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Review

Assessing the Economic Impacts of COVID-19 on the Aquaculture and Fisheries Sectors in Relation to Food Security: A Critical Review

Kamal Gosh [1,*], Santa Chowdhury [2], Debasish Chandra Acharjee [3], Abdullah-Al Mamun [4] and Robin Ghosh [5]

[1] School of Agriculture and Applied Science, Langston University, Langston, OK 73050, USA
[2] Department of Botany, University of Chittagong, Chittagong 2410, Bangladesh; santachy07@gmail.com
[3] Department of Agribusiness, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur 1706, Bangladesh; debasish.agb@bsmrau.edu.bd
[4] Department of Fisheries and Marine Science, Noakhali Science and Technology University, Noakhali 3814, Bangladesh; mamun_au22@yahoo.com
[5] Department of Computer and Information science, Arkansas Tech University, Russellville, AR 72801, USA; rghosh@atu.edu
* Correspondence: kgosh@langston.edu

Abstract: The aquaculture and fisheries sectors are critical sources of nutrition and employment generation in many developed and developing countries. Hence, any disruptions to these sectors due to the COVID-19 pandemic have a far-reaching impact, leading to a cascading chain of disorder affecting people's food security and livelihoods. Relating to these fish sectors, we reviewed COVID-19's implications for the food security of these vulnerable countries. The current study indicated that COVID-19 and its related preventive measures have severely disrupted the fish demand and supply chain by creating considerable fish price volatility. As a result, the vulnerable aquatic communities have adopted several short-term coping strategies, including fish overwintering, delayed fish stocking time, and feeding the overcrowded fish with low-priced food. Since the long-term coping strategies are still unclear, we recommended certain longstanding methods that are likely to safeguard food security and livelihoods if adopted.

Keywords: food security; livelihood; aquaculture; COVID-19; economic impact model; fisheries

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1. Introduction

According to the Food and Agriculture Organization (FAO), global fish production reached 179 million tonnes in 2018, out of which capture fisheries and the aquaculture sectors accounted for approximately 52% and 46%, respectively [1]. Of the overall fish production, 87% was used for human consumption, equivalent to an estimated annual supply of 20.5 kg per capita [1]. The rest was used for non-food items, mainly to produce fishmeal and oil [1]. China was a major fish producer, accounting for 35% of global fish production in 2018. Excluding China, a significant share of production in 2018 came from Asia (34%), followed by the Americas (14%), Europe (10%), Africa (7%), and Oceania (1%). Approximately 59.51 million people were engaged worldwide in the aquaculture and fisheries sectors, including fishing, fish production, processing, input transportation, distribution, wholesale, and retail marketing [1]. The highest number of aquatic workers resided in Asia (85%), followed by Africa (9%), the Americas (4%), Europe (1%), and Oceania (1%) [1].

The COVID-19 pandemic created enormous health and economic crises worldwide, severely disrupting food production and supply system activities [2–6]. As a result, there was a sudden price increase for essential food commodities [1,6,7]. Poverty incidences in the forms of food insecurity and livelihood vulnerabilities escalated due to the cumulative burden resulting from this pandemic [8]. The pre-COVID data of the United Nation's World Food Program showed that more than 800 million people were in a chronic-hunger

situation worldwide [9]. The current COVID-19 pandemic further exacerbated this situation by adding approximately 265 million new people to this figure, leading to a worse humanitarian crisis [9].

COVID-19 is a respiratory illness caused by SARS-CoV-2 that emerged in December 2019 in China. The pathogenic syndrome of this virus, also known as the coronavirus, was spread quite rapidly to the rest of Asia, Europe, Africa, Australia, and America, causing colossal population mortality [7]. In general, the COVID-19 infection is a contagious disease transmitted from human to human rather than a zoonotic disease [7]. Therefore, aquatic food animals and their products exchanged during trading transactions are unlikely to cause virus transmission to humans [10]. Currently, there is no proof that people can contract COVID-19 directly from food *per se* [4].

However, global fish supply chain activities were severely affected by the COVID-19 pandemic and its subsequent measures, such as lockdowns, stay-at-home orders, social distancing, mass quarantine, stricter border controls, reduced air traffic, and transportation halting [11–13]. Hence, unsold/leftover fish were frequently reported in aquaculture farms, causing a financial burden to the producers who had to purchase additional fish feed to keep them alive [14]. High mortality risk may arise from such husbandries where leftover fish are overcrowded for a prolonged period [14]. In Bangladesh, fish farmers followed a gradual reduction strategy due to decreased fish demand during the nationwide lockdown [15]. Similar instances were reported in the agricultural supply chain of China, Malaysia, Sri Lanka, India, and certain African countries, including Senegal, after COVID-19-related measures were imposed [12,16–21]. In Europe, the business closure frequency in the form of complete shutdown or bankruptcy of agri-supply chain/operators increased during the lockdown period [22]. In Cyprus, the average gross margin of fishers was reduced by four times compared to the preceding month after the national quarantine and lockdown strategies were imposed there [23].

Exports and imports slowed down or even stopped in some cases due to the pandemic. Most developing countries disbursed emergency stimulus packages to soothe such situations, which sometimes appeared to be inadequate for cushioning their vulnerable population during this crisis. Although measures varied, their effects on controlling COVID-19 were considered successful. However, a comprehensive assessment of the pandemic-related impacts and coping strategies for significant fish-producing countries is still missing. This work aimed to conduct a scientific review of the following aspects of the COVID-19 pandemic: (1) economic effects on resource sustainability, in particular, food security for major fish-producing countries; and (2) coping strategies used to safeguard food security and livelihoods.

2. Materials and Methods

Data Collection and Analysis

The COVID-19-induced pandemic created macro- and micro-economic impacts, including monetary inflation, unavailability of raw materials, partial collapse in the credit markets, exchange rate fluctuation, energy sector quandaries, and producer/consumer/labor market disturbances [24]. Since the primary data gathering related to the above-noted factors proved challenging during this pandemic crisis, we adopted an 'integrated' literature review approach [25,26] to assess the economic effect of COVID-19 on the food security, livelihoods, and trade activities of significant fish-producing countries. This review approach could synthesize literature according to emerging perspectives [25,26]. Moreover, it could combine original perspectives and insights originating from different research areas [27]. Apostolopoulos et al. (2021) adopted a similar approach in writing their review paper on COVID-19's impact on global agriculture [24,27].

While searching for the literature, we used the most extensive databases, which published studies in the last ten years (2012–2022). These include EBSCO, Emerald, Proquest, ScienceDirect, Scopus, Web of Science, Wiley, Google Scholar, and other non-governmental/governmental sources. When searching, we typed in different keywords

that matched our research aim. More specifically, we combined 'COVID-19' AND/OR 'economic impacts' OR 'aquaculture' OR 'fisheries' OR 'food security' OR 'livelihood'. The 'AND' and 'OR' operators were intentionally used during the search to make the search more comprehensive. To obtain geographical perspectives, major fish-producing countries, including both developed and developing countries, were considered. For the literature review, we only considered literature that was written in English, including peer-reviewed journal articles, book chapters, proceeding papers, and non-government/government reports. After ending the literature search, we started screening the literature to ascertain whether it aligned with our objectives noted above, following the instruction indicated in the diagram of PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses; Figure 1) [28–31]. Using such a PRISMA model provided essential transparency and trustworthiness for the selection process of published and non-published articles. We finally obtained 65 relevant studies that were used in this current study.

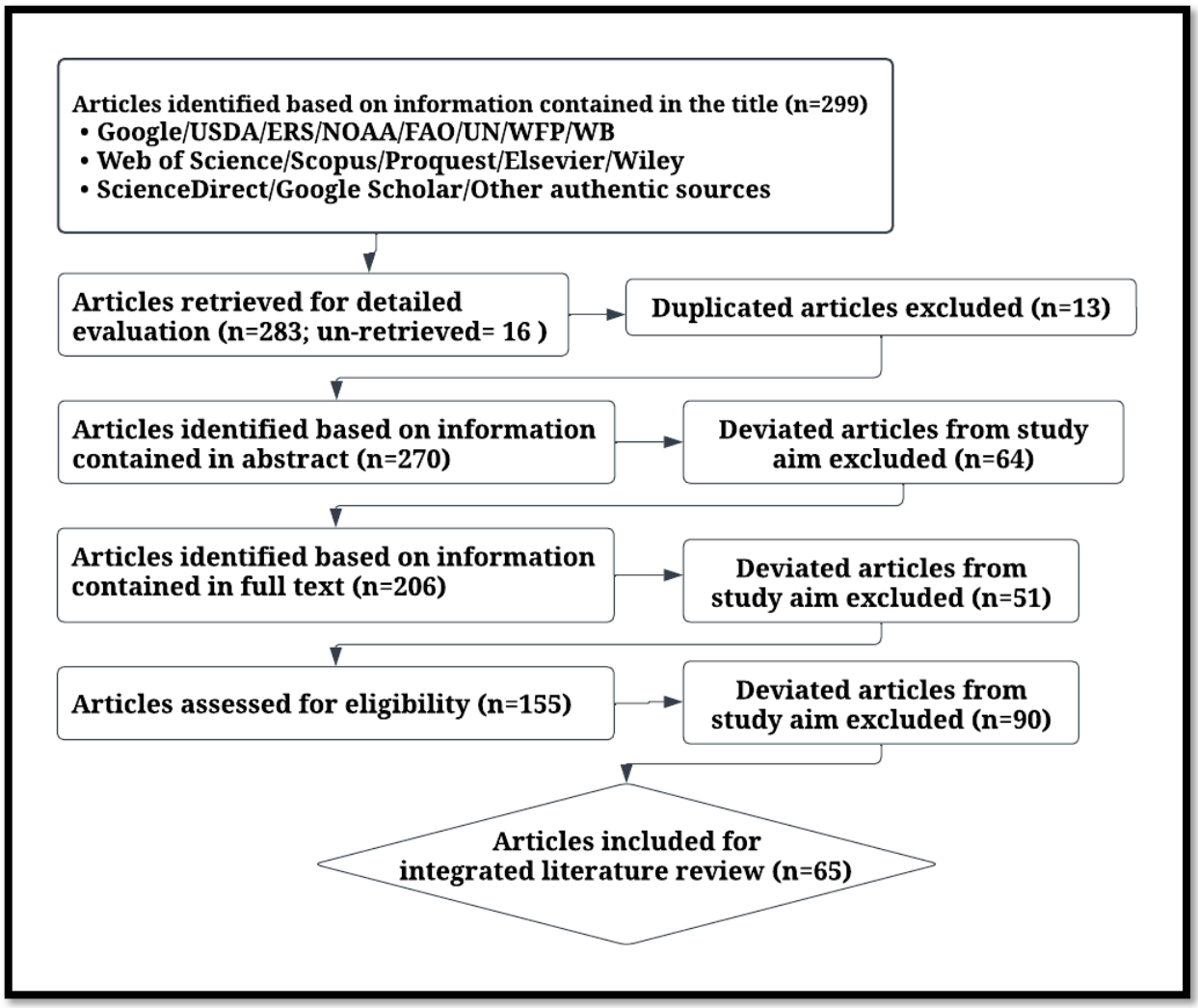

Figure 1. Integrated literature review process used for literature screening and selection process (concept adapted from Ref. [30]).

Once the literature was identified, we then imported it into the Mendeley software, which automatically encodes each article's information, including the authors' name, research title, keywords, abstract, publishing journal, year of publication, and ISSN (International Standard Serial Number)/DOI (i.e., Digital Object Identifier). Non-journal articles were saved manually in the Mendeley to ensure that all the pertinent information was encoded. After encoding the meta-data, we analyzed the data based on content, significant

keywords, and research clusters using VOSviewer software. This software allowed us to visualize the maps based on bibliometric networks and link the top research keywords by providing a systematic overview of research trends over time.

3. Results from the Meta-Data Analysis

Meta-data analysis indicated that most investigations were conducted by researchers from developing countries, including Asia and Africa, followed by Europe and America. In terms of a publishing timeline, the first contributions dated back to 2019 (two articles), 2020 (33 articles), 2021 (30 articles), and 2022 (seven articles). Researchers published the highest number of articles in 2020, followed by 2021 and 2019. In terms of research areas, four main clusters were identified, extracted from the examined articles' titles and abstracts (run by VOSviewer software): (a) COVID-19 impact on supply chain disruptions, food security, and livelihoods, which included seven essential items; (b) COVID-19-related demand disruption, which contained five items; (c) impact of COVID-19-related preventive measures on supply chain disruptions, which comprised of four items; and (d) coping strategies, which contained three items (Figure 2). In terms of publications, peer-reviewed journal articles were used published in Elsevier (n = 11), Springer (n = 4) and Wiley (n = 2). We also extensively used global reports and proceedings, produced by organizations such as the Food and Agriculture Organization (n = 6), the United Nations (UN, n = 6), and other organizations listed under the UN, such as the World Bank, World Health Organization, World Food Program (total, n = 5), and European Union (n = 1). We also used articles from government and non-government sources to prepare this review paper (n = 30). After finalizing the examined literature, we conducted an in-depth content analysis to create a thematic view, as noted below in Table 1 [28,29].

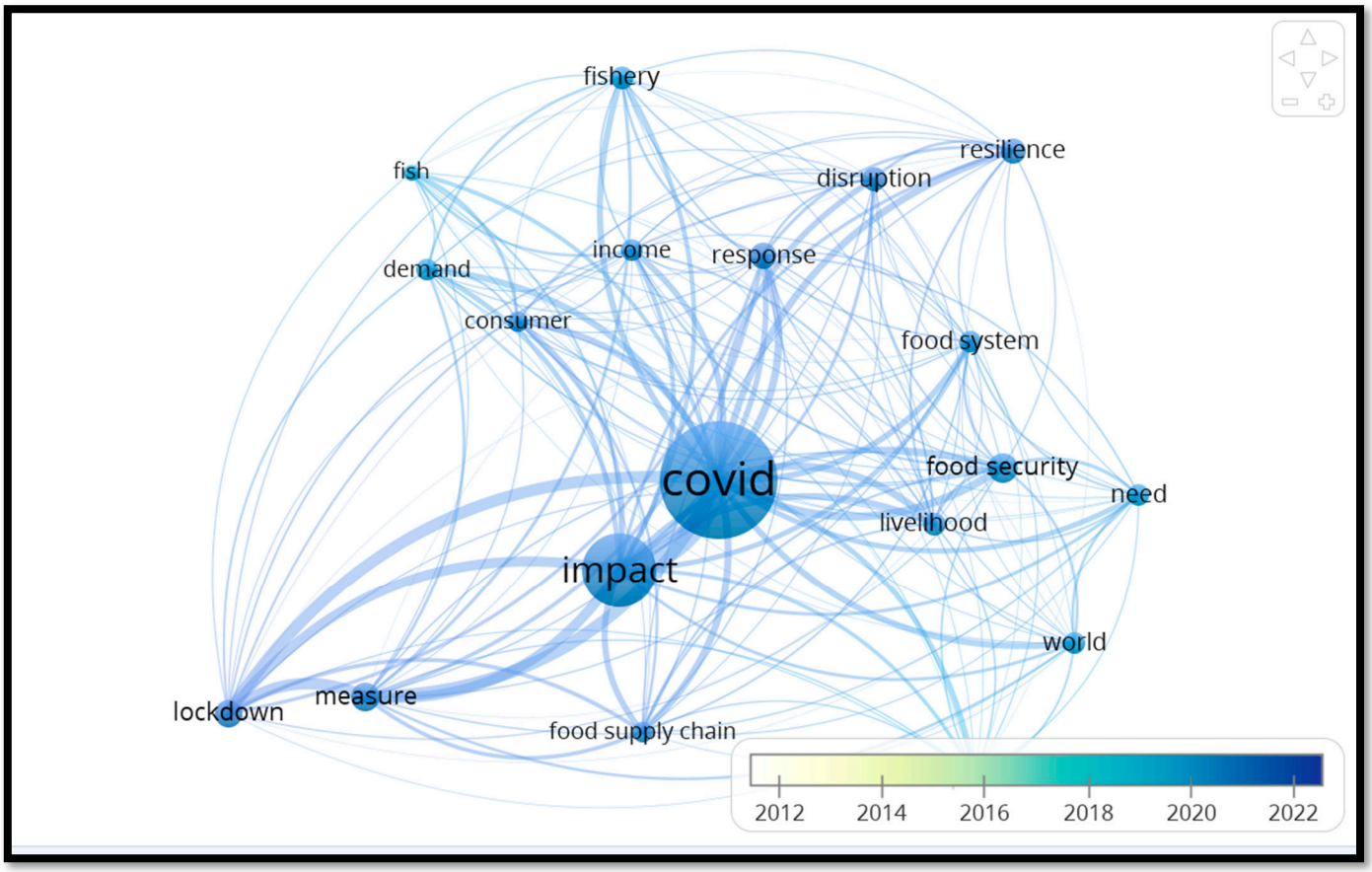

Figure 2. Visualizing the linkage among the top research keywords and their trends used by the examined articles (n = 65; analyzed via VOSviewer software; source: personal elaboration by the authors).

Table 1. Classification and characteristics of COVID-19 economic impacts on aquaculture and fisheries sectors.

Topic: COVID-19 Impact	Characteristics	References
Impact #1: Supply chain disruptions in the capture fisheries and aquaculture sectors	• Fishing activity temporarily halted; • Aquaculture farms overcrowded with fish due to reduced sales.	[4,13,22,30–44]
Impact #2: Fish demand and price	• Price volatility appears; • Temporarily increased demand for canned, frozen, and processed fish.	[6,12,15,37,45–48]
Impact #3: Trade	• International trading may temporarily collapse; • Shrimp farming may be affected.	[4,47,49–51]
Impact #4: Labor supplies	• Unemployment rate increased.	[18–24,46,52–58]
Impact #5: Food security	• The global malnutrition issue re-evolved.	[6,12,15,24,36,38,52,58–61]
Impact #6: Livelihoods	• The livelihoods of the vulnerable communities affected.	[12–15,19,24,32,40,42–44,52,58,59,61]
Impact #7: External factors and post-pandemic scenarios	• Chronic food-insecure situations may evolve; • Vulnerable populations may be forced to migrate and quit the fish farming business.	[52,62–67]

4. Impact of COVID-19 on Aquaculture and Fisheries Sectors

4.1. Impact #1: Fish Supply Chain Disruption

Fish supply from capture fisheries was temporarily halted due to decreased seafood demand in the national and international markets [4]. Fishing fleets, which usually harvest at a bulk rate, targeting the export markets, were more highly impacted than those fleets serving only in domestic and small markets. Sanitary measures, such as physical distancing among crew members at sea and/or the lack of necessary equipment such as facial masks and gloves, sometimes caused fishing activity to cease. Therefore, a sharp drop in harvesting was observed globally (Figure 3), particularly during the first weeks of the pandemic crisis [4]. On the other hand, imposing movement restrictions for professional seafarers and marine fishing personnel created a human rights crisis during this pandemic because they were stuck at port/transit point/sea due to not having embarking permission from the concerned sheltering country/territory's authority [50].

In the USA, fishers in certain states temporarily halted their fishing activities due to the decreased fish demand in the restaurant business during this pandemic. It should be noted that these restaurants sell approximately 75% of the seafood consumed in the entire USA, as reported before the pandemic [68]. Fish prices also temporarily fell by 34% due to a similar restaurant business shutdown, as written by the 'Portland Fish Exchange in Maine' in May 2020 [69]. In some instances, Maine's fishers received a low price at the docks and witnessed complex price volatility during this pandemic [69]. Therefore, Maine's wholesalers encouraged their fishers to temporarily refrain from fishing during the pandemic [69]. In the northeast USA, the fishers adopted multiple coping strategies during the pandemic, including temporarily stopping fishing, direct sales of seafood, switching species, and supplementing their income with government payments or other sources of income [43].

Similar COVID-19-related impacts were reported in France, Italy, and Spain, where fresh fish sales declined by 30% due to the sudden shutdown of restaurant businesses [31]. In Bangladesh, the fishers temporarily reduced their fishing trips to the Bay of Bengal following the pandemic-related preventive strategies, significantly affecting their livelihoods and income [37,38]. In such situations, non-governmental/governmental organizations

in Bangladesh provided little to no support, further increasing the country's vulnerability to food insecurity [41]. However, certain fishers in Bangladesh adopted multilevel resilience strategies at the individual and household levels to cope with such situations, including diversifying their livelihood, creating more friendships, and networking among supporters [63].

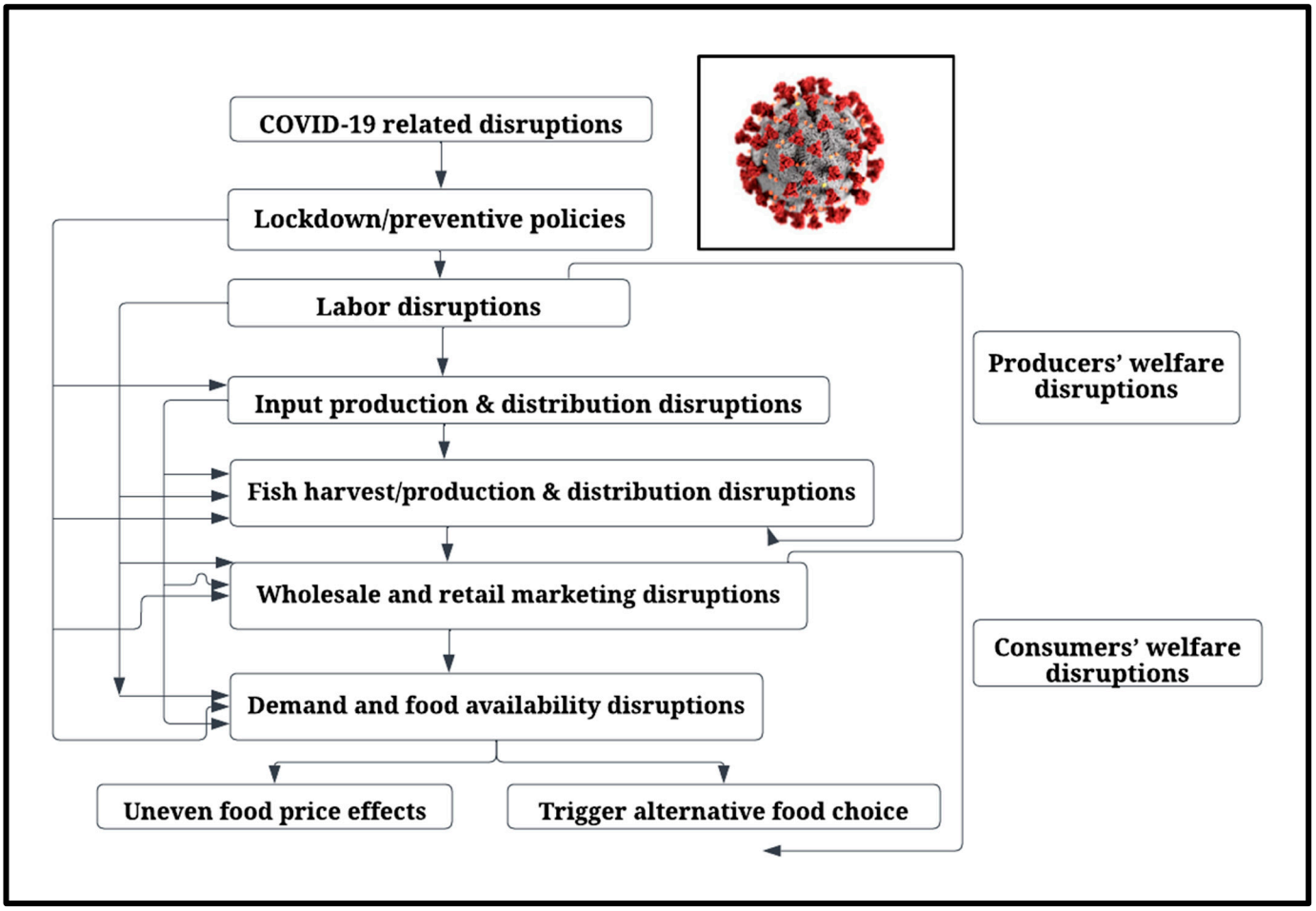

Figure 3. Impact of COVID-19 on producers' and consumers' economic welfare in the aquaculture and fisheries sectors (source: personal elaboration by the authors).

The COVID-19 pandemic also severely affected the global aquaculture supply chain by creating extended production delays (Figure 3) [4,13]. Additional problems faced in this sector included dilemmas regarding the transportation and selling of the final products at the market, shortage in production inputs, and difficulties obtaining credit from banks and other financial institutions, as reported for China [32]. Being the world's largest fish producer and exporter and third largest importer, China was one of the countries that suffered the most from this COVID-19 pandemic, which could be viewed in several phases [4]: First, the nationwide lockdown in China inevitably cut off their logistics and domestic distribution channels, which created a fish overstocking scenario at their farms resulting from the temporary fish feed shortage, inadequate transportation, and low consumer demand. Second, the closure of wholesale markets, supermarkets, and restaurants resulted in low consumer demand, putting more pressure on the farmers. Third, fish exportation was temporarily halted, particularly tilapia, catfish, and whitefish exportation, due to the stagnant fish demand in the international market [4].

COVID-19-related disruptions in the US aquaculture sector included loss of revenue, farm labor shortages, difficulty securing production inputs and services, and management challenges relating to the on-farm inventory of unsold fish and shellfish [34]. Similar

challenges were faced by the aquaculture value chain actors in India and Bangladesh after experiencing lockdown and other preventive strategies [13–15,33,38,39,41,42]. In Bangladesh, fish feed input prices increased considerably [57]. One example of a required raw material for fish feed is monosodium glutamate, the price of which increased by 16% from 2019 to 2021 [15]. On the other hand, Bangladesh's demand for hatchery fish fry was reduced by 40% from 2019 to 2021 [15]. Likewise, fish fry prices decreased by 20–25% from 2019 to 2021 [15]. One example was tilapia fry, the sales of which were reduced from 10 million in 2019 to 2.5 million in 2021 [15]. There are two potential reasons behind this: (1) farmers from neighboring districts were unable to come to fish hatcheries during to lockdown period, particularly in April when the peak season for fry selling begins; (2) some nursery owners were reluctant to stock hatchlings in 2021 because of the leftover fish available from the previous year [15].

However, the fishermen/fishers' situation improved after adopting COVID-19-related prevention guidelines [4]. In some instances, the temporary pause in fishing/fishing fleet operation created a new opportunity for recovering the depleted fishing grounds, which resulted from decade-long overfishing attempts [35]. Moreover, fossil fuel usage in the commercial fishing fleet declined during this pandemic, which potentially helped to reduce greenhouse gas emissions, consistent with climate change adaptation and mitigation strategies [36].

4.2. Impact #2: Fish Demand and Price Disruptions

As noted before, fish demand fluctuated due to pandemic-related public health safety measures (Figure 3) [4,48]. Similar cases were reported for expensive fish, such as lobsters, oysters, bluefin tuna, and mahi-mahi, as demand for them declined due to the closure of public restaurants and cessation of public/private events [6,49]. Hence, fish price volatility was observed [4]. The European market observatory data for fisheries and aquaculture also reported the same after highlighting that the price had declined by 20–70% for their Mediterranean fisheries [46]. Other European fisheries also observed high weekly price volatility, with price paths varying significantly across products and countries [46]. Likewise, the price of Hilsa fish (*Tenualosa ilisha*), harvested from the captured fisheries in Bangladesh, decreased by 6–13% [15]. The main reason behind such an outcome was the lockdown restriction and high transportation costs [15]. Hilsa fish distributors faced a substantial economic loss from such instances, but it allowed the local people to consume more, leading to improved consumer welfare (Figure 3).

However, most survey respondents (74%) in Senegal experienced a soaring price for their essential food products during the COVID-19 pandemic [18]. Similar instances were reported in Bangladesh, India, Myanmar, Egypt, and Nigeria, where the retail fish price peaked during the initial lockdown but dropped later due to declining demand [12,22]. Such significant price drops and uncertainties are challenging as they reduce fish producers' welfare but sometimes improve consumer welfare by giving them a substantial chance to consume more (Figure 2) [46].

Decreased demand for fresh fish products increased demand for canned, frozen, and processed fish (Figure 3). Retail sales of these kinds of shelf-stable fish products rose in supermarkets, notably during the early pandemic when consumers started stockpiling due to the panic and speculation relating to future shortage or consumption (Figure 3) [4,50]. Therefore, the processing industry for salmon and whitefish experienced positive sales trends compared to last year, particularly in areas where the fish supply chain was disrupted [23]. In certain instances, COVID-19 triggered increased demand and a price rise for locally sourced fish products. For example, small-scale fishers from Lake Victoria, Kenya, experienced a price rise for their catch as the import of frozen fish fillet supplies from China declined [23]. Organizations, which providing direct delivery services, connecting fishers and consumers in several OECD (Organization for Economic Co-operation and Development) countries, experienced expansion, particularly in COVID-affected areas [23,46]. However, the economic contraction caused by the pandemic and resulting

reductions in consumers' spending power could impact demand in the medium and longer term [23,46]. Under these circumstances, the market's recovery is likely slow and difficult to predict [23,46].

4.3. Impact #3: Trade (Imports and Exports)

Trade was affected by border closings, input availability declining, and increasing in global air-freight costs as passenger flights were canceled (Figure 3) [51]. These impacts created further challenges for selling fresh fish products, even though the demand for fish existed domestically and internationally [46]. For example, shrimp farmers in Peru faced obstacles while importing their post-larvae (PL) due to pandemic-related biosecurity restrictions. Such preventive measurements affected both their current and future shrimp production efforts. Before the pandemic, Peru imported more than 70 percent of its PL from overseas [48].

In certain instances, increasing the screening incidences for COVID-19 at the border and obtaining a positive COVID-19 result for certain products exacerbated the trade disruptions further (Figure 3). For example, China temporarily halted its seafood trading with Brazil, Chile, Ecuador, Indonesia, India, the Netherlands, and Russia after finding COVID-19 strains on the packaging materials at the border while screening. This risk-averse approach to food safety results in overly cautious rejection of suspected seafood products [6], even though the likelihood of virus transmission through food to humans is very low [3]. Often, this kind of news creates fear and panic among consumers, possibly resulting in the local food prices of essential commodities soaring or products being out of stock.

A collapse further compounded the loss of domestic demand in export markets. For instance, the cancellation of the Chinese lunar new year celebration devastated exporting countries' lobster fisheries, including Australia, Kenya, New Zealand, the United Kingdom, and the United States, which export to China [46]. Indeed, the Chinese lunar year celebration is one of their biggest festivals, during which the Chinese people prefer to consume high-valued seafood items [23].

In Bangladesh, carp fish hatcheries were severely affected due to the Indian border closure. Local vendors often imported a large amount of pituitary gland (PG) hormone from India for conducting artificial breeding programs during the pre-COVID-19 period. Due to COVID-19 movement restrictions, the availability of such PG hormone was reduced, resulting in a per-PG-hormone-bottle price hike of 180% between 2019 and 2021 [15]. Similar instances were evidenced for fish inputs (e.g., mustard oil cake and dry fish) and prawn PL importation from India as their availability/accessibility was significantly reduced, resulting in a price hike in the Bangladesh local market [15]. A review study showed that the supply of Indian prawn PL to Bangladesh was reduced by 50% in volume in 2021 compared to 40% in 2020. In the meantime, local prawn PL supply from local hatcheries and the wild in Bangladesh was significantly reduced during this pandemic, resulting in a fluctuating PL supply and price volatility in the local PL market [15].

4.4. Impact #4: Labor Supplies in Aquaculture and Fisheries Sectors

The unemployment rate in the fish supply chain increased due to partial and complete confinement measurements (Figure 3). Belton et al. (2021), who surveyed the aquatic value chain in India, Egypt, Nigeria, Bangladesh, and Myanmar, reported that the average share of male casual workers shrunk from 51% in February 2020 to 34% in April 2020 and then climbed again gradually to 45% in October 2020 [12]. Twelve percent of surveyed business owners reported hiring female casual workers in February 2020 [12]. This share shrank to 5% in May 2020 and remained static before climbing to 10% in October 2020 [12]. Travel barriers for seasonal or migrant workers added an obstacle that exacerbated this issue as many were temporarily trapped inside fishing boats, ports, and fishing vessels (Figure 3), as seen in multiple incidents that occurred in India, Thailand, and the South Pacific ocean (an Ecuadorian vessel), respectively [4]. India's nationwide lockdown forced hatchery

owners to close their hatcheries, feed mills, and processing plants [33]. Similar impacts were reported in Bangladesh and Myanmar [40]. Moreover, financial or cash-flow issues also forced the owners to lay off their labor temporarily or permanently from their farms [4]. COVID-19-related outbreaks also occurred among seafood process workers in Ghana, the US, and elsewhere [47].

In Bangladesh, the profit margin of finfish farmers was squeezed during the pandemic due to the input price hike and low fish demand [52]. Although the net return from carp and other catfish farming remained close to the break-even level, pangasius and tilapia farming potentially put farmers in debt in Bangladesh [52]. To compensate for rising operational costs and reduced income, fish farm owners were forced to lay off their staff and cut wages to balance the costs [52]. However, this compensation tool risks frustrating working-class people in rural areas and creates huge socio-economic burdens [52]. Similar instances were adopted for workforce reduction in the shrimp industry in Bangladesh when shrimp selling was reduced domestically and internationally [60]. Even though the Bangladeshi government has already withdrawn the COVID-19-related preventive measures from the entire country, the aquatic value chain actors are still adapting to the negative COVID-19 impacts previously affecting their operations, income, and livelihoods [15,16].

4.5. Impact #5: Food Security

The impacts of the COVID-19 pandemic shocked the national food systems [70], likely due to the lack of accurate data on pandemic handling and inadequate preventive measures and concerns relating to how residents would respond to the crisis after preventive restrictions were imposed [24]. Food system management was also affected due to limitations such as those noted above and the partial deficiency of timely government advisement for food supply chain actors. Thus, the market food stock decreased dramatically with a noticeable, sharp food price rise (Figure 3). In addition, it revealed that our current food systems are quite fragile [56]. As the pandemic worsened, peoples' purchasing power, production capability, and food-dispensing mechanism deteriorated, resulting in an acute burden, mainly carried by the vulnerable communities [4]. However, the delay in government advisement, particularly in developing/low-income countries, was quite logical for reducing panic among the residents. Otherwise, certain opportunist, unscrupulous, syndicated entrepreneurs might have exploited the situation by creating artificial scarcity for essential commodities in the market to gain a gigantic profit.

Global malnutrition issues were significantly affected after the reduction in fish consumption patterns during the pandemic. The case of the 'triple burden of malnutrition', which already existed globally, as reported before the advent of the pandemic, is likely to be worsened due to the current food insecurity crisis resulting from it [53]. Survey studies from Nigeria, Bangladesh, and Myanmar showed that food insecurity worsened as the surveyed respondents purchased less-than-usual food per month during the pandemic. Myanmar was notable because its share trended over time, reflecting the late onset of widespread COVID-19 infections [6]. Survey respondents from Senegal reported that COVID-19 created significant concern in multifaceted ways, including through reduced access to agricultural inputs, low ability to carry out planting (cropping, horticulture), yield reduction (cropping, horticulture), and little ability to feed and sell livestock and to hire labor (horticulture) [18]. Most survey respondents also indicated that COVID-19 made it difficult to purchase or sell their products at the market due to foreclosure or disruptions [18].

A review study for Bangladesh indicated that the fish consumption rate per household was significantly reduced during the pandemic period [59]. This was due to the reduced income and job loss occurrence reported by multiple survey studies conducted there [15,57,58]. This was also evident in affluent segments of the community there [59]. Hence, the surveyed people adopted different coping strategies, including decreasing the frequency of grocery shopping, shifting to online shopping, reducing consumption of high-price commodities, reducing junk food consumption, cleaning fish and meat with hot

water and vinegar, and increasing the consumption of protein- and vitamin-C-rich food items [59] (Table 2).

Table 2. Coping strategies adopted by fish producers/harvesters and consumers in significant fish-producing countries.

Coping Strategies	Short Term	Long Term
Fishers/capture fisheries	• Diversifying their livelihood [40,62]; • Creating more friendships and networking among supporters [63]; • Direct sales of seafood, switching species, and supplementing their income with government payments or other sources of income [43]; • Refraining from fishing [41]; • Digital solution [62]; • Seeking alternative sources of income [45]; • Declaring all the aquatic food value chain actors and their logistics 'essential' to be exempted from movement restrictions [62,71,72]; • Giving access to global trade flows at all times, if possible [73]; • Conduct regular consultation between the aquatic actors and concerned authorities [12].	• In extreme cases, people will switch professions [64].
Fish farmer: aquaculture	• Fish overwintering [15]; • Delaying the fish stocking time [15]; • Feeding overcrowded fish with low-priced food [15]; • Using digital communication for sales and monetary transactions [15]; • Providing financial assistance to the fish producers [15] and harvesters [41].	• Developing fish farmers association/co-operative [57]; • Seeking support from concerned authorities to develop fish processing plants to add value to the fish product, reduce problems associated with product perishability and fluctuating supply and demand, and create local employment [57].
Consumers	• Reducing consumer demand for fish [59,61] • Decreasing grocery shopping frequency [59]; • Reducing consumption of high price commodities [59]; • Reducing junk food consumption [59]; • Cleaning fish and meat with hot water/vinegar [59]; • Increasing consumption of protein- and vitamin-C-rich food items [59]; • Increasing demand for canned, frozen, and processed fish [4,50]; • Increasing demand and price rise for locally sourced fish products [23]; • Adoption of subsistence agricultural farming [15]; • Preserving food for future use [15]; • Providing supplemental food assistance programs to low-income people [15]; • Developing national safety net coverage for low-income people [15].	• Preferring online grocery delivery sector [66]; • Prioritizing "local" food supply chains over others [66]; • Shifting to mobile-based banking transactions [67].

4.6. Impact #6: Livelihoods

The aquaculture and fisheries sectors are an essential source of food nutrition and employment generation for millions worldwide. After the COVID-19 outbreak, the health status of these dependent communities was severely imperiled. For example, the informal sector in India was hit hard by the lockdown restrictions that blocked many aquatic fish actors from engaging in production and other value-addition activities [54]. Hence, they

received less household income, which increased their susceptibility to food insecurity [6]. Moreover, these vulnerable people often worked in crowded areas, preventing them from following social distancing guidelines and making them vulnerable to COVID-19 transmission. In contrast, these people could not stay indoors as they needed money for daily subsistence [24].

The reduction in fishing and fish farming activities also affected women's income and livelihoods as they have been traditionally and predominantly involved in this post-fish harvesting sector since times immemorial. Approximately 8.33 million women were engaged worldwide in fish sector, as reported in 2018 [4]. Therefore, imposing pandemic-related preventive restrictions on mobility affected this segment of women and further prevented them from processing and, thereafter, selling their fish. Additionally, they may have faced an increased risk of food loss and waste if appropriate storage and cold chain systems were located far away from their premises during the lockdown period [4]. In some instances, some rotational guidelines in accessing the port to ensure physical distancing also constrained this segment of women from accessing the resources/raw materials needed to process their fish [55]. To curb the effect of such unforeseen events, an all-inclusive and organized plan is essential, especially for the vulnerable population, with a view to the fulfillment of Sustainable Development Goal (SDG).

Islam et al. (2021) reported that, for Bangladesh, the COVID-19 pandemic severely disrupted fishers' livelihoods due to the reduction of fish market price and cancellation of foreign fish orders [42]. Transportation costs, which increased by 20–60% during the lockdown, worsened this issue further, resulting in increased input and maintenance costs [42]. Although the number of fish stocks increased due to reduced disturbance in fishing grounds, the pandemic could not bring societal benefits as all fisheries sub-sectors were affected differently [42]. FAO (2020) and Ben et al. (2021) almost said the same for Bangladeshi fishers, as noted above [4,13]. In another study, Sunny et al. (2021) indicated that this pandemic affected the Bangladeshi fishers' livelihoods in multiple ways, with sudden illness, reduced income, complications for starting production and input collection, labor crises, transportation abstraction, complexity in the food supply, a weak value chain, low consumer demand, rising commodity prices, and creditor pressure being the primary drivers [39].

However, fish farmers in Bangladesh adopted several short-term strategies, such as overwintering, delayed fish stocking time, and feeding the overcrowded fish using low-priced food [15,44]. Sometimes, the above-noted procedures were futile when the pandemic hit harder, resulting in severe financial and employment insecurity [16]. Hence, some were forced to seek a supplemental job for additional income. In certain instances, low-income people changed their family's daily food consumption charts by reducing consumption of fruit and animal-sourced meat items [16,44,59]. Though the adoption of subsistence agricultural farming in their backyard can provide particular food security to landholders, it is not enough for the poorest, who do not own any land and still need to rely on the local markets for purchasing their foods [16]. Preservation of food, when surplus vegetables are available, could be one way for the poor to support their nutritional security [16]. However, preserved food would also become scarcer if food production continues to stall [16].

4.7. Impact #7: External Factors and Post-Pandemic Scenarios

The pre-COVID-19-pandemic data showed that certain global people were already facing chronic food-insecure conditions due to pre-existing reasons such as lack of food availability, access, and utilization. The United Nations also stated that approximately 55% of the global population, mainly in developing countries, would lose access to social protection due to this pandemic [74]. This vulnerability further aggravates socio-economic losses, which could spill into the human rights and educational sectors and affect the marginalized poor owing to their losing access to food and nutrition [74]. In some cases, this food insecurity impact may force vulnerable people to sell their assets such as fish, farming equipment, and boats in exchange for money to feed their families. A study

indicated that these fish farmers might consume most of their produced fish instead of selling them to the market [24]. Such situations are quite challenging for low-income families who reside mainly in rural areas [24]. In extreme cases, some victims may abandon their homes and businesses and even be subjected to trafficking, searching for subsistence and livelihoods elsewhere [64]. One potential solution is to transform the current pandemic crisis into an opportunity for global structural change. Another possible solution is to urge the world's electronic and print media to move forward and vividly highlight the above-noted distress to the concerned authority before this pandemic becomes out of control [75].

5. Coping Strategies Adopted in the Long Run by Significant Fish-Producing Countries

Immediate interventions are mandatory for mitigating the COVID-19-related impact on these significant aquacultures and fish-producing countries. Such interventions can curb the fallout from the pandemic if COVID-19-like diseases persist or re-occur in the future. These include:

5.1. Supply Side

1. The aquatic food value chain actors, including producers and migrant workers, are being declared essential workers, exempting them from the movement restrictions rules. This rule should also apply to the logistics, including storage and transportation, the physical marketplace, and the 'lateral' value chain delivering inputs by designating them as essential items;
2. Allowing global trade flows to be as accessible as possible to ensure food security, food safety, and nutrition worldwide by avoiding border closures and restrictions on imports or exports. Additionally, making sure that disseminating information on food-related trade measures is fundamental;
3. Ensuring that the usual consultation process between the concerned authority and fisheries professionals exists so that any emerging aquatic-food-chain-related problems are identified and solved quickly;
4. Provision of financial aid or one-time loan forgiveness schemes by the concerned authority to these specialist fishers and aquaculture farmers to improve their health education, access to professional health facilities, and financial services;
5. Promoting digital communications through non-government/government platforms is highly recommended to increase business activity, which can be performed in any COVID-19 and non-COVID-19 scenario;
6. Providing national safety net coverage to these low-income people is advised to buffer food- and economic-related shocks in the short term and to help build resilience in the long term.

5.2. Demand Side

1. The concerned authority should establish a monitoring board that monitors market price, food safety, and quality for the sake of our consumers;
2. Concerned authorities should ensure that consumers can access the fish market price and availability whenever they need;
3. The concerned authority should start supplemental food-assistance programs by providing vouchers or food to the poverty-stricken people whose income level falls below the poverty line. Canned and dried fish products can be added to that program, containing ample protein and matching social culture and values;
4. The concerned authority should provide cash transfers to the vulnerable people, including laborers and pro-poor, to meet their basic livelihood needs.

6. Conclusions

The aquaculture and fisheries sectors have faced multiple crises, including overfishing, by-catching, shortage of raw inputs, price volatility, disease, soy-been price hikes, climate

change, and growth variability. The sudden appearance of COVID-19 exacerbated this situation further. Such a pandemic is analogous to a natural calamity, which is likely to threaten countries' food security and raises questions about whether the SDGs can be achieved by 2030. However, the majority of developing countries' governments were successful in handling this pandemic quite efficiently. Still, specific, swift actions are required to improve developing countries' capacity by implementing new risk management programs and insulating the people's livelihood by providing them with financial/food assistance.

The proposed strategies noted above would help to rejuvenate the aquaculture and fisheries sectors by contributing to the economies and transforming people into self-reliant people if adopted. In addition, such efforts would likely fulfill the SDG goals by 2030. That is why the FAO (Food and Agriculture Organization), WTO (World Trade Organization), and WHO (World Health Organization) authorities urge for global trade flows to be made as accessible as possible to ensure food security, food safety, and nutrition worldwide.

In developing countries, financial assistance or one-time loan forgiveness schemes are highly recommended for the aquatic value chain actors as they solely bore the financial risk during this pandemic. Otherwise, their outstanding credit balance will eliminate them from the current fish business and force them to switch their job from fish farming to other entrepreneurship. In certain instances, patronizing, index-based insurance to protect the aquatic food value chain actors is strongly suggested, where payouts are calculated based on an index related to agricultural losses. Moreover, providing national safety net coverage is advised for low-income people to buffer food- and economic-related shocks in the short term and to help build resilience in the long term. In addition, promoting digital communications through non-government/government platforms is highly recommended to increase business activity, which can be performed in COVID-19 and non-COVID-19 scenarios.

As the world becomes more interlinked, like a global village, all countries will likely be vulnerable to this health disaster. Failure to prevent the pandemic in one country means that other parts of the world are likely to be exposed. Therefore, future research on the world's food security, livelihoods, and market development is strongly suggested after consulting all the concerned players to obtain a concrete idea of how to combat a future pandemic if any new pathogenic strain of the COVID-19, such as the Delta, Omicron and BA.5 variants, re-appears.

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