Review

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Review

Do Low-Income Consumers of Forage Fish Subsidize the Production of Aquafeeds? Financial and Nutritional Significance

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Abstract: Forage fish are crucial to human nutrition, especially in developing countries. However, in these countries, most forage fish catches are used to make aquafeeds for aquaculture, which leaves only a small quantity for direct human consumption. This practice increases fish prices in local markets and undermines people's nutrition. Overfishing forage fish for industrial purposes harms the ecosystem, reduces the catch of larger fish, and marginalizes local fishermen. Although previous discussions have touched qualitatively on the ethics and injustice of this practice, this article provides quantitative scales to measure the impact of the practice on the finances and forage fish consumption of low-income consumers using reasonable assumptions and literature values. Increasing the annual supply of forage fish by 25% to the 5 million MT of fresh fish markets globally could save consumers several billion US dollars annually. Families could consume a higher percentage of nutritious fish for less money. Furthermore, leaving forage fish in the sea could benefit wildlife and increase the capture of larger fish, such as mackerel, which are in demand in local markets and fished by local fishermen. The unintentional and involuntary contributions of low-income societies to enable the growth of high-value fish and shrimp for affluent societies seem unjust and warrant further investigation.

Keywords: overfishing; poor families, fisherfolk, fishmeal; natural food chain; anchovy; sardines; social justice; supply and price; fish market

1. Introduction

1.1. Using Captured Forage Fish in Commercial Aquafeeds

Fish is an important source of protein and essential nutrients, and it can be produced through fish farming or caught in the wild. Its nutritional and health-promoting qualities are increasingly recognized, especially in low-income societies [1]. Fish is highly efficient in converting feed into high-quality food, providing income and livelihoods for many communities worldwide. The contribution of fisheries and aquaculture to food security and nutrition is influenced by various factors, such as the environment, policy, economics, development, and governance [2].

Forage fish captured from the ocean constitute essential nutritious ingredients in commercial aquafeeds. These feeds enhance fish growth by supplying proteins and fatty acids (*e.g.*, [3]). Aquaculture, farming aquatic organisms, is the single largest user of fishmeal, consuming over 60% of the global supply [4]. The reduction of small, bony fish to dried protein, known as fishmeal and oil fractions (the "practice"), is a well-established industry that has historically relied on stocks of captured fish. These low-trophic-level species or forage fish, which are near the bottom of the food chain, can have massive populations and support the largest fishery in the world, with an annual catch between 20 and 30 million MT globally, of which the Peruvian anchovy alone constitutes around 12 million MT of this catch [5,6].

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The protein and oil content of forage fish can be used for various industrial applications, with the most economically significant use being as ingredients for farmed animal feed, primarily fish feed. The oil is also used for human health food supplements. The protein content of these forage fish can have considerable nutritional benefits, particularly for children and young women of reproductive age. Some forage fish species in developing countries are more accessible and affordable than larger fish and other animal-source foods and vegetables. These locally available forage fish have considerable potential as cost-effective food-based strategies to enhance micronutrient intakes and the nutrition of malnourished children [7]. However, using forage fish as a food resource for feed or other uses reduces the quantity of fish available for human consumption, which is a concern (reviewed in [8]).

1.2. Demand for Live Forage Fish

The average global per capita consumption of live forage fish is less than 1 kg [9]. However, this value is much higher in low-income countries with a forage fish capture industry [10]. For example, in Peru, per capita, total fresh fish consumption reports varied between 4.2 and 11.2 kg (of which about a third were forage fish, from 2005 to 2011 [11].

About 22 million MT y^{-1} of forage fish is globally captured, with an estimated base cost of US$2000 MT^{-1} [12]. Only 10-20% of this is used for direct human consumption [13]. The average ex-vessel value of forage fish for human consumption has been around US$1700 MT^{-1} in recent years [14]. Including the retail margin [15], a value of US$2000 MT^{-1} is reasonable for the following calculations, even though prices vary depending on time and location. Thus, the global catch's value is estimated at around US$44 billion [16].

The small amount of forage fish reaching low-income fresh fish markets could result from the higher prices the aquafeed and canning industries paid fishermen, even though it is not legally straightforward [5,17]. On the contrary, according to Tai et al. [14], prices for forage fish that go to the industry were lower than those for direct human consumption. It could be that the sector is well-organized, subsidized, and has better access to these fish [10,18]. Concerted governmental efforts to rectify this situation in Peru have been ineffective [6]. Nevertheless, in other regions such as Central Africa [19], given the opportunity, the fresh fish market demand could have absorbed double the quantity of that available to it at that time. In Peru, the demand for forage fish could increase through proactive governmental intervention, considering that forage fish used to be a staple food there [20].

1.3. Socioeconomic Question

The heavy industrial fishing of forage fish has numerous consequences, with one of the most significant being the potential for poor nutrition in low-income communities in developing countries. When locally caught forage fish are used for industrial purposes, they are often exported as feed for high-value farmed species instead of being utilized for human consumption in the area. The "practice" raises questions about fairness and socioeconomic justice, particularly concerning its effect on the local communities' economics and nutrition [21,22].

Commercial fishing conducted by large boats harms the livelihoods of subsistence fisherfolk [7,23–29]. Additional studies describe qualitatively how the market price of forage fish has increased, and low-income families' nutrition and food security have deteriorated due to diverting a significant portion of these fish to other uses [13,18,30,31] and others.

The "practice" competes with local fishermen who supply local markets and endangers some piscivorous animals [3,11,23,32,33]. Reducing the capture of smaller fish could increase the artisanal fleets' catch of larger piscivorous fish, as evaluated below under mackerel as a representative of piscivorous fish. This, in turn, could lead to higher revenues for fisherfolk and improve overall ecosystem health [6,20,34–37]. As far as I could find out, none of these studies has attempted to quantify this practice's financial and consumption consequences for low-income fish consumers. This is crucial information that should be available to policymakers and regulators. This article aims to bridge this gap.

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1.4. Ecosystem Impacts

Excessive fishing by large industrial boats harms the environment. Fishing for forage fish at the maximum "sustainable yield" level can interfere with the ecosystem's natural functioning [31]. This is especially true when such fish make up a significant portion of the ecosystem's biomass or are highly connected to the food web; these fish species are crucial for transferring production from plankton to larger predatory fish, marine mammals, seabirds, and the fish market [13,32].

1.5. Beneficiaries of the Fish-Based Aquafeeds

Fish growers and the aquafeed industry benefit the most from captured forage fish [31]. Processors and retail markets receive a larger share of the benefits in the value chain due to their more substantial bargaining power; small-scale fisherfolk and fish farmers earn the least money for their efforts and products [35], a situation that seems unjust because these low-income individuals provide most of the forage fish to local markets in developing countries through their involvement in fishing, fish processing, and trading [2,35].

Reducing forage fish to fishmeal and oil has primarily benefited the culture of high-value carnivorous and omnivorous species intended for affluent societies. Salmonids (and shrimp) are at the forefront of this process, followed by other fish such as seabream, grouper, and tuna. Unlike them, the leading cultured fish- carp, tilapia, catfish, mullet, and milkfish- do not require fish products in their aquafeeds. Until recently, they were mostly fed "natural food"- organisms that develop in "green water" bodies [38], sometimes enriched with farm waste and even night soil [39].

Recently, some farmers who breed non-carnivorous fish species (currently produced in large quantities of nearly 40 million MT in 2020 have started including small fractions of fish products in their fish diets [8,9,39]. Although fish ingredients are not essential, they help improve these fish's growth rate, intensifying the farms and raising farmers' income. However, the cost of increased aquafeed and environmental impacts sometimes reduces profits [33,40]. While it is true that using aquafeeds containing fish products for low trophic level fish and shrimp increases the yield, it does not necessarily lead to higher profits [41,42].

Due to the rapid growth of the aquaculture industry, the smaller content of marine ingredients used in the feeds for high-value fish species has not led to a decrease in the overall consumption of fish products [8,39] because the increasing demand for these feeds has offset the reduction in the percentage of fishmeal and oil used in aquafeeds [43].

A significant portion of fish and crustacean culture production indeed relies on commercial aquafeeds, which may require large quantities of fish to be removed from the food market, with those negative socioeconomic impacts as mentioned above [10,13,44–47]. Despite this concern, no studies have examined the financial and social consequences of the "practice" on low-income families who rely on fish as a food source. In my opinion, assessing the social cost of this practice by quantifying the extent to which it burdens low-income families financially and nutritionally could encourage further quantitative research on the topic.

1.6. Feeding Fish with Fish (FIFO)

The capture of a large quantity of forage fish to produce a smaller amount of high-value aquacultured fish has been the subject of extensive research, debate, and controversy (*e.g.*, [48]). Briefly, farmed carnivorous fish used to consume more wild fish than they convert to their growth [35]. The use of fish products in aquafeeds has led to a dispute over whether fish should be used as food or feed; to address this issue, researchers have developed new aquafeeds that use alternative ingredients [49]. The controversy of "fish for feed vs fish for food" (*e.g.*, [50]) has been discussed in various publications, including those by Hecht & Jones [18], Naylor et al. [51], Schindler et al. [52], and Hilborn et al. [53], who have examined both economic and ecological factors. However, little attention has been given to the nutritional and financial interests of consumers who rely on fresh forage fish.

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Addressing this gap requires numbers to support the development of policies that promote the availability of fresh forage fish to those who depend on them. One potential solution is to divert some of the forage fish from industrial use back to local fish markets, which can benefit low-income consumers. Another option is to leave the forage fish in the water to support larger populations of larger fish, some of which can be captured by local fisherfolk for sale at local markets [6,35].

1.7. Fish Supply, Prices, and Demand

The economic benefit of forage fish to humanity has been estimated to be nearly US$20 billion y^{-1} for fresh fish and fish for the industry [31]. It's well-known that prices in this market are determined by the interplay of supply and demand [54]. It is also evident that the impact of reduced fish supply on local food fish prices and consumer purchasing patterns is complex and varies geographically and temporally; thus, "why prices change" is beyond the scope of this article [55].

Economists' evaluations of the impact of a change in the quantity of a commodity on its market price use several mathematical parameters of market elasticity [56–59]. However, the financial consequences of the "practice" haven't been studied in detail by aquaculture economists [20].

1.8. Nutritional Considerations

Populations in developing countries often suffer from poor nutrition. Forage fish caught locally contain a high concentration of essential nutrients and can be used to alleviate nutritional deficiencies. These fish are rich in micronutrients, including vitamin A, iron, calcium, and zinc, concentrated in the bones, heads, and gut. Small forage fish are often eaten whole, making them more nutritionally superior per purchased kg [6]). In contrast, larger fish are less nutritious, with only about half their body weight being edible [60]. These fish should be affordable and attractive to the local populations to provide their benefits. Alarmingly, most forage fish that reach the industry for reduction to aquafeed ingredients are food grade but are not readily available to the fresh fish markets [24]. Thus, despite the valid argument for supplying the local market with these nutritious low-value fish, the fishmeal/fish oil industry purchases the catch to use in the aquaculture of high-value fish (*e.g.,* [61]).

The fish-based aquafeed industry argues that fresh forage fish have low market demand due to the preference of local consumers for larger fish; therefore, reducing prices would not necessarily lead to an increase in their consumption [50]. In this context, I would like to examine the validity of this claim.

Despite years of promotion and marketing by the government and independent activists, the consumption of anchovy in Peru remains low [20,35] but is on an upward curve [62]. As a result, the market has a significant surplus of anchovy. It has been suggested that low demand is only one aspect of the story. It could be an oversimplification that ignores alternative explanations and impacts. Low demand for anchovy in the Peruvian and other markets could be attributed to the poor quality of the fish resulting from inadequate storage and sanitary conditions in the unrefrigerated boats that supply the local markets; this compounds the fragility of anchovy, which therefore tends to deteriorate quickly and develop an unpleasant taste if not stored and transported properly to the food market; furthermore, Peru's fishery has other widespread species such as mackerel, horse mackerel, and bonito, which are more affordable, versatile, and palatable from a culinary point of view; Peruvian households prefer these species over anchovy [5,9,35].

According to other reports, forage fish are nutritious, tasty, and easily accessible year-round, particularly close to the coast. The main reason why a large proportion of them end up being used in the reduction industry is not due to their lack of value as food but rather other factors. Nonetheless, I'd like to note that anchovies have historically been a crucial source of protein for Peru and have played a significant role in ensuring food security since ancient Andean civilizations [6,20].

In support of this view, according to some reports, the current price of anchovy for human consumption in Peru and other countries is higher than the landing price paid by the industry [14]. The implication is that with organized and proactive attention, human consumption can be increased, and the nutrition of people with low incomes can be improved. Reports suggest that the market

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demand and the price consumers are willing to pay for forage fish rise when they reach the market in good condition and are presented in an appealing form [5,6,63]. This situation can be compared to some African countries where local communities have a solid household market and can readily consume twice the captured forage fish available to them; however, they are deprived of it when the fish is sent to the industry or exported [19].

The present article aims to estimate the impact of the fishing industry's use of large quantities of forage fish on their consumption and prices in the fresh fish markets. Specifically, we want to know if the "practice" significantly affects the budgets of low-income consumers who rely on forage fish for nutrition and how it impacts their disposable income and fish consumption at a national and family level. Additionally, we want to evaluate if this has any global implications and if it can be justified given its potential impact on the nutrition of low-income families.

2. Materials and Methods

Obtaining precise numbers for the impact of market volume on the value of forage fish in third-world countries is complex, and even if available, the numbers are only relevant to the specific time and place of measurement [9,62]. Similarly, getting exact price responses to changing fish supply is challenging and can vary with time. Besides, data for every year are not readily available [64,65]. However, the purpose here is to estimate the order of magnitude of the impact of the "practice" on the price range for the total catch and for a hypothetical family that consumes 12 kg of fresh forage fish annually. Notably, the per capita forage fish consumption in third-world countries with developed fisheries has been estimated at approximately 2.4 kg y^{-1} [11].

According to Lem et al. [59], a 10% change in fish price results in a 4-5% change in supply, while in Cornelsen et al. [66], a 10% price change leads to an 8% change in demand. Hecht [19] and Hecht and Jones [18] provided a detailed case of fresh fish market supply and prices. They reported that in 16 African countries in 2004, the average price of forage fish increased from US$2 to 2.43 kg^{-1} due to spoilage of a quarter of the 2.8 million MT catch. If this quantity had remained in the market, the fish price would have decreased by about 21%. This means that a 25% weight change in supply leads to a 21% price change, like other published values [64]. For the convenience of the calculations below, a 21% price change due to a 25% change in supply will be used unless better numbers are available. These numbers cannot be precise, but they give an idea of the order of magnitude of the processes. Of course, if the addition is 30%, the impact is higher, and vice versa.

3. Results

3.1. Case Studies

3.1.1. South Africa

In 2004, the total forage fish caught in South Africa was 614,153 MT [18]. This harvest was relatively consistent. Using a fish value of US$2000 MT^{-1}, or US$2 kg^{-1}, the total value of the harvest was US$1.23 billion. The industry purchased two-thirds of the harvest, while the remaining 204,680 MT (a third of the total catch) worth US$409,360 million was sold in the fresh fish market.

Increasing the supply of fish in the fresh fish market by 25% to 256000 MT would drop the price to US$1.6 kg^{-1}. A lower price would have resulted in the population saving money or receiving 25% more fish for their money. While the total value of the fish remained the same, a family that consumed 12 kg forage fish annually would have saved nearly US$5, worth several days' wages [18], or they could have increased their fish consumption by up to 25%.

Furthermore, the total difference of 25% out of 204,680 MT (worth US$409 million) would have constituted over a US$100 million difference, paid by the fresh fish consumers. This is a significant amount, especially when compared to the total worth of the fish products produced by the fish that went into the country at that time to the "practice" of only US$71 million [18])!

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3.1.2. Central Africa

Hecht [19] and Hecht and Jones [18] associated a 25% drop (due to spoilage) in average forage fish supply in a catch of 2.8 million MT in 16 African countries with a price rise of 21%, from 2 to 2.43 US$ kg^{-1}. Only half, or 1.05 million MT, of the remaining 2.1 million MT catch went to the fresh fish market, with a total value of US$2.43 billion [18]. Had 25% more fish (0.26 million MT) reached the market, 1.31 million MT's price per kg would have dropped to US$2, and the total value would have risen to US$ 2.62 billion. In this example, the individual five-person family who consumed 12 kg in 2004 paid an annual levy of [12x(2.43-2.0)] over US$5. The total involuntary expense levied on those families for the entire 1.05 million MT fish sold in the Central African fresh fish market in 2004 was US$430 million!

3.1.3. Peru

Forage Fish

For the Peruvian example, several reports have estimated the consumption of forage fish, especially anchovy, and their market price in Peru. Reported prices range from US$600 to US$1100 MT^{-1} [5,67,68]. Reported consumption values for fresh forage fish range from minuscule [5] to 2.4 kg or more per capita per year [11], while much higher values, up to 218 kg per capita per year, have been reported more recently for fishers' communities [69]. Using the 2.4 kg consumption value, the total Peruvian consumption for the 30 million population for the year reported was 72,000 MT, with a total value (US$1000 MT^{-1}) of US$72 million. If 25% more fish were added, the value would drop to US$800 MT^{-1}, a total of US$57.6 million. In this example, Peruvian consumers pay a levy of approximately US$14 million annually for their consumption of forage fish. However, this levy can be much higher for coastal fishers communities when they buy their preferred food of forage fish, which make up half of the supply [69]. Applying an annual consumption value of 500 kg per family, for instance, pushes up the levy paid by such families to an unbelievable value of over US$500 y^{-1}.

Next, I calculated the potential impact of leaving the 12 million MT catch of Peruvian forage fish in the water on the capture of larger fish, with mackerel as a representative of all species.

Mackerel Catch as a Representative of Piscivorous Fish in Peru

There is no quantitative estimate on the impact of capturing millions of MT of forage fish on piscivorous fish's availability and market price [34,70]; therefore, it was estimated. I assumed a conservative slope of 1%, which means that leaving X MT of forage fish in the sea increases the capture of mackerel-like predators by 0.01 X MT [11,31,70]. Hence, if the entire forage fish catch of 12 million MT y^{-1} remained in the Peruvian upwelling water, it could have increased the capture of larger and more desirable fish, such as mackerel, from 72,000 MT in 2018 [68]) by 120,000 MT y^{-1} to 192,000 MT. To assess the order of magnitude of the financial impact of this hypothetical situation, I assumed that the mackerel price dropped by 50%. Using the ratio in [18] of 1:0.8 MT to US$ is invalid here.

Peru's live mackerel market prices have been reported to be above US$ 2420 MT [68]). Therefore, the added supply would have caused the original 72,000 MT to drop in price to US$1210 MT^{-1}. The total value of the original 72,000MT would drop from US$174.240 million to US$86 million. As a result, the local consumer could pay half the price (US$1.21 per kilogram) or less. A family of five that consumes 12 kg y^{-1} could reduce the expense on mackerel-sized fish by at least US$14.5 y^{-1} (assuming each person consumes 2.4 kg of such fish per year, as described above). By ceasing the industrial harvest of forage fish on the entire original mackerel consumption quantity of 72,000 MT, the saving for the Peruvian consumer would be US$87 million per year.

3.1.4. Global Calculations

The calculation below aims to estimate the price-quantity relationship in a hypothetical global fresh forage fish market. The quantity-to-price ratio of 1:0.8 is used in the national examples.

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The fisheries globally capture about 22 million (estimates vary) MT*** of forage fish each year, valued at US$2000 MT^{-1} [5,68]). Only 5 million MT of catch worth US$10 billion reaches fresh fish markets; the rest, worth over US$30 billion, goes to the industry [11].

Assuming a 25% increase in captured forage fish reaching local markets, the fresh fish market would receive 1.25 million more MT of forage fish, for a total of 6.25 million MT. This increase in supply would lead to a drop of 20% in the worth per MT, to US$1600 per MT, while still maintaining the total value of US$10 billion. This means that a family of five who consumes 12 kilograms of forage fish annually would pay US$4.8 less for their fish than they would in the actual situation. The difference of US$400 per MT multiplied by 5 million MT is worth US$2 billion! This is the order of magnitude of the total financial levy on forage fish consumers.

4. Discussion

The ethics of diverting forage fish from the human food market to other uses should be considered, as it competes with the direct consumption of highly nutritious forage fish such as sardines, anchovies, and mackerel. This reduces the supply, increasing fish prices (reviewed in [71]) and making fish less affordable to those who are financially and nutritionally challenged. The injustice associated with the "practice" has been suggested to contribute to "lost access to marine resources required for food security and well-being." [72] and justify the present calculations until better ones emerge.

The calculations presented in this article only provide an estimate of the impacts of industrial fishing. It is necessary to conduct professional studies to determine the exact socioeconomic costs of the "practice." On a national or regional scale, the impact on local fish consumers can range from tens to hundreds of thousands of US dollars annually. Globally, the effect is in the billions of US dollars, favoring an industry estimated at around 60-70 billion US dollars per year [73].

When the supply of a commodity decreases, its price usually increases until the demand and supply are balanced (*e.g.*, [55]). This shift in supply and prices can impact people's consumption patterns. For example, higher prices of a preferred may cause people with low income to switch to cheaper and less nutritious products like chicken or less preferred fish species; alternatively, they may reduce their overall consumption of fish and animal protein [5,14,54,59]. The higher price paid involuntarily by the consumers can be considered a socially harmful contribution from the low-income consumers in the Southern Hemisphere to the industrial use of forage fish to feed high-value fish and shrimp for the more affluent Northern Hemisphere consumer. This cost to the individual consumer in terms of money and nutrition can amount globally to a billion-dollar-a-year burden that disproportionately affects low-income people [28,32,74,75].

5. Conclusions

This article discusses the various ecological, economic, ethical, and social concerns associated with the reliance on forage fish as feed in the fishing industry, with rough financial and fish affordability estimates. It highlights the involuntary and socially harmful contributions of low-income forage fish consumers to producing high-value fish for more affluent societies, which can result in significant price impacts. These impacts can amount annually to tens of US$ for a family, hundreds of thousands of US$ nationally, and billions of US, and therefore require detailed scrutiny by economists and market experts and concern from policymakers and those focused on social justice authorities [27,31,32]. Additionally, the reliance on forage fish can negatively impact low-income fisherfolk, whose livelihoods are diminished by the industrial fishing fleet and the scarcity of fish [2,5,37,69]). The natural populations of the fished waters are also affected, as the trophic structure is disturbed by fishing and the overfishing of forage fish [30,31].

Achieving a balance between the aquaculture of farmed fish and the economic and nutritional needs of disadvantaged populations requires the attention of all stakeholders and social representatives [76]. They need to explore alternative feed options, ensure the quality of fresh fish that reach food markets, make proactive concerted efforts to increase the availability and attractiveness of nutritious forage fish and develop better storage and transport technologies. By

working together, industry, interested organizations, and the authorities can create a brighter and more sustainable future for the fisheries industry that balances economics, nutrition, and socioeconomic justice.

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