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Impact of COVID-19 Pandemic on Fisheries Sector and Actions Taken to Cope with the Situation: A Case Study from a Top Fish-Producing Country

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Abstract: Bangladesh, one of the top fish producers in the world, has rapidly been expanding its annual fish production. However, the COVID-19 pandemic and related preventative measures have had a substantial impact on the nation's fishing sector. In this study, a survey was performed in the Brahmanbaria subdistrict of Bangladesh to assess the impact of COVID-19 and the subsequent efforts made by the Department of Fisheries (DoF), Bangladesh, to mitigate the negative impact on the culture and capture fisheries. The socioeconomic profile of fishery stakeholders for the years 2019, 2020, and 2021 was used to assess the impact of the COVID-19 pandemic situation on fish farming, fish hatcheries, fish nurseries, the fish feed industry, and the dry fish industry. Data analysis showed that the COVID-19 pandemic had a negative impact on the income of fishery stakeholders and their livelihoods. The income of fish farmers decreased by 47.49% in 2020 as compared to the base year of 2019 but increased by 129.34% in 2021, showing the effects of COVID-19 and mitigation efforts. Transport and movement restrictions adversely affected the culture fisheries while favouring capture fisheries with an increased annual catch. To counter or reduce most of those issues, the DoF, Bangladesh, took necessary steps, such as constructing a virtual control room and engaging the fishermen in some unique activities. Fishermen and other stakeholders benefitted because of farm visits, online training, improved interdepartmental coordination, monitoring of fish-selling marketing channels, activation of the FIAC (Farmer's Information and Advice Centre), and women's engagement through the provision of subsidies and loans. The DoF constructed fish sanctuaries and implemented law enforcement in 2020 and 2021 to safeguard the habitat for small indigenous species (SIS). These actions might have improved the stakeholders' income and the post-pandemic scenario by increasing fish productivity. However, further study is recommended on the effective mitigation measures for drawing a clear conclusion.

Keywords: COVID-19; impacts; fishermen; fish farmer; biodiversity; fish production

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1. Introduction

The virus, known as COVID-19, has rapidly spread around the world and affected almost every socioeconomic group. Before COVID-19, people survived deadly pandemics

such as the Spanish flu, Ebola, and the mediaeval plague [1]. However, the highly transmissible mutation qualities of the virus, plus the contemporary globalization state, have made this pandemic unmanageable. It has dramatically altered the spatial distribution of the world's population. Most nations responded to the pandemic by implementing travel restrictions, restricted borders, social segregation measures, and full- or partial lockdowns [2]. As a result, every part of life may be affected by the pandemic. According to a World Bank assessment, the pandemic would cause the world to enter the worst recession since World War II, with a more than 5% decline in the global economy [3]. Emerging nations will definitely run across new issues as they attempt to rebuild their economy. Experts estimate that up to 150 million individuals in emerging nations may experience extreme poverty [4]. Continuous and long-term lockdowns in several regions led numerous industries to close, significantly increasing unemployment and impacting global food security. For the poor and low-income earners, the consequences could be disastrous. The World Food Programme's Executive Director, David Beasley, has warned that the world could face repeated biblical-scale famines [5].

It should not come as a surprise that Bangladesh is one of the top fifty nations with the highest rate of disease prevalence [6]. The country has the densest population, with 39.6 million people living below the national poverty line [3], which is expected to rise after the pandemic. Since the first COVID-19 case was confirmed on 8 March 2020, the country has been subjected to repeated lockdowns and harsh limitations on people's movement due to increased COVID-19 instances. On 26 March 2020, the government imposed the first nationwide lockdown, with transit restrictions lifted on 1 June 2020 [7]. People were forced to leave Dhaka, the capital of Bangladesh, since there was very little employment for middle-income and wage earners at the time. After the first lockdown, nearly 11 million people fled the city [8]. Later, the Government of Bangladesh implemented various tactics to combat the second wave of the epidemic, which involved restricting people's movement, halting offices and companies and imposing travel bans, among other things. These restrictions hindered Bangladesh's economic sectors, including agriculture and fisheries.

The fisheries sector, which contributes 3.50% of Bangladesh's GDP and directly or indirectly employs more than 18 million people, is one of the country's fastest-growing economic sectors [9]. In 2018, Bangladesh was also placed third for inland fish production and fifth for aquaculture production [10]. Despite the sector's promotion, its long-term viability is in question because of both natural and man-made causes, such as pollution, overuse, harmful fishing, and habitat degradation [9]. As a result, any negative influence on this sector could spell disaster for the food production system and millions of people's earnings. Lockdown and transit halt caused by the sudden outbreak of COVID-19 has created a significant shock to the fisheries sector, from the fish farm to the country's fish market. Aquaculture productivity was projected to suffer because of the scarcity of seeds and feed. Small-scale fishermen became more susceptible due to increases in gasoline prices, as they could not conduct fishing operations [10]. Furthermore, border closures and travel restrictions have impacted the shrimp and fish industries [11]. Despite the adverse effects, COVID-19 has had favourable impacts on open-water fisheries resources due to fewer human disturbances, particularly on fish habitats and stocks [12]. As a result, it is critical to examine the pandemic's impact on various fisheries subsectors and stakeholders.

The Government of Bangladesh has put forth much effort through several departments to combat the effects of the COVID-19 pandemic. The Department of Fisheries (DoF) has also undertaken significant efforts to mitigate the pandemic's effects on the fisheries sector. Each aspect of strategy and management can be compiled as a prenote for future policymaking. In this case, it is also vital to summarise the DoF's actions and assess their long-term consequences. The authors chose the Brahmanbaria Sadar Upazila of Brahmanbaria district to study the effects of COVID-19 on the fisheries sector and DoF's action because this area is rich in both advanced aquaculture and inland capture fisheries [13,14]. Brahmanbaria Sadar is a model Upazila for both capture and culture fisheries. Aquaculture flourished in this area with advancements in earthen ponds and cemented tanks such as

biofloc [13]. Bangladesh's one of the best fish-producing inland waterbody, the Titas River, yielded 1955 metric tons of fish during 2018–2019, greatly helping to fulfil Brahmanbaria's protein requirements [14]. Additionally, the region is known for its profitable dry fish production and distribution. Both government and private fish hatcheries are present in the area. Due to its proximity to the Indian border, this study area has great potential for supplying fisheries products to India. Bangladesh's fisheries industry primarily relies on freshwater, and both culture and capture fisheries have significant contributions. Therefore, the chosen study area can serve as a representative of the entire country. However, the purpose of this study is to (i) examine the impact of the COVID-19 pandemic on various fisheries subsectors and stakeholders, (ii) outline the strategy and steps implemented by the Department of Fisheries to address the consequences, and (iii) explore the COVID-19 effects on the Titas River's fish abundance and diversity.

2. Materials and Methods

2.1. Study Area

The research was carried out among the eleven unions and one municipality of Brahmanbaria Sadar Upazila using primary and secondary data sources (Figure 1). Brahmanbaria Sadar Upazila is one of Bangladesh's most resourceful Upazilas with both capture and culture fisheries. Furthermore, transportation infrastructure, both in river systems and on roadways, water and soil quality, the abundance of fish fry and fingerlings, and the availability of low-cost labour make this area important for fisheries. However, during the COVID-19 outbreak's peak, most unions in Sadar Upazila were locked down for several days.

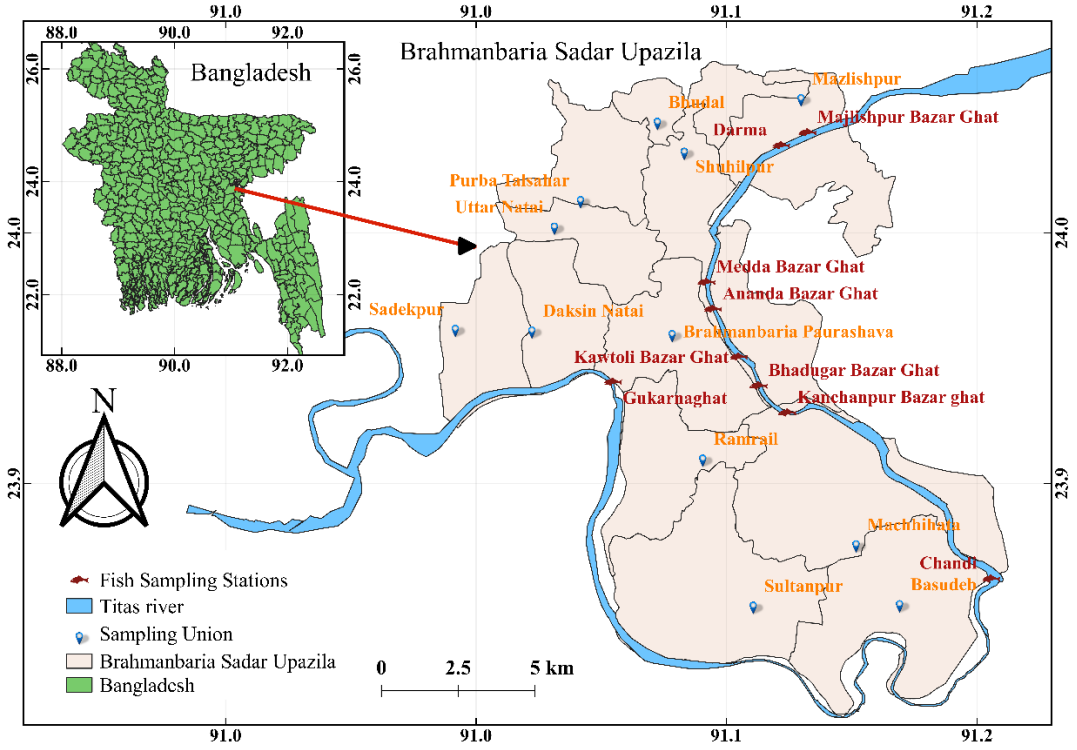


Figure 1. The study area showing Brahmanbaria Sadar Upazila includes the Titas River.

2.2. Data Collection Procedure

This study illustrated the sampling design tree with the data collection procedure in Figure 2. We conducted individual interviews and collected primary data through questionnaires that were sent to 20 Local Extension Agents for Fisheries (LEAF) under the National Agricultural Technology Program Phase-II Project (NATP-2) and Expansion of Aquaculture Technology Services up to Union Level Project (Phase-2). The questionnaires were used to gather information about the socioeconomic profiles of fishery stakeholders

to evaluate the impact of the COVID-19 pandemic on fish farming, fish hatcheries, fish nurseries, the fish feed industry, and the dry fish industry. In total, 260 respondents from different fisheries agencies participated in the study. We also conducted face-to-face interviews with government officials to assess the actions taken by the government to address the situation.

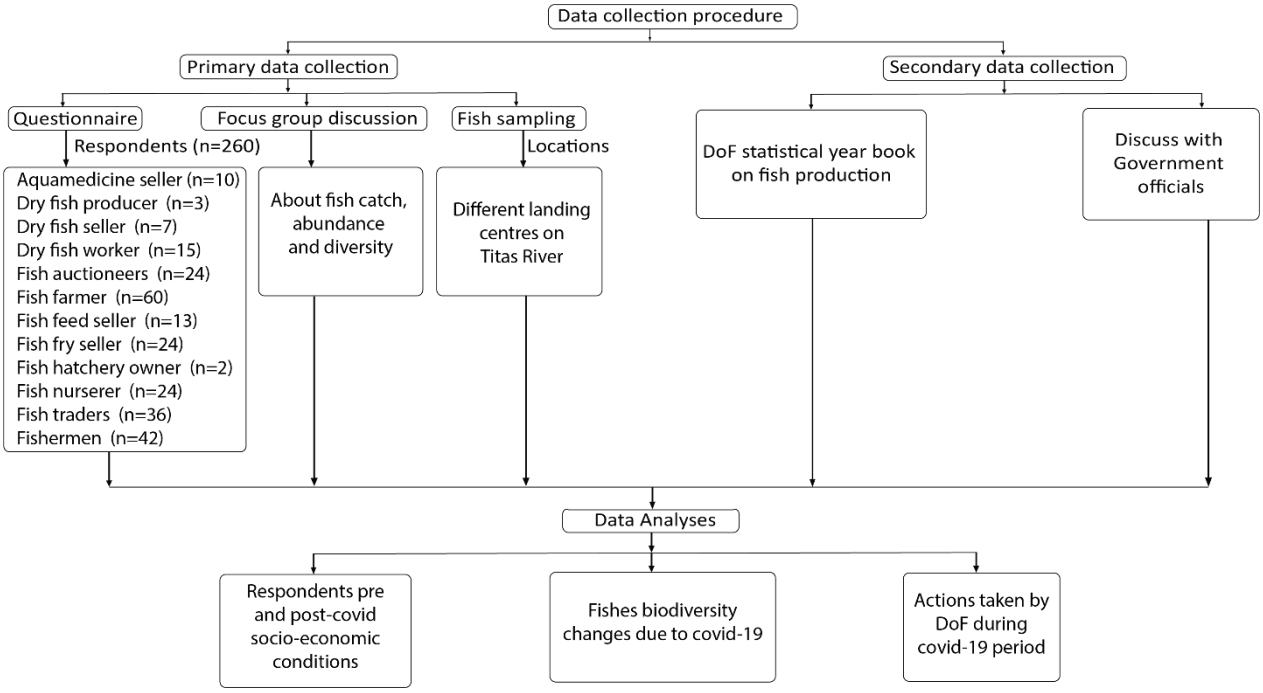


Figure 2. Sampling design tree with data collection procedure.

Additionally, we conducted Focus Group Discussions (FGD) during the peak fishing season in the Titas River. We gathered data on fisheries diversity from various locations, including fishing areas, fishing boats, and fish landing centres, and questionnaire discussions with fishermen in the fishing community. We also used visual assessments, pictures of various fish, and fish samples to collect data on fish species. We selected nine locations with higher capture rates and collected data for five days each year during similar months. Fish samples that were difficult to identify at the fishing place were stored in a 7–10% buffered formalin solution and brought to the office of the Senior Upazila Fisheries Officer's laboratory in Brahmanbaria Sadar, Bangladesh, for identification and further study. We also conducted ten key informant interviews with government officials and local entrepreneurs to gather and verify relevant information. All responses to the survey questionnaires and key informant interviews were provided voluntarily. The Department of Fisheries in Brahmanbaria examined the research involving participants in this questionnaire and granted permission to conduct this study. We also obtained secondary data on fisheries and aquaculture production from the Department of Fisheries (DoF) published reports. The mean values of each species collected from the respondents for each year were used to analyse the diversity indices. Secondary data were gathered from scientific journals, technical reports, and press reports for Supplementary Items.

2.3. Fish Diversity Analysis

Relative abundance (RA = percentage of catch) of fish across the Titas River was calculated for three years. RA of individual species was computed by multiplying the product of the number of samples of that species by 100 and then multiplying it by the total number of samples. For three years, fish species diversity was subjected to diversity analysis using several indices such as species richness, evenness, and the Shannon–Wiener index. The results examined the impact of COVID-19 and fisheries management on fish diversity.

2.4. Shannon–Wiener Index

Shannon–Wiener index is a widely used method for calculating biodiversity in aquatic and terrestrial ecosystems. It is also an insensitive measure of the S:N (total number of individuals of one species divided by the total number of individuals of all species), dominated by abundant species. This study used the Shannon–Wiener diversity index (1949) to estimate the diversity as follows [15]:

$$H' = -\sum[(Pi) \times ln(Pi)] \quad (1)$$

where Pi = S/N, S = number of individuals of one species, and N = total number of all individuals in the sample. The diversity index criteria are as follows: $H' \leq 1$ = low diversity, $1 < H' \leq 3$ = moderate diversity, $H' \geq 3$ = high diversity.

2.5. Pielou's Evenness (J)

Relative abundance of different species that make up an area's richness is quantified by Pielou's Evenness (J), which is calculated using the formula [16]:

$$J = H'/ln(S) \quad (2)$$

Evenness index value ranges between 0 and 1. Furthermore, evenness index based on Kreb, 2006 [17] is categorized as follows: $0 < J \leq 0.5$ = depressed community, $0.5 < J \leq 0.75$ = unstable community, and $0.75 < J \leq 1$ = stable community.

2.6. Simpson's Dominance Index (D)

Simpson's dominance index (D) is a commonly used metric for quantifying habitat biodiversity, which takes into account the number of species as well as the abundance of each species [18]:

$$D = 1 - \sum ni(ni-1)/N(N-1) \quad (3)$$

where ni is the total number of individuals of a particular species, and N is the total number of individuals of all species. The value can range from 0 to 1 and can be grouped into the following categories: $0 < D < 0.5$ = low dominance, $0.5 < D \leq 0.75$ = moderate dominance, and $0.75 < D \leq 1.0$ = high dominance [19].

2.7. Margalef's Index (d)

The following formula was used to calculate Margalef's index (d) [20] to determine species richness:

$$d = (S - 1/ln\ N) \quad (4)$$

where S is the number of species and N is the number of individuals in the sample.

2.8. Data Analysis

Questionnaire survey results were exported and analysed in Microsoft Excel and IBM SPSS 24 (IBM Corp). The graphical representation of the data was provided through graphs and tables. Data exploration and graphical presentations were carried out using the R-program (version-4.2.1) packages tidyverse and ggplot-2, respectively. After reviewing all the data, home telephonic interviews were used to verify each type of responder.

3. Results and Discussions

3.1. Pre COVID Situation in Bangladesh

Bangladesh is considered a rising star with the fastest GDP growth rate for the last couple of years before the COVID-19 period. Agricultural production and fisheries, both of which are important contributors to the country's economy, are experiencing an upward trend in growth. A report from FAO about the agri-food system stated escalating performance despite challenges of climate change and poor logistical infrastructure [21]. Some of the achievements of the country in the agri-food system for the last couple of years

could be summarised as being fourth in the world in rice production [22], being one of the top producers in closed-water aquaculture and all other agricultural subsectors, such as vegetables, livestock, and poultry, were making significant improvements [23]. The country did well in this sector to achieve its SDG target by 2030. Before COVID-19, the country's supply and demand of aquatic food systems was a decent way to achieve SDG targets of food security and animal protein supply [24].

3.2. Demographic Information

The demographic characteristics of different stakeholders during the COVID-19 pandemic are shown in Table 1. Most respondents in the current study were male, except for dry fish workers and producers (20%). Most of them were adults, except for a small percentage of fish nurturers (4.17%) and fish sellers (retailers) (11.11%), who are primarily between the ages of 31 and 40. A significant proportion of respondents in the fish production and processing industries are illiterate, while most graduate respondents run fish hatcheries. Most respondents from producers and sellers of dry fish and retail fish sellers still have a combined family, whereas most respondents from other respondent groups are from nuclear families. The male-to-female ratio of respondents' family members is not considerably different, but most respondents' groups have a greater number of female family members. Only one-third of the family members are employed; hence, most are in dependent groups. Except for respondents who sell fish, dry fish or fish feed, most respondents who worked in fish production and processing had received training from the DoF. Furthermore, during the pandemic, most responder groups sought or willingly received technical assistance from the DoF for any emergency in their specialised field. Marginal numbers of respondents in each group were affected by COVID-19. On the contrary, family members of fish hatchery operators and dry fish producers were not infected with COVID-19. Even though all fish hatchery owners, dried fish manufacturers, and fish feed vendors were vaccinated, 10 to 33.33% of the other groups did not receive the vaccine.

3.3. Impact on Fish Hatcheries and Nurseries

Fish hatcheries and nurseries were affected by the COVID-19 epidemic due to decreased demand and pricing for fish fry, labour shortages, higher transportation costs, the absence of aquaculture inputs, and unanticipated health-related expenses (Figure 3). According to hatchery owners, due to unsold fish still in the farmers' culture ponds since the previous season, the demand for fish fry and fingerlings dropped dramatically. Most poll respondents believe that COVID-19 affects fish hatcheries. Transportation of fish fry and fingerlings around the country, like other sectors, has been severely hampered by the pandemic. Hatchers faced a crisis due to a lack of permanent personnel, forcing them to hire temporary labour daily and weekly. Labour expenditures have risen since hatcheries have been known to pay entire days' wages for two to three hours of work. Due to a shortage of skilled labour, hatchery and nursery owners often prefer unskilled workers, resulting in the production of poor-quality fish fry and fingerlings. Some hatcheries had to pay for their stuff even though the hatching activities were not running. Hatcheries were selling their product at low prices, and most were uncertain whether they would be able to meet their production costs. An informant stated that the lack of aquaculture inputs such as fertilizer, lime, aqua chemicals, and feed had hampered brood fish growth. COVID-19 has had a detrimental impact on brood fish collecting or sharing, availability of competent technicians, and demand for local carp fish fry and fingerlings, according to 100% of hatchery operators. On the other hand, fish fry farmers had significantly suffered due to a lack of timely delivery of fish fry from the hatchery. However, to make the sector more motile, the DoF has taken some innovative actions such as online marketing, proper coordination, and enlisting and tracking the sales of fish fry. Those actions made an animated market of fry in late June, where it was very stagnant in March. The average number of days hatcheries functioned each month grew from 9 in February to 27 in March, then stayed steady between 23 and 29 days until July [25].

Table 1. Demographic characteristics of different respondent fishery stakeholders during the COVID-19 pandemic (n indicates sample sizes).

Respondent Attributes	Attribute Types	Contribution (Percentage)											
		Fish Hatchery Owner (*n* = 2)	Fish Nurturer (*n* = 24)	Fish Fry Seller (*n* = 24)	Fish Farmer (*n* = 60)	Fish Seller (Retailers) (*n* = 36)	Fish Seller (Whole Seller) (*n* = 24)	Dry Fish Processing Worker (*n* = 15)	Dry Fish Producers (*n* = 3)	Dry Fish Seller (*n* = 7)	Fishermen (*n* = 42)	Fish Feed Seller (*n* = 13)	Aquamedecine Seller (*n* = 10)
Sex	Male	100	83.33	83.33	68.33	94.44	100	20	20	100	100	100	100.00
	Female	0	16.67	16.67	31.67	5.56	0	80	0	0	0	0.00	0.00
Age of respondents	<18		4.17	0.00	0	11.11	0		0	0	4.76	0.00	0.00
	18–30		16.67	12.50	18.33	13.89	8.33	0	20	0	33.33	0.00	10.00
	31–40		29.17	33.33	31.67	30.56	20.83	33.33	30	28.57	38.10	15.38	10
	41–50		20.83	29.17	26.67	25	25	66.67	40	57.14	16.67	53.85	50
	51–59	100	16.67	16.67	16.67	13.89	20.83	0	10	14.29	7.76	23.08	20
	>60		12.5	8.33	6.67	5.56	25	0	0	0	2.38	7.69	10
Educational status	Illiterate		37.5	29.17	25	61.11	12.5	80	60	71.43	80.95	0.00	10
	Primary		29.14	33.33	28.33	22.22	45.83	20	30	28.57	19.05	7.70	40
	Secondary		16.67	20.83	21.67	11.11	25	0	10	0	0.00	30.77	30
	Higher Secondary	50	12.5	16.67	16.67	5.56	12.5	0	0	0	0.00	38.46	10
	Graduate	50	4.17	0.00	8.33	0	4.17	0	0	0	0.00	23.08	10
Family types	Joint	50	37.5	41.67	46.67	55.56	33.33	66.67	60	71.43	61.90	46.15	40
	Nuclear	50	62.5	58.33	53.33	44.44	66.67	33.33	40	28.57	38.10	53.85	60
Family member's sex	Male	33.33	44.79	41.41	45.83	47.78	52.38	52.22	35	47.62	52.38	47.62	46
	Female	66.67	58.33	58.59	54.17	52.22	47.62	47.78	65	52.38	47.62	52.38	54
Family member's employment status	Employed	22	35.42	38.38	41.25	36.11	46.67	23.33	31.67	33.33	29.76	42.3	28
	Unemployed	78	64.58	61.62	58.75	63.89	53.33	76.67	68.33	66.67	70.24	57.69	72
Training on respective field	Yes	100	54.17	81.67	81.67	27.78	37.5	53.33	70	25.57	90.95	15.38	10
	No	0	45.83	18.33	18.33	72.22	62.5	46.67	30	71.43	19.05	84.62	90
DoF Technical support in emergency	Yes	100	41.66	16.67	58.33	16.67	20.83	6.67	66.67	14.28	38.10	69.22	70
	No needed	0	54.17	79.16	35	83.33	79.17	93.33	33.33	71.44	78.57	30.78	30
	No	0	4.17	4.17	6.67	0	0	0	0	14.28	21.43	0.00	0
Government subsidy of financial support	Yes	0	0	0.00	3.33	2.78	8.33	0	0	0	23.81	0.00	0
	No	100	100	100	96.67	97.22	91.67	100	100	100	76.19	100	100
Affected by COVID-19	Yes	0	4.17	4.17	11.67	5.56	8.33	6.67	0	14.28	4.76	7.69	10
	No	100	95.83	95.83	88.33	94.44	91.67	93.33	100	85.72	95.23	92.31	90
Any family members affected by COVID-19	Yes	0	3.33	1.67	6.33	4.63	5	2.22	8.3	1.67	7.14	0	0
	No	100	96.67	98.33	93.67	95.37	95	97.78	91.67	98.33	92.86	100	100
Vaccination	1st dose	0	45.83	41.66	33.33	38.89	41.67	40	33.33	28.57	38.1	53.85	40
	2nd dose	100	41.67	29.17	51.67	27.78	33.33	33.33	66.67	57.14	33.33	46.15	60
	3rd dose	0	0	0	5	0	4.17	0	0	0	0	0	0
	No	0	12.5	29.17	10	33.33	20.83	26.67	0	14.28	28.57	0	0

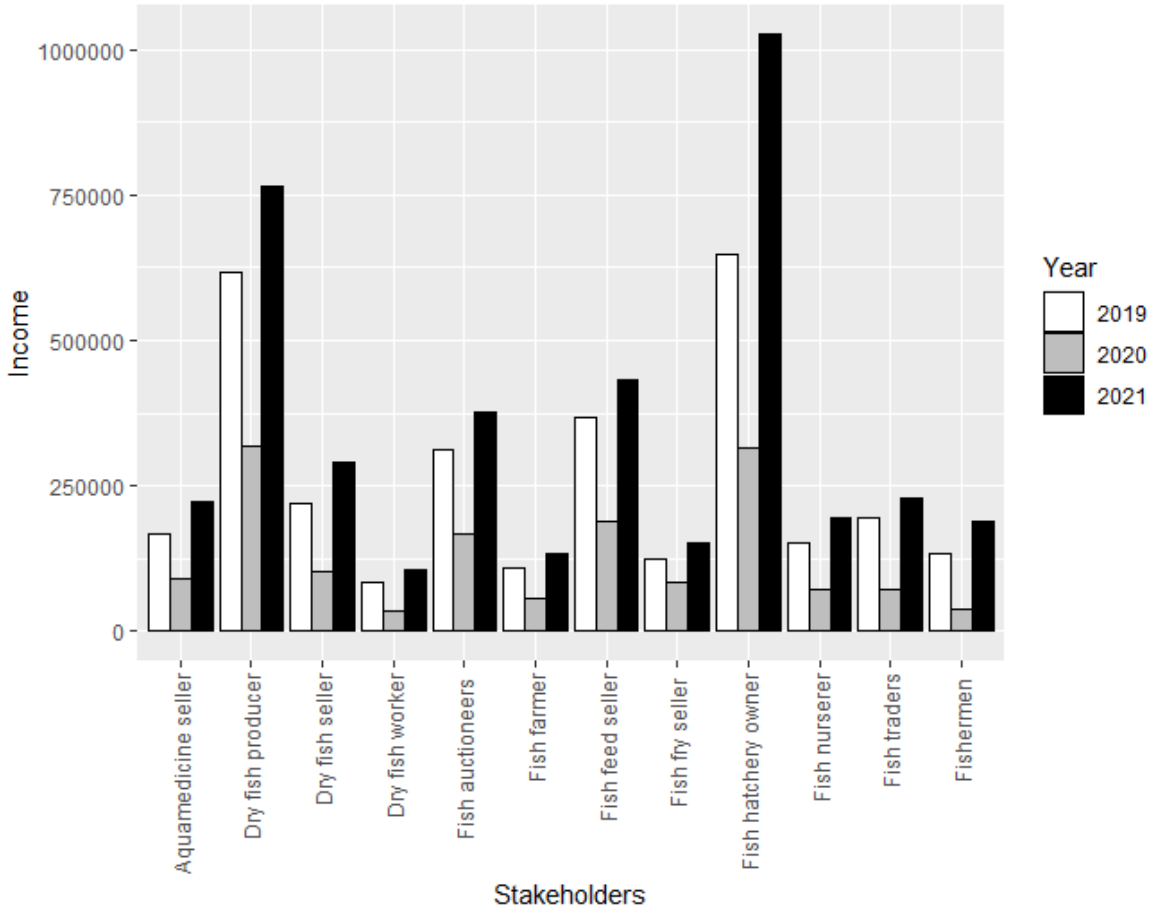


Figure 3. Comparison of fishery stakeholders' last three years' gross return from their respective fisheries sectors.

3.4. Impact on Fish Fry Seller

COVID-19 has wreaked havoc on the livelihood and earnings of mobile fish fry vendors. They could not obtain enough fish fry during the 2020 lockdown because of a breakdown in fish hatchery operations. Furthermore, fish fry could not be sold due to the closure of public transportation. The average income of mobile fish fry sellers was much lower in 2020 than in 2019 (Figure 3), but it increased by 81.30% due to the government's essential steps. The DoF had provided some permission letters for selected fish fry sellers to continue their selling service of fish fry coordinated with the lockdown authority. These steps kept the fish seed available for the culture fisheries and continued the aquaculture sector stable. In order to increase the sector's mobility and provide a reliable supply of food and protein, South Africa's Department of Fisheries relaxed the restrictions on migratory small-scale fishing after experiencing sluggish output and supply of fisheries products [26].

3.5. Impact on Fish Farming

Fish aquaculture has suffered due to the pandemic, resulting in higher production costs due to higher feed prices, transportation expenses, and lower fish selling prices. According to the current study, fish feed firms have increased feed prices by about 10%. Due to poor market demand, the price of cultured fish has plummeted, resulting in a protracted period of increased production and maintenance costs, according to fish farmers. COVID-19 harms freshwater fish aquaculture, according to 58.34% of respondents, with 13.33% strongly agreeing with the fact (Table 2). Although 15% of respondents disagreed with the new COVID-19 unfavourable impact on freshwater fish farming, 8.33% strongly disagreed. Furthermore, compared to the 2019 base year, fish farmers' income declined by 47.49%,

while it climbed by 129.34% in 2021. During face-to-face interviews, all fish farmers stated that the price of cultured fish dropped due to poor market demand. During the current pandemic, most consumers lost their jobs and experienced a cash flow crisis, resulting in a reduction in their incomes [10]. In addition to a drop in fish prices, Indonesia has also seen a decrease in the number of fishermen employed [10]. Abul Bashar et al. reported a 42.8% average profit reduction in the shrimp farming industries of Bangladesh [27]. In the present case, fish was purchased directly from small-scale fish farmers with the help of the Upazila Fisheries Office, which was particularly hit hard by the pandemic. According to local media, online and social media-based fish marketing is gradually gaining popularity; thus, consumers are receiving better fish at a reasonable price. Fish producers' incomes also increased because of online fish sales. FAO and Meharoof et al. [25,28] also proposed that fish be purchased for institutional use and that local sales be increased through online deliveries, direct and indirect marketing, and community participation.

3.6. Impact on Fishermen

COVID-19 significantly impacted the income and livelihood of marginal fishermen in the Titus River and its environs. Fishermen's revenue fell by 71.72% because of the COVID-19 pandemic but increased dramatically (399.69%) in 2021 (Figure 3). This upward tendency could be attributed to government financial and nonfinancial incentives to increase consumption, online fish marketing, and alternative sources of income (distribution of calf). According to the survey, fishermen believe that lower demand in the supply chain and lower fish prices are detrimental to their income and lives. Larger family numbers exacerbated the problem, while COVID-19 produced a complication in fish supplies and a scarcity of fishing gear on the market due to low consumer demand, rising commodity costs, and creditor pressure. The global fishing community's livelihood has been seriously affected by difficulties in storing and marketing fish [29]. About 88% of fishers reported they could not go fishing together due to the COVID-19 restriction, while 79% of fish farmers mentioned COVID-19 harmed their fish production due to a lack of inputs and service providers. In response to a question regarding whether the COVID-19 restriction adversely impacted their ability to meet their household food consumption needs, 71.1% of respondents agreed, 9.5% dissented, and 19.4% could not eat three times a day. Another study found that almost 59% of fishing labour involved in fish processing, harvesting, and marketing were unemployed due to this prolonged pandemic [24].

3.7. Impact on Open Water Capture Fisheries and Fish Habitats

According to key informants, COVID-19 benefits open-water capture fisheries since the lockdown reduces human disturbance. According to 70% of fishermen who responded to the questionnaire study (Table 2), COVID-19 has positively impacted open-water capture fisheries and fish habitats. Furthermore, this shows a significant variation in the Titas River's annual catch. Due to the COVID-19 pandemic issue and lockout, the catch in 2020 was lower than the previous year (Figure 4). As a result, open-water fish found a more favourable environment for growth and production and undisturbed nesting sites. In this case, the capture was made in 2021 rather than the prior two years. In 2019, 63 species were caught, down from 63 in 2019 to 56 in 2020, but up to 69 species in 2021. In addition, five new species were found in 2021: *Rasbora daniconius* (Hamilton, 1822), *Botia dario* (Hamilton, 1822), *Chandramara chandramara* (Hamilton, 1822), *Anguilla bengalensis* (Gray, 1831), and *Labeo boggut* (Sykes, 1839) (Table S1). Different banning protocols by the DoF in capture fisheries also impact a bold role output a significant production in 2021 in comparison to 2019 and 2020. Despite the COVID-19 epidemic having an impact on livelihoods, fish stocks benefited from a decrease in fishing efforts in Kenya [30]. Aura et al. [30] showed that imposed curfews in inland capture fisheries and COVID-19 sanitary restrictions make positive impacts on inland capture fisheries in Kenya. Moreover, less pollution and reduced pressure in fishing habitats during COVID-19 make the capture fisheries more suitable for fisheries production [31].

Table 2. Perceptions of the fishery stakeholders on the influence of COVID-19 in the Fisheries sector.

Questions	Responses (%)				
	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree
COVID-19 has negatively influenced the brood fish collection or sharing	100	0	0	0	0
COVID-19 has negatively influenced the availability of skilled technicians in the hatchery	100	0	0	0	0
COVID-19 has negatively influenced the demand for local carp fish fry and fingerlings	100	0	0	0	0
COVID-19 has negatively influenced the fish production	13.33	58.34	5	15	8.33
COVID-19 has positively influenced the open-water capture fisheries and fish habitats	70	18.33	6.67	3.33	1.67
COVID-19 has negatively influenced fish selling and income	53.33	41.67	5	0	0
COVID-19 has negatively influenced the availability of potential customers in the market	36.26	60.44	3.3	0	0
COVID-19 has negatively influenced the availability of fish processing workers	20	53.33	6.67	20	0
COVID-19 has negatively influenced the availability of indigenous fish fingerlings from far districts	63.34	28.33	5	3.33	
COVID-19 has negatively influenced the commencing production activities in due time	75.46	15.1	3.77	5.67	
COVID-19 has negatively influenced the price of fish and fisheries products	79.52	9.77	6.05	2.33	2.33
COVID-19 has negatively influenced the availability of aqua drugs and medicine	9.17	74.17	10	4.16	2.5
COVID-19 has negatively influenced the availability of fish feed	8.7	51.3	17.39	18.26	4.35
COVID-19 has negatively influenced the availability of fish and fishery products in the marketplace	50.75	47.76	1.49	0	0
COVID-19 has negatively influenced the workdays and hours of fishery activities	13.68	55.56	25.64	5.12	0
COVID-19 has negatively influenced the availability of transport for fishery products	9.3	60.47	16.28	12.09	1.86
COVID-19 has negatively influenced the quality of transported fishery products due to the lockdown	9.3	35.34	23.26	28.37	3.73
COVID-19 has negatively influenced the fishing activities	42.86	47.62	7.14	2.38	0
COVID-19 has negatively influenced the demand for aqua medicine and drug	50	40	10	0	0
COVID-19 has negatively influenced the demand for feed and feedstuffs	40	40	10	10	0
COVID-19 has negatively influenced the meal pattern and numbers	35.38	41.54	20.39	2.69	0
COVID-19 has negatively influenced the attendance of the service provider	31.92	47.69	8.85	11.54	0

3.8. Impact on Fish Sellers and Auctioneers

One of the most traded food items worldwide, fish and fish products account for 38% of international trade [10]. COVID-19 has had a terrible effect on fish traders and auctioneers in general. According to the study, 53.33% of the respondents of fish traders and auctioneers strongly agreed that the volume and income from fish sales had declined significantly (Table 2). This could be related to consumers' diminished spending power and shortened marketing hours as the pandemic continues [12]. In 2020, the income of fish traders declined by 62.12%, while the income of auctioneers decreased by 46.39%. After overcoming the adverse condition, it recovered to a profitable position in 2021 (Figure 3). The current investigation is also supported by the research findings of Mandal et al., who found Indian major carp and tilapia to be the most abundant fish species in the fish market.

However, they were less available during the COVID-19 period. They also found that small indigenous species (SIS), shrimps, and prawns abruptly decreased, which caused an increase in the price of fish in Dhaka [32]. On the other hand, fish farmers suffered economic losses due to the transport barrier reported by Habib [33]. Consultative Group for International Agricultural Research (CGIAR) has also stated that fish retail prices dropped because of customers' fears of infection during this period [34].

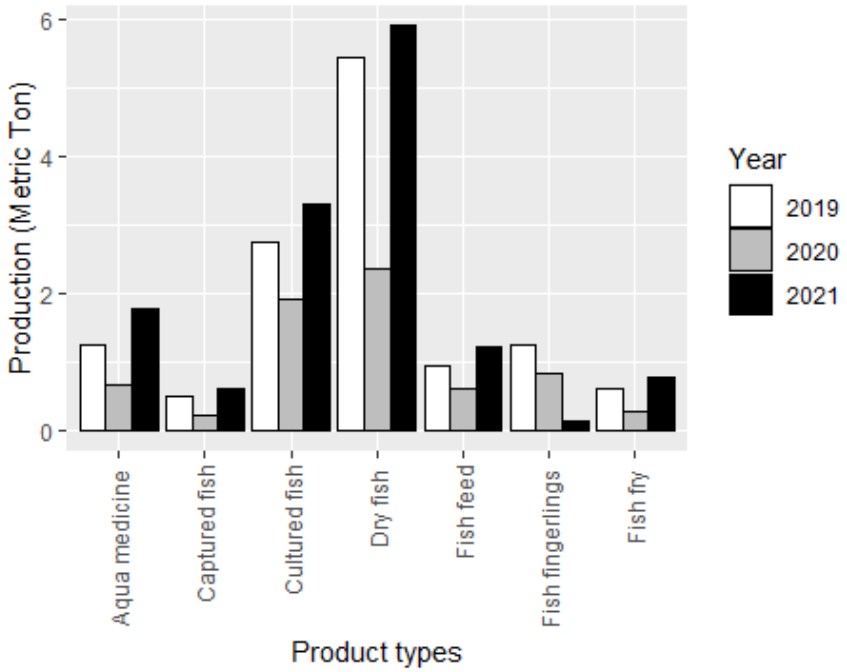


Figure 4. Mean production and supply of fish and fisheries products (values of fish feed * 10^3).

3.9. Impact on Dry Fish Producers, Dry Fish Production Workers, and Dry Fish Sellers

The fish drying business in Brahmanbaria is encountering difficulties because the open sun drying method necessitates human intervention to complete the drying process. Due to the lockdown, consumers could not go to the market and get their preferred dried fish. Because the vendors could not sell their products on time, they incurred a loss. According to the survey, dry fish processors faced increasing transportation costs, decreased workforce availability, decreased consumer demand, and a decrease in market pricing. According to the survey respondents and questionnaire results, COVID-19 had a detrimental effect on production (Table 2). Dry fish producers reported that their businesses failed in a pandemic in 2020 and did not receive any government financial assistance but rather training instead. Incomes of dry fish production workers, producers, and sellers have decreased by 57.28%, 48.27%, and 52.90%, respectively, reaching a profitable level in 2021 (Figure 3). The DoF had conducted some training for the long-term preservation and packaging of dry fish and helped in exporting the dry fish to India through nearby borders. As a result, the dry fish sector earned an excellent profit in 2021. This action shows the potentiality of dry fish export abroad.

3.10. Impact on Fish Feed Sellers

Most of the fish feed sellers agreed that the pandemic had harmed the fish feed industry due to a shortage of raw materials, labour, lower feed sales, market closures, and higher transportation expenses, forcing factories to raise feed prices. COVID-19 has had a detrimental impact on the supply of fish feed up to the farmer level, according to 51.3% of survey respondents (Figure 3). The pandemic has temporarily prompted fish feed shops to close, putting suppliers in a financial bind. Feed unit prices have grown due to the difficulty of carrying feed on the market. The feed companies requested that the transportation system be simplified and the VAT on imported materials be reduced. Feed prices could be lower if

local raw materials and ingredients are used, which would cut down on the cost of shipping. The DoF had claimed the supply and transport of fish feed as an emergency to reduce the lockdown imposed. As a result, in June and July of 2020, the pelleted feed industries started in full swim [27], and feed sellers started to flourish their business.

3.11. Comparative Fishery Diversity Analysis through Fish Catches

A comparative fishery diversity analysis with species number and catch weight (kg) expressed as a percentage for three consecutive years from 2019 to 2021 (Figure 5). In 2020, the catch weight was cut in half, but in 2021, it was raised to the third half (Figure 5 and Table S1). *Corica soborna* (Hamilton, 1822) is the leading species in terms of overall catch percentage. However, *Channa punctata* (Bloch, 1793) led in weight catch in 2019, but *Heteropneustes fossilis* (Bloch, 1794) led in the following two years. In 2020, the small indigenous species (SIS) fish species (length < 25 cm) habitats were made more secure and quiet for fish production due to the COVID-19 movement restrictions and decreased use of fixed engines (fixed fishing gears). As a result, five new SIS species were introduced in the Titas River from an adjacent water body in 2021. However, the species catch in number is not significantly different ($p > 0.05$) but significantly different ($p < 0.05$) for the weight of the fish in the three consecutive years (Tables S2 and S3). This means there has been a significant increase in catch of fish weight after the COVID-19 pandemic. In addition, the various diversity index values displayed in Figure 5 were all greater in 2021. When a population's number of species and evenness increase, the value of a diversity index rises [35]. In 2021, all of the diversity index values increased, indicating a rise in species and individuals. The Shannon–Wiener index (H) for ecological data runs from 1.5 to 3.5 and seldom surpasses 4.0 [35], primarily connected to our computed data. Fish variety in the Titas River was categorised as 'Moderate'. However, Pielou's evenness score and results found by Iqbal et al. [36] were lower, and the species were converted from a depressed to an unstable community in 2021. Margalef's richness index revealed similar patterns to Pielou's evenness score of the fish diversity of the Titas River. However, a study from Stokes et al. [37] revealed a different situation caused by the pandemic in fisheries. They found an increase in fishing pressure in Southeast Asia and Eastern Africa as the environmental parameters (for example, abiotic factors which control the fisheries ecology) faced less pressure. They also rationalise that the impact is due to the high increase in unemployment in this region. The fish population became more varied, and production increased significantly because of the undisturbed habitat and lower catch intake. As a result, quota-based catches and very strict spawning seasonal bans can help develop fishery population variety and production in the Titas River.

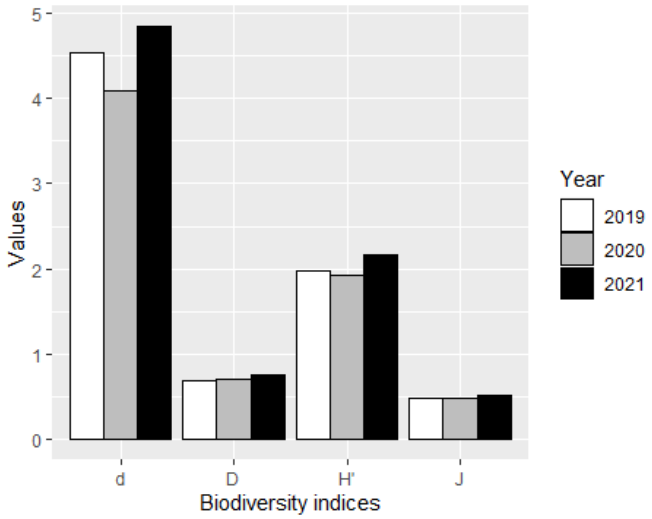
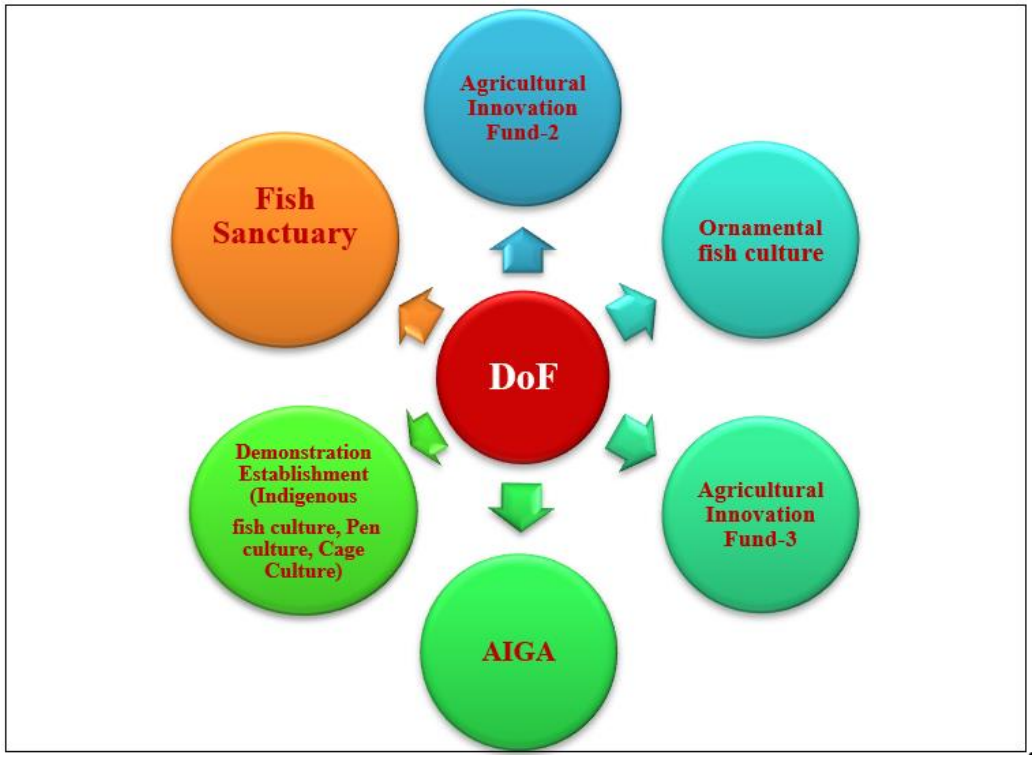


Figure 5. Comparison of yearly fish diversity of the Titas River through diversity indexes [Margalef's index (d), Simpson's dominance index (D), Shannon–Wiener index (H'), and Pielou's Evenness (J)].

Role of the Upazila Fisheries Office in Combating COVID-19 Impact on Fisheries Sector.

In response to the COVID-19 outbreak, the Brahmanbaria Sadar Upazila Fisheries Office conducted various activities in order to mitigate adverse conditions in the fish production and supply chains (Figure 6).



(**a**)

(**b**)

Figure 6. (**a**) Developmental work (**b**) Emergency and Technical support measures for combating and minimizing the negative effects of COVID-19 in fisheries sectors.

Visiting the fish farm: Almost all vehicles and people were restricted from going outside during the lockdown, except for essential supplies and authorised people. Because agriculture, livestock, and fisheries sectors are all involved in production economics, they

are emergency supplies. Senior Upazila Fisheries Officer and his team visit various fish farms regularly, offering advice on keeping production going, maintaining social distancing, using masks, washing hands with sanitiser and avoiding COVID-19.

Conducted online training and service: During the lockdown, the Upazila Fisheries Office provided free online training using the Zoom app and other social networking sites. LEAFs also gave fish farmers online training. The control room, operated by an Extension Officer (EO) and two Field Assistants (FAs), and LEAFs provide services via video call and cell phone in an emergency. LEAFs also held a campaign in their FIAC centre and used a microphone to broadcast fishery warnings to their local unions every month.

Interdepartmental coordination: The control room was established to facilitate interdepartmental coordination and transportation of fishing sector beneficiaries and necessary goods. Except for the manufacturing sector during the severe shutdown, all transportation services were shut down during COVID-19. Uninterrupted transportation and logistical assistance were ensured for an efficient supply chain of fish to markets. Law enforcement agencies would not allow any vehicle to move without sufficient evidence of manufacturing economic transportation. To avoid issues transporting fish feed, fish fry, fingerlings, or table-sized fish, the Upazila Fisheries Office granted NOCs. It also maintained frequent touch with the local administration to keep fish feed and coloured fish shops operational. However, beginning in May 2020, the government would allow the shipment of fishing goods. From June 2020, general travel restrictions would be lifted on the condition that health requirements be followed, such as wearing a mask and cleaning hands regularly.

Maintained fish marketing channel: During COVID-19, fish producers had difficulty selling their catch because all markets were closed. The Upazila Fisheries Office has established a growth centre and a mobile fish market to address the issues outlined above, in which fish farmers sold their fish in violation of cleanliness regulations. The Upazila Fisheries Office also established several fish producer organizations (POs) and connected them to the growth centre to get the fish produced to consumers. Following the epidemic, those POs are still operational and earning money.

Agricultural Innovation Fund (AIF): CIG (Common Interest Group) members were given pick-up vans from the AIF-2 budget to help them transport and sell fish more effectively. In addition, under the AIF-3 fund, an ice plant was established where unsold fish supplied by fish farmers could be frozen. The AIF-3 fund was also used to establish an ornamental fish hatchery.

Alternative Income Generating Activities (AIGA): The COVID-19 pandemic severely impacted the fishermen's livelihoods. More than 500 registered fishermen received training on alternative income-generating activities for themselves and their families. They are taught how to make handicrafts, better fish culture, agriculture, cattle farming, dressmaking with a sewing machine, and embroidered quilts. Trained fishermen were given calves as an alternative source of income to help them improve their financial situation. Some of the calves were turned into cows, giving birth and providing an alternate income source for the fishermen's families.

Demonstration establishment: Demonstration farms of native fish species such as pabda (*Ompok pabda*), gulsha (*Mystus cavasius*), striped snakehead (*Channa striatus*), and stinging catfish shing (*Heteropneustes fossilis*) were established to encourage fish farmers to invest in modern fish farming technologies in order to counter the economic damage caused by the COVID-19 pandemic. Furthermore, fish farming demonstrations in cages and fish farming in pens have been set up to bring open water areas under cultivation. Performing these activities may encourage women, unemployed people, and remittance earners who lost their jobs due to COVID-19 to engage in fish farming.

Established fish sanctuary: Fishermen did not frequent the river and the beel adjacent to the river, resulting in significantly less open-water fishing during the COVID-19 period. As a result, two sanctuaries in the river have been established to boost the abundance of native fish species. Apart from establishing fish sanctuaries in open-water bodies, frequent monitoring was carried out to ensure that fish conservation rules were followed.

A small number of fishing boats were noticed during the surveillance. On the other hand, monitoring systems must become increasingly technologically advanced and digitalized. For example, a closed-circuit camera or censor could be mounted on the open water. Remote surveillance and non-observer monitoring systems with cameras and electronic reporting systems are being used to improve fishing activity control, monitoring, and surveillance [25]. Following economic recovery, the environmental regulatory framework for freshwater fish biodiversity must be maintained and strengthened [2].

FIAC centre: The FIAC centre activities at the union level have been stepped up to give door-to-door services to fish farmers and beneficiaries in the fisheries sector. A LEAF at the FIAC centre gave the visitors the necessary guidance and served as a communication link between the beneficiaries and the Upazila Fisheries Office. The FIAC centre serves as a one-stop solution for all service needs.

Women's participation in fisheries sectors: The income of all beneficiaries in the fisheries sector has been substantially reduced because of the COVID-19 outbreak. Women have been encouraged to work in the fisheries sector to supplement their family's income. A priory-based demonstration program facilitated increased women's participation in the fisheries sector. The DoF have some development project where it is compulsory to engage a certain number of women in aquaculture and fisheries extension. Thus, the fisheries sector will contribute significantly to women's empowerment. Women have much more time than men to look after the fish farm as they remain at home. Additionally, unemployed women or women who do not want to work remotely or outside the home can engage in fisheries as prime business contributes more to their family income or animal protein supply.

Beneficiary selection in providing subsidies and loans: During the lockdown, the government provided financial assistance to vulnerable communities in the fisheries sector through subsidies and incentives. In order to provide subsidies and loans, the beneficiary selection process was quite complicated. The Upazila Fisheries Office selected the actual beneficiaries in the fisheries sector and aided banks in giving low-interest loans to fish producers. Targeted subsidy packages (e.g., aid and loans) can go a long way toward helping fishermen and fish growers who are in trouble [37–39]. The Indonesian government has set aside 69 million USD, or 18% of its 2020 budget, to assist pandemic-affected fishery stakeholders, as well as to monitor poaching and review the finances of the international fishing industry [10]. India has pledged $267 million over the next five years to support aquaculture production by enhancing the value chain, increasing employment and income, and ensuring fish farmers' economic and social security [40]. Other sources, such as CIG, can provide loans with comparatively cheap interest rates to fishery-related enterprises such as hatcheries and feed manufacturers. However, because of the pandemic's overwhelming effects, they should be included in the subsidy or very low-interest credit, especially to assist.

4. Conclusions

The purpose of this study was to evaluate the impacts of COVID-19 on the fisheries sector of the Brahmanbaria subdistrict and to address the steps taken by the government to mitigate these effects. The comparative data on fish production, farming status, fishery product traders, farmer's income, fish diversity, etc., for pre-COVID (2019) and during COVID (2020 and 2021), indicated the adverse impacts of the pandemic, including low fish production, low market demand, high feed cost, low income, and loss of job. Fish farmers' income declined by 47.49% in 2020, and about 71% of fishermen admitted that they even lost their ability to meet their daily household food consumption needs (three times a day). On the contrary, COVID-19 had positive impacts on open-water capture fisheries (e.g., an increased annual catch in 2021) and fish habitats (increased fish diversity), possibly due to lockdown and having a favourable environment for growth and production and undisturbed nesting sites. The DoF implemented activities such as farm visits, online training, improved interdepartmental coordination, monitoring fish-selling marketing channels, and providing subsidies and loans by the DoF has improved the situation as perceived by the public perception. However, further research is necessary to understand

how initiatives taken by the DoF have contributed to the adverse situation caused by COVID-19 in the fisheries subsectors.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su15043605/s1, Table S1: Fish diversity of fish with catch (number of individuals and total weight in kilogram) in three consecutive years. Table S2: One-way ANOVA for fish catch (number) and fish catch (weight). Table S3: One-way ANOVA (Tukey HSD) multiple comparisons for fish catch (number) and fish catch (weight).

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