculture in Bangladesh is directed towards domestic markets and is not traded internationally. Although mostly small-scale, freshwater aquaculture systems have become increasingly intensive and commercial in their operations (Ahmed et al., 2019). Aquaculture growth and its contribution to food and nutrition security in Bangladesh have resulted from public investment in infrastructure, a positive business environment for small- and medium-size entrepreneurs, and 'light touch' government control over the type of systems and species produced (Golden et al., 2016).

whole, in value chains, and in the places where they live (Bush et al.) (see Section 3.3).

3.1.3. Include blue foods in all food system policies

To be effective, structural reforms need to be followed by policy inclusion – governments could integrate blue foods into the policies that regulate, guide and support the food sector. For example, government strategies to meet the Right to Food (Fakhri, 2020) – a component of the International Covenant on Social, Economic and Cultural Rights – can embrace the potential of blue foods to offer accessible, affordable sources of key nutrients and better ensure that interventions, including from energy and agriculture, do not further erode access to blue foods (see Section 3.2). Dietary guidelines could include the nutritional contributions of different blue foods, to help consumers understand their value for addressing nutrient deficiencies and obesity, diabetes and coronary disease. Safety net programs for children and pregnant and lactating women could also include blue foods, as fish can be a rich source of essential micronutrients for vulnerable populations, helping to prevent stunting and cognitive deficits (Golden et al., 2021). In sub-Saharan Africa, numerous pilot programs are underway to bring nutrient-rich fish and fish powder to school meals (Ahern et al., 2021) (Box 2). Improved access to blue foods can also be catalyzed via integration with food assistance programs, as exemplified by two long-standing programs on the U.S. West Coast that connect low-income consumers to regional fisheries and aquaculture producers (Koehn et al., 2020). Policy inclusion should pay particular attention to and support food systems and food sovereignty of Indigenous Peoples (Levkoe et al., 2017).

Including blue foods in policymaking for the food system allows governments to better manage the interconnections between terrestrial and aquatic food systems (Cottrell et al., 2018). That includes the regulation of agricultural and inland aquaculture runoff and other land-based pollution that can undermine inland and coastal fisheries and marine aquaculture, such as nutrients that cause coastal dead zones and toxins that can compromise food safety. Governments can also better manage the allocation of crops and fish to competing uses – for food or feed – and support the development of a circular economy in which wastes or by-products from one part of the food system are used as feed inputs to another (Campanati et al., 2022).

3.2. Protect and develop the potential of blue foods to help end malnutrition

Many blue foods contain high concentrations of bioavailable minerals and vitamins, essential fatty acids (in particular EPA and DHA), and animal protein (Thilsted et al., 2016) – globally, humans derive roughly 8% of zinc and iron, 13% of protein, and 27% of vitamin B12 from blue foods (Golden et al., 2021). Blue foods can therefore make key contributions to diet-related health challenges. They can reduce micronutrient deficiencies that lead to disease; improve heart, brain and eye health by uniquely providing omega-3 fatty acids; and replace over-consumption of less healthy red and processed meats (Golden et al., 2021). The micronutrient contributions of blue foods are especially important for childhood development, pregnant women and women of childbearing age (Kawarazuka and Béné, 2011; Bogard et al., 2015; Starling et al., 2015) and can reduce nutritional inequities for girls and women (Golden et al., 2021).

Not all fish are nutritionally equal. For example, a single serving of small indigenous species in Bangladesh, eaten whole, contributes more than five times as much vitamin B12 as a single serving of tilapia fillet (Golden et al., 2021; Brugere et al., 2021). Which blue foods are on a plate, in what form matters as well as how much (Golden et al., 2021; Hicks et al., 2019). Yet, blue food policy often considers blue foods only as a protein source, which neglects the nutrient diversity of fish (in terms of micronutrients and fatty acids) and excludes the contributions of aquatic plants altogether. In the Bangladesh case discussed below (Box 3), for example, growth in (farmed) fish consumption has led to an increase in total protein consumption but an apparent decrease in consumption of certain micronutrients, highlighting the challenge of balancing high nutrient content provided by small native fish with employment and revenue generation offered by tilapia and pangasius production (Bogard et al., 2017). Adopting a nutrition-sensitive approach to aquaculture and fisheries, rather than just a production focus, can address these issues (Bennett et al., 2021; Thilsted et al., 2016; Gephart et al., 2021b; Robinson et al., 2022).

In many countries, ministries manage blue foods for their wealth-generating benefits, focusing policy on high economic-value blue food production, often for export. Such a focus risks undermining the critical welfare functions of blue foods by neglecting the nutritional characteristics, livelihood contributions, accessibility, and cultural patterns of blue food consumption (Bennett et al., 2021; Hicks et al.; Thilsted et al., 2016; Brugere et al., 2021; Hicks et al., 2019). Nutrient-dense blue foods are regularly exported from nutritionally vulnerable countries to serve either as a high-quality product for wealthy consumers or to be reduced to fishmeal to feed farmed fish for high-income countries (Isaacs, 2016). Orientation towards export markets affects not only coastal and riparian populations, but also inland communities who have historically depended on richly nutritious dried or smoked fish transported from the coast (Gordon et al., 2013).

The quantity, quality and safety of blue food supply are threatened by food loss and waste (amounting to 35% of fish harvested globally (FAO, 2020)), management failures (including overfishing and Illegal, Unreported, and Unregulated fishing), environmental degradation, and climate change (FAO, 2018). It is estimated that declines in marine fish catch over the next three decades could subject an additional 845 million people (11% of the world's population) to vitamin A, zinc, or iron deficiencies (Golden et al., 2016). Though all of these pressures occur globally, their effects are highest and most strongly felt in tropical and low-income countries with high dependence on blue foods for nutrition and health, livelihoods and income (Tigchelaar et al., 2021; Golden et al., 2016).

Finally, blue food policy misses opportunities to support nutrition goals when it fails to address unequal distribution of the benefits from blue food systems or the concentration of power (Brugere et al., 2021). Women in particular are underrepresented in policies and decision-making (Hicks et al.; Lawless et al., 2021; Udo and Okoko, 2014). Where gender equality is lacking, blue foods are less affordable (Hicks et al.) and blue food waste and losses are greater (Kaminski et al., 2020). To manage blue food systems for the benefit of nutrition and health, governments could:

3.2.1. Recognize the centrality of the right to food in blue food trade and domestic policy

The Right to Food states that everyone is entitled to adequate, accessible, and safe food, that corresponds to their cultural traditions in a fulfilling and dignified manner (Fakhri, 2020). A Right to Food means that governance of and investment in blue food systems should seek a balance between economic opportunities and local rights to food provisioning (Bennett et al., 2021; Hicks et al.), aiming to sustain and innovate with the full diversity of species, production and harvest methods, product forms and distribution channels in mind (Golden et al., 2021). Recognizing the Right to Food requires taking a food systems approach in which nutrition, sustainability, climate-resilience and equity can be considered together (see Section 3.1) and which ensures all actors are represented, including through engagement with grass-roots and civil society organizations (see Section 3.3)[1,5]. Recognizing the food rights of Indigenous Peoples who harvest aquatic foods is of particular importance, whether such Peoples have Nation status or not. At a national level, blue foods could explicitly be included in food and nutrition policy (see Section 3.1)[1,8,53]. Internationally, it would be beneficial to position blue foods as a vital food source in the context of the UN Sustainable Development Goals, health national adaptation plans (HNAPs), and other international efforts to alleviate malnutrition (Bennett et al., 2021).

3.2.2. Harness the nutritional diversity of blue foods

To ensure that the nutritional potential of blue foods serves to improve the health and diets of nutritionally vulnerable people, governments could recognize and sustainably harness the diversity of local blue food nutritional profiles, preparation methods and dietary practices (Golden et al., 2021).

Managing capture fisheries to optimize for nutritional benefits (Robinson et al., 2022), not just for maximum sustainable yield, would allow governments to uncover opportunities to diversify fish production without increasing pressure on existing stocks (Golden et al., 2021; Bernhardt and O'Connor, 2021). Aquaculture development could foster the sustainable production of native small fish species that can supply context-specific nutrient needs. For example, *mola*, a fish species from the Gangetic floodplains, can easily be produced in homestead ponds and offers 80 times more vitamin A than commonly farmed silver carp (Brugere et al., 2021).

By evaluating exports and licenses to distant water fleets, governments could better ensure they do not compromise nutritional goals. In some cases (e.g., Namibia) retaining just a small portion of current exports could meet local nutrition goals (Hicks et al., 2019), though this requires infrastructure to support equitable distribution and access to blue foods locally (see Section 3.3).

Public health policies and investments focused on reducing malnutrition would be more effective if they included blue foods in programs to address the specific nutritional needs of pregnant and lactating women, young children and the elderly – with appropriate consideration of food safety and pollutants – as was done with the introduction of dried small fish powder in Myanmar to support children's health (WorldFish, 2020) (see Box 2).

3.2.3. Halt loss of nutrients from blue food systems

To ensure that blue foods important for nutrition are available, accessible, and affordable, we urge governments to take steps to reduce losses in the system.

Estimates of post-harvest losses are hindered by poor assessments but are recognized as significant, with macro-level estimates ranging from 29 to 50% (FAO, 2020; Kruijssen et al., 2020). Efforts to reduce such losses can be implemented across value chains, particularly at processing and transportation stages for lower-income countries, and at marketing and consumption stages in higher-income countries (Hodges et al., 2011). Improved processing methods can additionally preserve and concentrate nutrients and increase availability and also improve nutritional quality (Siddhnathet al., 2020). The Usipa fishery of Malawi (Box 1), for example, could significantly decrease post-harvest quantity and quality losses by 54% at the processing stage through increased access to basic education and technology such as solar dryers (Torell et al., 2020; Nagoli et al., 2017), additionally enhancing nutritional contributions to distant consumers by concentrating their micronutrients for transport (Siddhnathet al., 2020).

In many places, better management of capture fisheries through harvest controls or spatial restrictions, for example, can restore fish stocks and increase yields (Hilborn et al., 2020; Melnychuk et al., 2021; Anderson et al., 2018). Better regulation of economic development in rivers (dams), floodplains, riparian, coastal, and ocean ecosystems can help protect blue food production and reduce risks to food safety (Niane et al., 2015; de Oliveira Estevo et al., 2021).

Fisheries and aquaculture policy is more effective if it also anticipates and adapts to the loss of nutrients resulting from climate change (FAO, 2018; Tigchelaar et al., 2021). Governments could consider nature-based solutions like mangrove and seagrass restoration and restorative aquaculture that can help strengthen the resilience of aquatic ecosystems (Gattuso et al., 2018; Hoegh-Guldberg et al., 2019). Coral reef restoration methods, for example, are actively being piloted in island states like Barbados (Brathwaite et al., 2022) and elsewhere. Additional climate adaptation options are context-specific but include shifting to offshore fish stocks (McDonald and Torrens, 2020), devising climate-smart agreements for transboundary resources (Oremus et al., 2020) and investing in climate information systems, including early warning systems for extreme events (Cinner et al., 2018; Turner et al., 2020). For example, a study in Timor-Leste found that Fish Aggregation Devices could provide a cost-effective alternative food supply for rural communities that otherwise rely on coral reefs impacted by anthropogenic change (Tilley et al., 2019). Place-based responses to climate change are particularly important for Indigenous Peoples whose cultures and identities are closely linked to their local environments (Whitney et al., 2020).

3.2.4. Improve the distributional equity of blue food production and consumption

Participation in activities along the value chain is often socially differentiated; for example, men dominate blue food production and women blue food processing (Weeratunge et al., 2010). Governments thus need to collect data on what roles, from fish producers to post-harvest processors, traders, and consumers, different groups in society hold and why (Bennett et al., 2021). When divisions of labor exist because of unequal opportunities to participate across the value chain, they are likely to result in distributional and nutritional inequities (Udo and Okoko, 2014). Investments to address the drivers of unequal opportunities, such as through strengthening women's empowerment, are known to lead to improvements in outcomes for women and their families. For example, in Zambia, strategies to remove underlying structural barriers that prevent equitable outcomes, such as unequal norms and attitudes, increased women's participation in production processes, and their control over resources (Wabnitz et al., 2021; Kaminski et al., 2020; Cole et al., 2020). Governments need to ensure the full diversity of actors (Short et al., 2021), across social groups, including gender, class, and ethnicity, and along the value chain and scale of production, are fairly represented in decision-making processes (Hicks et al.) (see Section 3.3). In addition, governments should recognize subnational differences in nutritional vulnerability and blue food access (O'Meara et al., 2021) in national policy and align subnational policies and instruments with nutritional goals.

3.3. Support the central role of small-scale actors in fisheries and aquaculture

Small-scale fisheries and aquaculture (SSFA) have been marginalized in dialogues about sustainable and equitable food system transformation, despite being central to it in many contexts (Bennett et al., 2021; Cohen et al., 2019). SSFA play a key role in supplying nutrition and supporting local economies in many countries. They produce more than half of the global fish catch and contribute over two-thirds of blue foods destined for direct human consumption (FAO, 2020), with the potential for lower environmental footprints (e.g., lower fuel use than in large-scale operations (Gephart et al., 2021a)). In addition, the value chains that process and sell their products support about 800 million livelihoods, half of which are women (FAO, 2020; FAO, 2012). SSFA produce a high diversity of aquatic foods. This diversity underpins healthy diets, and resilience in the face of shocks, climate and market changes (Ferguson et al., 2022; Hicks et al., 2019; Gephart et al., 2021b; Bennett et al., 2020; Campbell et al., 2021). SSFA also contribute to intra-regional trade, especially in smoked and dried products, which can have more direct impacts on food security and poverty alleviation than the globalized system (Béné et al., 2010).

SSFA worldwide face a growing range of threats and challenges, including resource over-exploitation, habitat degradation, poor political representation, market-driven competition for resources (e.g., patterns of trade and foreign fishing), assumed links between informality and illegality (Song et al., 2020), climate change (Monnier et al., 2020), and shocks such as the current COVID-19 pandemic (Short et al., 2021; Bennett et al., 2020; Farmery et al., 2021). Cumulatively, SSFA are being 'squeezed out' of the spaces they occupy on the land-water margins by other more powerful sectors, such as tourism, residential and industrial land use, oil and gas exploration, industrial fisheries and aquaculture (Cohen et al., 2019). Within SSFA, inequitable access to resources and opportunities and limited gender and social inclusion are key threats. Indigenous Peoples whose lands and waters have been colonized by others, and whose harvesting activities tend to be small-scale, continue to be marginalized by public policy. Finally, pervasive data and monitoring limitations pose major challenges to understanding the status of SSFA (Pauly and Zeller, 2016) as a lack of data leads to underestimating SSFA contributions, marginalizing SSFA in policy and decision making, and aggregated and categorical data fail to represent the diversity of SSFA actors and benefits.

Governments and policies predominantly focus on industrialized, large-scale fisheries and aquaculture that generate production volume, profit, and foreign exchange revenue, leading to a lack of voice and support for SSFA (Cohen et al., 2019). One reason for this persistent neglect is that policy makers struggle with the diversity, dynamism and perceived informality of SSFA and their associated cultures (Hicks et al.). Most policies affecting the sector make unrealistic assumptions that SSFA are a homogenous group limited to producers (Gelcich et al., 2018; Johnson, 2006). In contrast, the sector is extraordinarily diverse along many dimensions (Short et al., 2021). Successful transformations of SSFA require placing this sector at the center of national sustainability, human development and food security strategies, creating initiatives that support the capabilities of the diverse SSFA actors. Supporting the viability of SSFA would require governments to:

3.3.1. Include actors from SSFA in decision-making and policy development

Inclusion of SSFA in decision-making is essential to enable more adaptive governance mechanisms and policies that build on the strengths of the diversity of SSFAs, acknowledge the cultural importance and specific roles of blue foods for diverse actors and steer food systems towards a more equitable distribution of blue food benefits. In South Africa, a national policy specific to small-scale fishers was enacted that recognized the sector's role to livelihoods and food security and proposed mechanisms to promote these contributions including support for infrastructure, subsidies and training (Sowman et al., 2014).

Women are greatly underrepresented in policy and decision making even though they make up half of the workforce in SSFA globally (Harper et al., 2020). Recent efforts to improve gender equity in blue food policy have tended to adopt a narrow focus on women, overlooking men or gender relations (Lawless et al., 2021). Such a narrow focus risks exacerbating inequities by placing the blame, or burden for change, on women (Hicks et al.; Bank et al., 2020; Gattuso et al., 2018). Blue food policy development therefore not only needs to involve more input and leadership from women, but also should take a gender transformative approach to improving intersectional equity in SSFA (Hicks et al.; Lawless et al., 2021; Cole et al., 2020).

Indigenous coastal and riparian People tend to be more blue-food dependent than the wider population in the countries they live in (Bayley, 1981; Cisneros-Montemayor et al., 2016). They also have proven systems for food system governance – including knowledge systems – that, if recognized and supported, could enable the 'decolonization' of their food systems (Coté, 2016). As access to traditional food sources has been lost, adoption of unhealthy diets based on processed foods has led to high rates of diet-related non-communicable diseases (Kuhnlein and Receveur, 2003; Hawley and McGarvey, 2015). Thus, by supporting Indigenous Peoples food (and wider) sovereignty claims, governments could contribute to transformative health benefits in these communities and nations.

To realize the many benefits of small-scale fisheries and aquaculture, governments could support and strengthen multi-stakeholder initiatives that have SSFA at their core (Cohen et al., 2019), including organizations of fish workers, harvesters and producers at global, regional, and national levels such as the World Forum of Fish harvesters and Fish-workers (WFF), the World Forum of Fisher Peoples (WFFP), the African Women Fish Processors and Traders Network (AWFishNET), and the International Collective in support of Fish Workers (ICSF).

3.3.2. Expand capabilities through investment in institutions and human capital, and investment in environmental protection and restoration

Securing the future of SSFA requires adaptive action that supports their capabilities to deliver both market and non-market societal benefits (Bush et al.) (see Box 3). Positive environmental outcomes, for example, require engagement of SSFA actors to co-produce knowledge, forge strategies for sustainability and climate adaptation, and participate in and lead environmental restoration, conservation and adaptation efforts (Cinner et al., 2018).

Governments can realize the potential of SSFA to contribute to sustainable development by creating space for them in plans to expand agricultural, and industrial aquaculture and fisheries sectors (Cohen et al., 2019; Cisneros-Montemayor et al., 2019). Using public and private regulation and financial mechanisms would enable SSFA actors – including Indigenous Peoples – to (re)gain control over the resources, rights, skills and knowledge necessary for environmentally resilient and socially equitable production and trade (including insurance, credit, and market mechanisms to buffer against extreme events) (Short et al., 2021).

Governments have the opportunity to allocate and enforce land, water and labor rights to SSFA through user rights-based systems, creation of preferential access areas, coastal and inland land use zoning, or other measures (Allison et al., 2012). To support the roles of SSFA in creating livelihoods and resilient and equitable food systems, governments could also provide capital, through public and private financial mechanisms that empower rather than undermine SSFA actors (Pomeroy et al., 2020). In the case of Indigenous Peoples, recognition of their collective sovereign rights is the key starting point (Bennett, 2018).

3.3.3. Support diversification and sustainable intensification

For many SSFA producers, it will be crucial to find pathways for sustainable intensification (to increase output and production efficiencies while reducing negative externalities (Belton et al., 2020a)) or expansion of their operations or for diversification into other SSFA products or other sources of livelihood (Finkbeiner, 2015). To that end, government investment in research and development, together with facilitation of access to venture capital, could support innovation in species/production systems that are of high value for nutrition, livelihoods, and justice. Governmental support may also be needed for the development of complementary livelihoods, which are often critical to continued participation by SSFA actors, their control of the resource base and its sustainability (Hanh, 2021).

Costs, trade-offs, and potential environmental and social impacts of sustainable intensification and diversification should be carefully considered, and diversification should be proactively designed and monitored (Belton et al., 2020a; Hanh, 2021). To this end, efforts should be made towards the better integration of different data types and sources and enabling the effective and timely access and use of data by relevant actors. Investment is needed in monitoring systems for catch, effort, production and consumption, and in national surveys of engagement in SSFA which are fully gender-inclusive, and reflect intersections of gender, age and ethnicity (Basurto et al., 2017). Promotion of research and development aimed at technological solutions for data collection, storage and communication/accessibility barriers would effectively support these needs.

3.3.4. Secure economic and nutritional benefits through trade policies and the development and protection of local and national markets

Governments, in particular low-income food insecure nations, need to be able to regulate the activities of large corporate actors and trade to protect the rights (e.g., labor rights, human rights, right to food) of SSFA workers (Allison et al., 2012), to ensure that terms, conditions, and revenues from trade are transparent and fair, do not impact on local food security, and where needed retain high nutritional value products for local consumption (Said and MacMillan, 2020). Regulation should consider the potential trade-offs and linkages between nutritional and economic value of resources (Hicks et al.; Crona et al.). Well-designed regulatory mechanisms will establish transparent processes, monitoring systems, and accountability mechanisms to ensure traceability and visibility of social impacts (Brugere et al., 2021). Market-based approaches that encourage actors to add value to products through processing, marketing or certification need to carefully consider trade-offs in economic, social, environmental, and public health outcomes (see Section 3.1).

Governments could also explore opportunities to support "alternative" systems based on short supply chains for products with strong local identities and local, decentralized production and processing (Levkoe et al., 2017). Diversity, deeply embedded in these food systems, could be supported by policies mandating or incentivizing local retention of SSFA products to ensure food self-sufficiency, for example, the development or control of local markets and school feeding programs (Love et al., 2021; Ahern et al., 2021).

4. Towards blue food futures

Blue foods have vital roles to play in the transformation of the global food system. By bringing blue foods into the heart of their food decision-making, governments could better value, manage, and rebuild the entire terrestrial and aquatic food system by creating organizational structures or cooperation that integrate blue foods fully into food policies, budgets, and programs. By recognizing the Right to Food, states could harness the nutritional diversity of blue foods in ways that ensure the equitable distribution of blue food production and consumption. By empowering and supporting the millions of small-scale actors in fisheries and aquaculture who produce, process, distribute and trade most of the food we eat, states can unlock a vibrant, sustainable, healthy, and equitable blue food economy. Recognizing and acting upon the potential role of blue foods in all dimensions of food policy would be a clear win for the 2021 U.N. Food Systems Summit and achieving the 2030 Agenda for Sustainable Development.

While governments and their agencies play an important role by setting objectives, programs, regulations, laws and funding priorities, government policy alone is insufficient to drive transformative change (Moberg et al., 2021). (Blue) food system transformation will require a simultaneous and synergistic shift of government, market and financial institutions to enable the adoption of just, sustainable, and nutrition-positive practices (Bush et al.). Meanwhile citizens, civil society organizations, and academics play an important role in articulating values and goals, outlining possible futures, spurring and informing actions and holding institutions accountable. The BFA offers a handful of briefs for non-government actors (http://bluefood.earth/policy) but more work is needed to further elaborate new levers for change that can overcome key challenges and trade-offs in (blue) food systems.

Even though the diversity of blue food species and systems offers opportunities for health, sustainability and resilience, not all blue foods will inherently contribute to these outcomes (Farmery et al., 2021; Belton et al., 2020b) and many challenges around social and environmental impacts, as well as resource management, remain to be addressed. As outlined in Section 2, negative environmental externalities of blue food production include overfishing, habitat change, biodiversity loss, nutrient and chemical pollution, disease spread and related antibacterial and antimicrobial resistance, and greenhouse gas emissions (Gephart et al., 2021a; Naylor et al., 2021a; Mariani et al., 2020). Blue food futures must be examined in the context of the limitations imposed by human stressors such as climate change, as substantial contribution of blue food to people will likely be conditioned on effective climate mitigation (Tigchelaar et al., 2021). While it's beyond the scope of this paper to provide a comprehensive set of policy recommendations addressing all blue food challenges, these issues need to be addressed if expansion of the sector is to contribute to multiple sustainable development outcomes.

In wild-capture fisheries, improved management to sustain and rebuild stocks can have important co-benefits with carbon emissions and fishery livelihoods, but can be costly (Gephart et al., 2021a; Costello et al., 2020). In aquaculture, effective spatial planning and site regulation will be essential for the environmental success of the sector, as is addressing sustainable feed use and composition (Gephart et al., 2021a; Naylor et al., 2021a). While there has been considerable progress in feed conversion ratios and efficiency of marine resource use in the past few decades, growing demand for fed fish will continue to put pressure on aquatic and terrestrial ecosystems. Innovations to improve feed conversion ratios, feed ingredient use, use of by-products and novel aquafeeds are actively being developed (Gephart et al., 2021a; Naylor et al., 2021a; Cottrell et al., 2020), but often beyond the reach of smallholder producers of low-value species. This highlights a need for innovation in public and private financing, governance, and capacity building in addition to technological innovation (Section 3.3).

Finally, when making decisions about blue food futures it is critical to evaluate potential trade-offs across food system goals (Cohen et al., 2019; Farmery et al., 2021; Crona et al.). For example, use of novel aquaculture feed ingredients to reduce environmental impacts can reduce the nutrient density of farmed fin fish (Sprague et al., 2016). Climate adaptation strategies addressing the technical challenges of climate impacts can create or exacerbate socioeconomic disparities, as exemplified by the expansion of shrimp aquaculture in Bangladesh (Paprocki and Huq, 2018). An increased emphasis on blue foods for domestic food and nutrition security could reduce government revenues from blue food exports and allocation of fishing rights. In short, policies and actions to promote blue foods will require a food systems approach that examines nutrition, health, equity, justice, economic and environmental outcomes and trade-offs across land and sea.

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