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FOOD, HEALTH, AND THE ENVIRONMENT (D LOVE AND K NACHMAN, SECTION EDITORS)

Fisheries and Policy Implications for Human Nutrition

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Abstract

Purpose of Review This review brings together recent key research related to the role of fisheries as a source of nutrients to improve human health and discusses the implications of fisheries policy on food- and nutrient-security.

Recent Findings Recent studies highlight the critical role of fisheries to support human nutrition, describing the nutrient composition of hundreds of species of fish, the global distribution of these fish, and the strategic role of fisheries in addressing micronutrient deficiencies.

Summary In many developing regions and emerging economies, fisheries can address malnutrition with local supplies of critical nutrients such as fatty acids, zinc, iron, calcium, and vitamins, making these accessible to low-income populations. However, this local potential is jeopardized by overfishing, climate change, and international trade, which reduce the local availability of nutritious and affordable fish in low-income countries, where they are most needed. This calls for policy reforms that shift management focus of fisheries as a commodity provider to a domestic public health asset to ensure food- and nutrient-security.

Keywords Food-security · Nutrient-security · Micronutrients · Fish consumption · Small-scale fisheries, large-scale fisheries · Industrial fisheries

Introduction

Fish[1] constitutes a major component of the diet of more than 3 billion people around the world, with per capita consumption increasing from around 9 kg/year in the 1960s to approximately 20 kg/year in 2017 [1•]. Due to the high nutritional value of fish, fisheries are increasingly regarded as a key element to address global nutritional deficiencies that lead to cognitive under-development, diseases, and deaths [2, 3, 4•]. In high-income countries, fish consumption has been promoted as a means to "healthier" diets and to battle chronic diseases, caused by diets full of low-quality nutrients and processed products [5•, 3]. However, the most critical contribution of fisheries to human health lies in low-income countries, where under-nutrition affects around 13% of the population, leading to child under-development, deficiency in growth, and high mortality rates at all ages [5•]. In low-income countries, local fisheries are often the major source of essential nutrients to poor communities, which often cannot afford obtaining these from other sources [4•, 5•]. As such, empowering local sustainable fisheries and promoting access to fish have been identified as important pathways to achieve the United Nations Sustainable Development Goals (SDG) related to malnutrition, including No Poverty (SDG 1), Zero Hunger (SDG 2), and Good Health and Well-being (SDG 3), among others [5•, 6, 7].

[1] In fisheries terminology, "fish" refers to all finfish and aquatic invertebrates that are caught in marine and freshwaters as part of fishing operations.

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Fish as a Source of Food and Nutrients

In 2017, fish was thought to account for 17% of the animal protein and 7% of all protein consumption in the world [1•]. Despite the relatively modest contribution as a global source of protein, the growing knowledge of the nutrient composition of different fish species brought attention to the importance of

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fish as source of essential nutrients, especially micronutrients [4•, 8]. Fish are rich in essential fatty acids, bioavailable minerals and vitamins, with concentrations varying by taxon and ecological traits [8–10]. Many marine fish, especially small pelagic species such as sardines and herrings, are rich in essential fatty acids and poly-unsaturated fatty acids such as omega-3, and have lower concentration of saturated fat when compared with other sources of animal protein such as red meat derived from beef [2, 11]. These nutrients are important to support neurological functions and cardiovascular health, lowering blood pressure and reducing risk of heart disease; moreover, deficiency in fatty acids is a leading risk factor for human mortality, responsible for more than 2% of global deaths alone [3, 10, 11].

The contribution of micronutrients from fisheries is essential to ensure the survival, growth, and health of vulnerable groups, such as pregnant woman and children, reducing mortality and preventing fetus malformation, cognitive deficiencies, and immunological issues [12, 13]. In particular, fisheries are a major source of calcium, zinc, and iron, which are essential for health but largely lacking in diets in many low- and middle-income countries [9••, 12]. Fish, and especially small pelagic forage fish and shellfish, are also a good source of vitamins A, B12, and D, with some species providing at least twice as much vitamin A with considerably higher bioavailability compared with plant-based diets [8, 9••, 13]. Selenium, a micronutrient important for good metabolic function and protection against oxidative stress, can also be obtained from wild-caught marine fish; however, this micronutrient occurs in higher concentrations mainly in deep-water species and colder regions, which makes it relatively less accessible [9••]. Small freshwater species have particularly high concentrations of zinc, iron, and iodine, and in low-income countries, these species are often consumed whole, meaning that they are also good source of calcium and vitamin A [14, 15]. In many places, these micronutrients may be obtained through synthetic food fortification policies; however, the conditions required to implement such polices in low-income countries and rural areas are often limited or cost prohibitive [16]. In contrast, in such areas, fish may be the most easily available source of micronutrients.

The nutritional benefits from eating fish are also influenced by the manner of consumption and degree of processing and preparation. Fish filets have high concentration of proteins and fatty acids; however, bones, heads, and viscera are rich in highly bioavailable micronutrients, and thus can add considerable nutritional value to fish as a food source. For this reason, dried and ground-up whole fish are often used as a low-cost complementary food item, helping to improve diets in low-income communities and address malnutrition issues such as cognitive under-development and nutrient deficiencies during pregnancy [12, 17]. Cooking methods may also influence the nutritional value and health benefits of eating fish, with lower impact processing methods, such as baking and broiling, retaining more nutrients than higher impact processing methods such as frying [18].

The Role of Fisheries in Human Health

The regular consumption of fish may reduce the risk of all-cause mortality by 6–14% compared with a standard omnivorous diet, with the relative risk of type II diabetes, coronary mortality, and cancer potentially being reduced by about 25%, 20%, and 12%, respectively [19, 20]. This strongly suggests that fisheries may have a strategic role in preventing some of the most impactful diseases of modern society and highlights the need for a better understanding of the capacity of fisheries to supply nutrients to address local diet-related diseases, particularly in regions of severe nutrient deficiencies. Nutrient composition of fish varies among trophic level, habitat, spatial distribution, and thermal regimes [9••], and tropical marine fisheries are well placed to supply coastal communities in tropical low- and middle-income countries with essential micronutrients, thereby addressing severe regional micronutrient deficiencies of iron and zinc in Africa and Asia, and calcium deficiency in the Caribbean. Furthermore, such dietary micronutrient availability in many coastal low- and middle-income countries is critical for addressing dietary deficits of children under 5 years and pregnant women [9••].

Freshwater fisheries are also crucial for nutrient- and food-security, particularly in Africa and Asia; however, due to the lack of adequate data on catch volumes and distribution, the global contribution of these fisheries to nutrient- and food-security is largely underestimated [21, 22]. Freshwater fisheries, which are often extremely critical for low-income inland populations, are important sources of essential fatty acids, vitamins, iron, iodine, and zinc [7, 14, 21]. Moreover, many small freshwater species are also consumed whole, i.e., with bones and viscera, which makes them also an important source of calcium. However, many freshwater fisheries are under substantial threat due to overfishing, pollution, habitat degradation, and freshwater diversion for agriculture, which jeopardizes their capacity to provide food- and nutrient-security [21].

Recommendations on Fish Consumption

The increasing recognition of the potential benefits of fish for human health has driven regional and global organizations to recommend the regular consumption of fish [23, 24]. Currently, the World Health Organization (WHO) recommends the consumption of one to two servings of fish/week,[2]

[2] https://www.who.int/nutrition/topics/5_population_nutrient/en/index13.html

while the European Food and Safety Authority (EFSA) recommends adults consume 300 g of fish/week [25]. For omega-3 rich species, this amount is sufficient to reduce the chances of heart diseases by more than 30% when compared with a standard diet [26]. Such recommendations balance the nutritional benefits of fish consumption with concerns over bioaccumulation of contaminants and pollutants that are present in fish and fish products [24, 25, 27].

More recent recommendations adopt a more holistic approach and balance the nutritional benefits with concerns over the environmental impacts of food production [2, 20, 28]. According to the food-based dietary guidelines of the Food and Agriculture Organization of the United Nations (FAO),[3] this view is aligned with the need of shifting to more sustainable diets and food systems, with particular care for the origin of the food products (e.g., fish from sustainable sources) and condition of production [29]. Such considerations are particularly important given the challenges of feeding a growing global population with healthy food without continuing the environmental collapses due to habitat degradation, increase in freshwater consumption, pollution, and emission of greenhouse gases [2]. Moreover, growing evidence indicates that significant health benefits can be achieved with the adoption of largely plant-based diets supplemented with little to moderate animal protein consumption, and recommends fish as a preferred animal source [2, 20]. In particular, a pescatarian diet has been shown to be effective in improving general health, reducing the risk of chronic dietary-related diseases with a lower environmental cost when compared with an omnivorous diet [20]. However, the environmental impacts in terms of greenhouse gas emissions and habitat degradation will vary according to the fisheries production system, yet the widespread underreporting of fisheries catches and fishing effort presents a major challenge to quantify the extent of these impacts [20, 22, 30, 31].

Hazards of Seafood

Industrial activity and ocean pollution are major sources of contamination of marine life [27]. International intergovernmental organizations, such as the FAO and the WHO, consider that the benefits largely outweigh the potential risks of contamination from regular consumption of fish [5•, 24]. However, concerns remain that contaminant research often focuses on a limited number of pollutants and/or species, suggesting that fish consumption recommendations may not fully account for the actual contamination risks [11, 32]. For example, the susceptibility of fish to accumulate high levels of heavy metals, such as mercury, lead, cadmium, and arsenic, and the toxic effects of these substances in humans are well known [33]. However, fish can also accumulate a range of other contaminants including dioxins, polycyclic aromatic hydrocarbons, polychlorinated naphthalenes, diphenyl ethers, and perfluorinated compounds, and the effects of such compound accumulation on human health are not yet adequately understood [11].

Moreover, plastic pollution is a rapidly escalating issue in the world's oceans, and an increasing number of studies in the last few years have reported the ingestion of plastics by marine animals [34]. Recent evidence shows that at least some commercially important species of fish are contaminated by microplastic [35]. In the Northeast Atlantic, it has been estimated that the consumption of these species at levels recommended by the EFSA, i.e., 300 g/week, may result in the ingestion of between 500 and 3000 plastic items per person per year [36]. The ingestion of microplastics has neurotoxic effects on fish, which clearly highlights the need for better investigation of the potential consequences that consumption of such fish may have on human health [36]. Given that plastic particles readily accumulate harmful contaminants [37, 38], the bioaccumulation of plastic-related contaminants in fish and the toxicity of these contaminants to humans requires careful attention [35].

There is a general acceptance that the nutritional benefits of fish consumption outweigh the potential harm it may cause to human health, and that the contamination risk can be further mitigated by selecting species of lower trophic level as these tend to have lower pollutant accumulation [8, 24, 39]. However, recent findings of high plastic contamination levels in low trophic level species, e.g., shellfish, that often may be consumed whole call for more detailed analyses of contaminants in seafood and more comprehensive advice regarding consumption [35]. Furthermore, given that contamination of aquatic environments due to anthropogenic impacts is an escalating issue, regular monitoring of fish contamination by a broad range of contaminants should become a default, common practice associated with national food safety monitoring and import/export rules to enable the regular assessment of the effects of fish consumption on human health.

Assessing the risks and benefits of fish consumption on human health is particularly important for critical life stages such as pregnancy and early child development, when the adequate intake of fish may have disproportional health benefits on fetal development, lactation, early childhood cognitive development, and prevention of malnutrition diseases [12, 40–42]. For this reason, some regulatory agencies, e.g., the US Food and Drug Administration, have developed specific guidelines for fish consumption by pregnant women and young children, detailing recommended species and regular intake amounts considered safe and beneficial.[4] However,

[3] http://www.fao.org/nutrition/education/food-dietary-guidelines/background/sustainable-dietary-guidelines/en/

[4] https://www.fda.gov/food/consumers/advice-about-eating-fish

such recommendations and much of the underlying research largely focus on the potential benefits of eating fish against the potential harms of methyl-mercury intake, with less consideration being given to the effects of other pollutants on critical life stages [11, 41, 43, 44]. Despite the harmful effects of these pollutants on early human development, the focus on mercury may be related to the fact that many pollutants can be absorbed from various sources, while fish intake is the primary source of bioavailable mercury to humans [33, 42]. Given the increasing evidence of the detrimental effects of a broader range of pollutants, detailed assessments that consider region-specific concentrations and species-specific accumulation potential can assist in providing safer recommendations for the regular intake of fish to optimize health benefits, especially during critical human life stages.

The Role of Fish-Provision Sectors in Nutrition- and Food-Security

Three sectors are the main sources of fish for human consumption: (1) domestic small-scale wild capture fisheries (i.e., artisanal and subsistence fisheries), (2) domestic and foreign large-scale wild capture fisheries (i.e., industrial fisheries), and (3) aquaculture production (i.e., fish farming). These sectors are sometimes interconnected or overlap, but have very distinctive roles in food- and nutrient-security.

Small-scale fisheries can be broadly defined as coastal domestic fisheries that use relatively low levels of capital investments and generally passive or stationary fishing gear [31, 45]. This sector provides protein and essential micronutrient for over four billion people worldwide, constituting the main source of food for nutrient- and food-security of over a billion people, mostly in low-income countries [10, 46]. The small-scale fisheries sectors are occasionally considered “labor intensive”; however, a better perspective is to consider this sector as being the global fisheries leader in supporting the largest number of livelihoods [47]. The small-scale fisheries sector accounts for approximately 97% of the world’s fishers and approximately two-thirds of the people working in the ocean economics sector [46, 48, 49]. Small-scale fisheries largely supply locally caught fish to local communities, often consisting of the only steady and affordable source of essential nutrients to poor communities in low-income countries. Such local self-sufficiency is particularly the case in regions of political and economic instability or where disruption of the supply chains commonly takes place [46, 50]. Despite addressing crucial socio-economic as well as nutritional needs of an often neglected sector of society, small-scale fisheries are largely underrepresented and marginalized in regional and global ocean policy discussions [47, 51], which far too often focus on strictly market-based and export-oriented sectors such as industrial fisheries and intensive aquaculture [8, 46].

Large-scale industrial fisheries can be classified as largely mechanized fisheries with high capital investments in generally large to very large vessels and gears, and which can operate in most marine environments and depth zones [45]. The majority of large-scale fisheries operate mobile fishing gears that are actively moved through the water column or across the seafloor, e.g., trawl or purse seine gears, using the often substantial engine power of industrial vessels [45]. This sector includes both domestic fleets fishing in home Exclusive Economic Zone (EEZ) waters and distant-water fishing fleets operating in foreign EEZs and international waters. In 2010, the industrial fishing sector was responsible for approximately 80% of global marine catches [31], exploiting or capable of exploiting essentially all of the world’s ocean areas [52, 53], sustaining a multi-billion international trade industry and representing the main supplier of fish to food- and nutrient-secure populations in high-income countries [54]. Unfortunately, industrial fisheries are also responsible for the vast majority of extremely wasteful discarding in global fisheries, accounting for over 90% of the total global discards of around 10 million tonnes per year [55].

Given the promotion of increased fish consumption for health reasons in higher income sectors of society, industrial fisheries occupy a central role in supplying these markets [56]. However, industrial fisheries in the higher income countries are often limited by historically overfished stocks due to decades of overcapacity of these fisheries driven by large, harmful taxpayer-funded subsidies [47, 57]. As a consequence of this subsidy-driven overfishing of domestic stocks, industrial fishing fleets have undergone a massive global expansion of fishing capacity to the waters of low- and middle-income countries [52, 53] to satisfy the demand of high-income countries [8, 54]. This increase in industrial fishing effort in the waters of low- and middle-income countries leads to local overfishing, competition with and displacement of small-scale fishers, and increases in prices of local fish, ultimately depriving low-income populations of essential nutrients, thus intensifying malnutrition [56].

The industrial fishing sector is also the major supplier of fishmeal and fish oil for livestock feeding and aquaculture (e.g., [58]). Over the last 60 years, more than 20% of the global marine fish catch was destined to fishmeal reduction, with most of this catch comprised of food-grade or even prime food-grade species perfectly suitable for human consumption [58]. Over 70% of this fishmeal is used for aquaculture feed [59], as a consequence, aquaculture of carnivorous species competes directly with low-income populations for fish [58]. Furthermore, the demand of the fishmeal market for small forage fish, which may also be the most accessible fish for many low-income populations, increases prices of local fish, which may become costly prohibitive for the most in need [56, 58, 60]. Importantly, the diversion of wild-caught fish into aquaculture products via inefficient food conversion ratios is still far too common in many aquaculture systems, which is not helpful for food-security [61, 62]. Nevertheless, examples of local aquaculture sectors improving food-security of local populations do exist [63, 64]; however, the often high fish prices and lower nutritional value of many farmed species still raise concerns regarding the potential of aquaculture to compensate the loss of nutrient intake from wild-caught fish [65]. Thus, despite the potential of aquaculture to contribute to global food-security, the cost and benefits of food production by this sector need to be taken into account when estimating its net contribution to human health (see comments on aquaculture in 61, 62).

Impact of Overfishing and Climate Change on Human Health

Despite its strategic importance for supplying essential nutrients, the extent to which fisheries can address world hunger and malnutrition has been increasingly compromised by growing and uncontrolled anthropogenic stressors, in particular overfishing and climate change [5•, 66]. Food production is currently the largest human pressure on oceans, and the lack of adequate and restrictive control through effective fisheries management has led to widespread overfishing globally [31, 67]. Overfishing has a stronger negative impact on nutrition of low-income coastal populations, which often rely on fish for food but also on fishing for their livelihoods, and which may not have alternative sources of income when fish populations are depleted [46]. This problem is further aggravated by the lack of adequate basic fisheries data and strict enforcement of existing regulations, which unfortunately is the norm for most regions around the world.

Global fisheries catches have been declining since the mid-1990s by approximately 1% per year (Fig. 1), largely due to overfishing [31, 68]. Projections of the impact on global fish biomass suggest that if fisheries management is not severely improved worldwide, the decreasing trend in catches and fish biomass will continue [67]. If not addressed, the resultant loss in biomass is predicted to translate into shortage of fatty acids and essential micronutrients, affecting more than 10% of the global population, with a disproportionally high impact in tropical low- and middle-income countries [4•]. While effective fisheries management that restricts unsustainable fishing effort and removes excess fishing capacity can potentially reduce the impact of overfishing, the synergetic effects of this stressor with climate change and other potential global drivers also need to be considered [69].

Climate change is having major impacts on fisheries, affecting diversity, distribution, abundance, and biology of fish populations [70, 71]. These changes are causing major shifts in the availability of nutrients by reducing and shifting fisheries productivity [9, 70]. Overall, global catches are projected

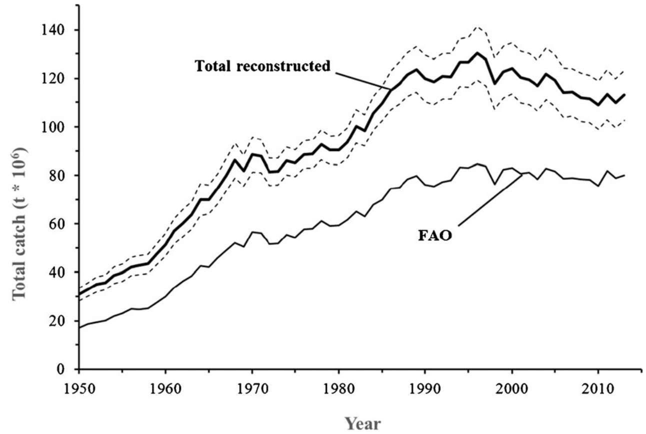

Fig. 1 Global total reconstructed marine fisheries catch (± 95% confidence intervals), including discards (55), based on the sum of the national catch reconstructions performed or inspired by the *Sea Around Us* (31, 77), and global catches (landings only) as reported by the Food and Agriculture Organization (FAO) based on the submissions of its member countries (reported by countries and by the FAO without confidence intervals, despite being estimates and sampled data). The approximate confidence intervals of reconstructed data (dashed lines) were estimated by combining for each year, using a Monte Carlo method, the uncertainty associated with each fishing sector in each national reconstruction into an overall 95% confidence interval (31, 61), which was then doubled to counter the tendency of Monte Carlo methods to underestimate the confidence interval of sums. All data represent marine wild capture fisheries excluding plants, corals, sponges, reptiles, and marine mammals (45), and excludes aquaculture production and inland (freshwater) fisheries. Figure adapted from Zeller and Pauly (47)

to decrease by 3 million tonnes for every 1 °C of global warming, and species distributions are shifting polewards, thereby reducing potential catches in the tropics and possibly increasing in higher latitudes [72]. As some species move out of national jurisdictions of fisheries, fishers may have to target different species [70, 73], which could lead to shortage of some essential micronutrients [4•, 9••]. For small-scale fisheries that are of crucial food- and nutrient-security in low-income countries, this will be a major challenge due to limited mobility, resources, and capacity to adapt to new conditions [70]. Thus, countries need to urgently develop and implement climate-sensitive management strategies that promote resilience to global change and food- and nutrient-security of populations that depend upon marine resources.

The Role of Fisheries Policy in Human Health

Despite being a strategic sector to address food-insecurity and malnutrition, particularly for low-income populations, global fisheries discussions and national policies hardly ever classify fisheries as a public health asset or have adequate policies to safeguard their role in food-security and national health [8, 74]. Instead, the policy focus generally lies on maximizing profits, often supporting and promoting export-oriented fisheries [7, 8, 56]. In fact, fish is one of the most widely traded food "commodities" in the world, with approximately 35% of the global production entering the international trade [5•]. While the global volume of fish and fish products traded between low- and high-income countries seems to be balanced, the net flow of nutrients shows a different scenario, as low-income countries export their high-quality fish and import low-quality fish, thus creating a net loss of essential nutrients [8, 54].

From a public health perspective, this nutrient trade imbalance has food-security implications in low-income countries, as fisheries-derived economic trade benefits may not be returned to society in terms of health policies to ensure food- and nutrient-security [46]. Moreover, the current focus of national policies on maximizing fish production, i.e., maximizing profit, through management strategies that allow fisheries to exploit populations beyond sustainable levels has driven widespread overfishing globally, further putting pressure on aquatic ecosystems and production systems [2, 47]. Thus, the market-based policy approach to fisheries has harmful consequences for low-income countries, not just affecting their populations' food- and nutrient-security and health but also potentially weakening their economies and environment.

Society may need to feed nearly 10 billion people by 2050, and thus governments are being challenged to boost their food production systems to become capable of providing their populations with adequate nutrition [2]. However, many countries do not have the luxury to be able to increase pressure on their ecosystems, as the consequences of increasing exploitation rates, land use, pollution levels, energy use, and greenhouse gas emission are prohibitive [2, 4•, 20]. If, instead, fisheries were to be managed biologically sustainably, they have the potential to increase their contribution to food-security without placing further pressure on aquatic ecosystems [2, 20, 47, 67]. In fact, by combining effective and sustainable fisheries management with strong reductions in fishing fleet overcapacity, harmful subsides, and exploitation rates, it will be possible to decrease fisheries pollution, energy use, and greenhouse gas emissions while sustainably increasing catches to improve food- and nutrient-security [30, 47, 75].

Globally, the current market-based policies drive fisheries to overfishing, in turn leading to widespread fish population depletion, and is responsible for the net export of high-quality nutrients from low-income countries [31, 54]. Thus, to improve the capacity of fisheries to contribute to global human health, a major shift in policy is needed to prioritize rebuilding fish populations and improve access of the local populations to local fish [4•, 8, 9••, 47, 69]. The global implementation of deep structural improvements in effective fisheries management may result in a potential increase in annual catch of 16 million tonnes, also generating approximately $53 billion in profits [67]. Policies that promote local small-scale fisheries, a largely marginalized sector in the current debate on food-security, can further increase food-security benefits by generating jobs and strengthen the local economies in low-income communities [10, 31, 46, 47]. Most importantly, given the crucial role of small-scale fisheries in food- and nutrient-security in these communities, such policy changes would address nutrition deficiency by improving access to fish but also allowing more disposable income for expenditures on higher quality food to complement diets [8, 60, 76]. Lastly, policies and management strategies that reduce waste in value chains and discards from fisheries would further increase the capacity of fisheries to assist nourishing the global population [8, 55].

Conclusion

The role of fish in human health is well known; however, the recent increase in knowledge of the nutrient contents of fish and their spatial distribution has highlighted the strategic role fisheries can have in improving human health by addressing malnutrition and nutrition-related diseases in regions where this is most needed. This is particularly true for tropical low-income countries, where the widespread shortages of fatty acids and micronutrients such as vitamins, calcium, iron, and zinc in the diets of low-income populations can be readily addressed by the consumption of local coastal and freshwater fish. However, the potential of fisheries to supply nutrient-rich fish to combat micronutrient deficiencies has been poorly explored through nutrient-sensitive policies in low-income countries, precisely where these sources may have the highest importance. Moreover, the lack of adequate health- and nutrition-focused fisheries policies has contributed to widespread overfishing and the net export of high-quality nutrients from low-income countries to high-income countries, reducing the availability of fish for local low-income communities, thereby increasing food-insecurity and malnutrition.

Governments and intergovernmental organizations have an important role in establishing national and regional fisheries policies and management strategies focused on addressing local food- and nutrient-security instead of only maximizing industry profits. Such a change in paradigm, from fish as a commodity to fish as a local public health asset, also requires improved and refocused management approaches. Fisheries are at a global crossroad, and implementing fisheries reforms now will increase the availability of nutrients, generate livelihoods, and ultimately improve the health of the oceans. However, failing to do so may prevent fisheries from further contributing to the targets of the United Nations Sustainable Development Goals related to malnutrition.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflicts of interest.

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