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ORIGINAL ARTICLE

Aquaculture

COVID-19 impacts on the Bangladesh shrimp industry: A sequential survey-based case study from southwestern Bangladesh

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Abstract
Shrimp farming is fundamental to the national economy of Bangladesh, particularly through earning foreign currency. The nationwide lockdown and international cargo restriction jeopardized the sector and breaking its marketing chain. Assessing the degree of farming socio-economic peril from COVID-19 and suggesting early coping strategies and long-term mitigation measures are pressing to build resilience for this food production sector. To collect survey data, two key-informant face-to-face surveys with 51 shrimp farmers and 62 consumers in southwest Bangladesh were accomplished. As national lockdowns restricted access to export markets and movements within the country, farm incomes decreased against rising production costs. To compensate, farmers reduced their workforce (29.4%), but even with the sale of co-cultured finfish still suffered from large drops in revenue (42.8% average profit reduction). Furthermore, we present evidence that shrimp farmers should consider diversification of aquaculture product type as co-culture of additional shrimp species was a poor mitigation strategy against large market price fluctuations. Product price reductions were passed on to the consumer, who enjoyed falling product prices including more expensive shrimp products, but the markup for nearly all aquaculture products increased. The current jeopardy and consequences of shrimp farming future are discussed, including coping strategies to help policymakers in building resilience against future uncertainties.

Keywords COVID-19 · Shrimp industry · Farm practices · Sustainability · Bangladesh

Introduction

Shrimp farming around the world has developed and intensified over the years as a legacy of on-growing animal-based protein demand, contributing to food security at both household and national levels. Currently, it represents 18% of the total world fish trade (FAO 2020a) and it has been projected that global demand for shrimp will go up by 50% between 2010 and 2030 (Larkin 2012). In Bangladesh, shrimp farming is an industrial workforce sector directly employing about 1.15 million people in farm operations, and a further 5.2 million people indirectly in different parts of the supply chain of this industry (DoF 2019a; Biswas et al. 2021). For example, there are 100 seafood processing plants in Bangladesh, mostly located in the southern and coastal regions of Bangladesh that mainly employ a large female workforce (DoF 2019a). Consequently, the shrimp sector has become an important income-generating opportunity for coastal communities of Bangladesh, with the industry contributing US $383 million through export earnings (75.8% of the total fish and fish product exported in the financial year 2018–19), and subsequently playing a substantial role in the national economy (DoF 2019a). In the southwestern part of Bangladesh (Bagerhat, Khulna and Satkhira districts within the Khulna division), shrimp farming has been adopted by thousands of farmers, as it has a better benefit–cost ratio (BCR;

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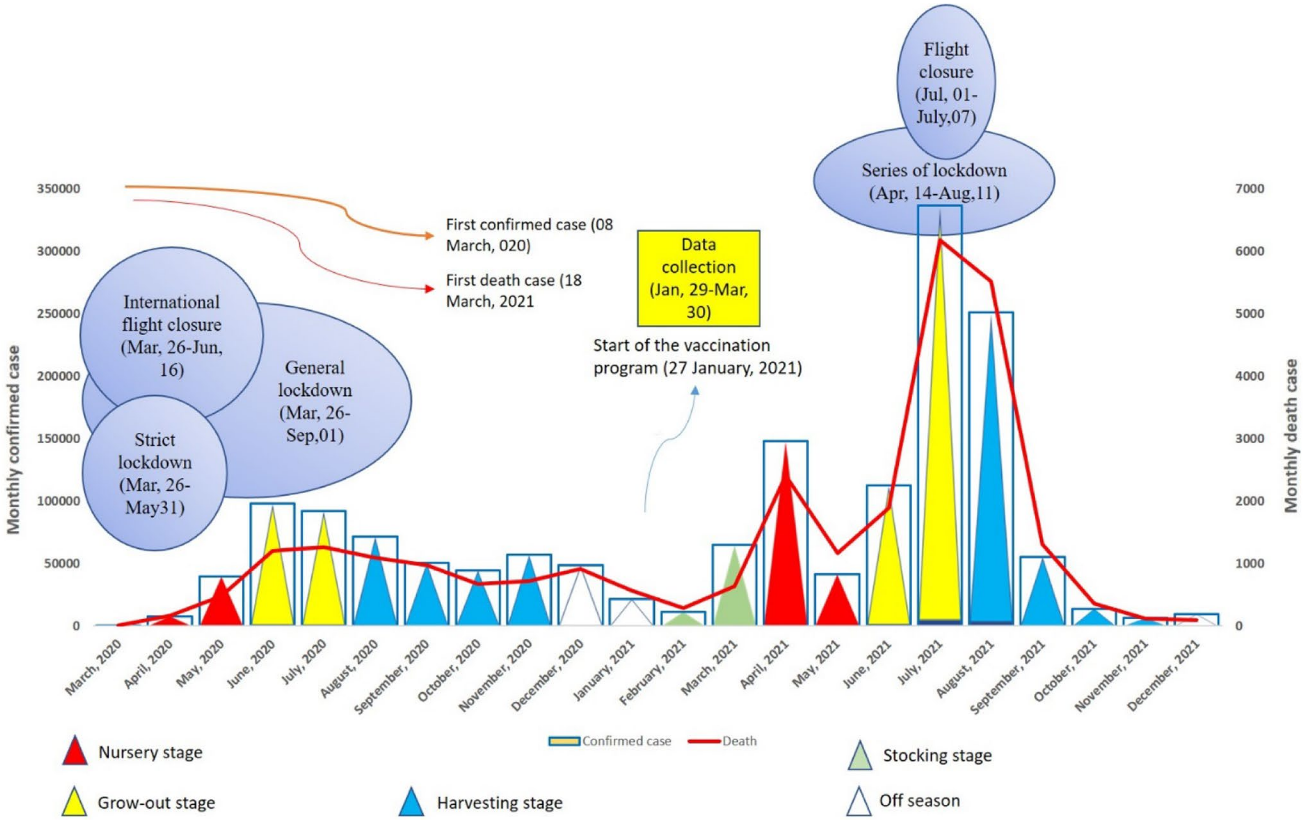

Fig. 1 COVID-19 timeline of Bangladesh showing monthly confirmed cases and death cases recorded from March, 2020 to December, 2021. *Colored triangular shapes* inside the confirmed case bar represent shrimp culture stage/phases of Bangladesh

2.46; Rasha et al. 2019) compared to finfish (1.16; Khan et al. 2021). Typically, these farms are family-run, small enterprises with produce being used for family nutrition with income generated through farm gate or marker produce sales. These small enterprises are vulnerable to productivity shocks, such as that produced by disease outbreaks in the crop (Heal et al. 2021).

Rapid growth of the shrimp industry has elicited many problems (Ali et al. 2018) and the export value of this industry dropped about 7.76% (from 36,168 MT to 33,363 MT) between the financial years 2017–18 and 2018–19 (DoF 2018; DoF 2019a). A major emerging issue has been the increased disease prevalence caused by clustering of farms, stocking of poor-quality post-larvae, shared water sources, and poor biosecurity (Hasan and Haque 2020a; Hasan et al. 2020). Since the start of the century, white spot disease (WSD) has been the major problem in the shrimp industry, causing losses of approximately US $20 billion in Asian countries (UndercurrentNewsWeb: https://www.undercurrentnews.com/2016/09/09/disease-has-cost-asia-shrimp-sector-over-20bn/ "Accessed 09 May 2021"), including in Bangladesh (Hasan et al. 2020). In addition, the impact of early mortality syndrome (EMS) has been growing and, since 2009, competes with WSD as a major disease factor. Other infectious diseases suppress income by up to US $3924 per ha (Ali et al. 2018), and together the effect of infectious disease has nearly brought the Bangladesh shrimp industry to bankruptcy. The emergence of SARS-CoV-2 corona virus (hereinafter COVID-19) has further debilitated the shrimp industry of Bangladesh.

On the January 30, 2020, the World Health Organization declared that the novel COVID-19 outbreak constituted a Public Health Emergency of International Concern and on the March 11, they declared it a pandemic. Worldwide, countries adopted measures to safeguard public health by reducing the spread of the disease. These measures involved a massive reduction in travel and consequently stalled economic activities throughout the world (Hasan et al. 2021b). Following the first case reported on March 8, 2020, the government of Bangladesh initiated non-pharmaceutical interventions (NPI), including a strict nationwide lockdown from the March 26, 2020 with a series of extensions until September, 2020 (Hossain et al. 2022). Maintaining social distancing and wearing face masks were mandated and restrictions on human movement were only relaxed for industrial and agricultural workers and frontline workers from May 1, 2020. Nonetheless, closure of international borders and flights were maintained from March 26, 2020 to the June 16, 2020 (see Fig. 1).

Unfortunately, these restrictions coincided with the major annual shrimp farming cycle in Bangladesh (February to September). National shutdowns placed limitations on restaurants (Yang et al. 2020) and dining out (Ben Hassen et al. 2020) leading to an increase in global demand for frozen grocery food items, including shrimp products. However, Bangladesh has not profited from this demand (Sarafat 2020). Disruption to supply chains due to export restrictions and limited freight shipping of agricultural goods (FAO 2020b) has hampered transportation of goods both locally and internationally. International orders have been cancelled, including one worth US $4.6 billion in a single month (Sarafat 2020) further placing the industry in a difficult financial position. Further, being costlier than finfish, shrimp tend to be consumed by the affluent community of Bangladesh and the presence of COVID-19 has deterred the upper class from visiting markets (Mandal et al. 2021; Hasan et al. 2021a), while consumers with reduced incomes have been reported to prefer finfish to shrimp (Sunny et al. 2021). As a result, shrimp demand has reduced in the local markets. Overall, COVID-19 risks damaging livelihoods of thousands of people who have no other alternative means of income, driving more people under the poverty line and thus potentially affecting food security in the longer term (Shammi et al. 2021; Mandal et al. 2021).

Like the forward chain, the backward chain of the shrimp industry also largely relies on national and international transit and transportation systems. In Bangladesh, shrimp hatcheries are predominantly located in Cox's Bazar, near the Bay of Bengal, and stock is transported by air to the production hubs in the coastal regions of Bagerhat, Khulna, and Satkhira (Debnath et al. 2016). These three districts account for 61.46% of the total shrimp production from Bangladesh (DoF 2019b). Moreover, most of the shrimp farming inputs, feed, farm appliances, fertilizers, and chemicals are imported from overseas. Limited international and national movements have translated into input shortages and increased production costs; for example, reduction of sea fishing by 34% due to the COVID-19 ban (Coll et al. 2021) and limited ocean freight have pushed up the cost of fish meal by up to 47%[1]. Potential decreases in demand and price of shrimp, coupled with increased production costs, has led to farmers being reluctant to restock ponds.

Emerging literature suggests that COVID-19 is jeopardizing the fisheries and aquaculture sectors throughout the world (Love et al. 2021; Sunny et al. 2021; Bassett et al. 2021). While we (June 2022) were revising this article, the infection rate with fatality of COVID-19 was increasing in Bangladesh (UNB 2022), and at the same time, a new COVID-19 wave was starting all over the world (Worldmeters 2022; Hasan and Haque 2020b; Hasan and Siddik 2020). This indicates that COVID-19 will occasionally rise and fall globally and its negative effects will remain in fisheries and aquaculture as in other sectors. It is clear that COVID-19 was disrupting worldwide supply chains (Coluccia et al. 2021; Bassett et al. 2021) but it is doing the same and not known to what extent this has affected the shrimp industry in Bangladesh. In our previous study, we contributed to an in-depth discussion on what extent the COVID-19 overshadowed the finfish aquaculture industry of Bangladesh, in particular disruption of forward and backward supply chains, shaping marketing structures, and changing consumer behavior (Hasan et al. 2021a). In response to COVID-19 affecting production and supply chains, institutional roles were seriously criticized and short- to long-term coping strategies were recommended in favor of market growth. However, the study focused on finfish only and ignored another important pillar of aquaculture sector—the shrimp industry sector. In line with the recommendation from Sarà et al. (2021) and O'Neill et al. (2022), we considered how co-culturing of fish with other aquatic animals could reduce the economic loss on marginal farmers against the COVID-19 shock (Hasan et al. 2021a). Product diversification through practicing co-culture is considered one of the best resilient tools to cope with vulnerability contexts in food production systems (Ahmed et al. 2014; Inaotombi and Mahanta 2015; Mohsen and Yang 2021; Kim et al. 2022). It is well established that integration of finfish/shrimp with rice, vegetables, seaweeds, mollusks, etc., provides increased economic resilience through provisioning better marketing opportunities and reducing the risks of production (Haque 2007; Haque et al. 2015; Mohsen and Yang 2021). To avoid economic risk from climate events (e.g., abrupt change in salinity and temperature) and disease outbreaks, farmers of southwest Bangladesh adopt similar approaches, including co-culture of shrimp with finfish and prawns, which are more resistant to stressors and diseases. However, whether co-culture could mitigate the COVID-19 shock remains inconclusive and therefore we sought to assess its worthiness in economic mitigation. Current literature covering the broad strategic assessment of the shrimp sector following COVID-19 is still limited to the Indian and Iranian markets (Kumaran et al. 2021; Pazir et al. 2022). Rahman et al. (2021) addressed the impact of COVID-19 on coastal shrimp farmers of Bangladesh in the light of socio-economic parameters and livelihoods but did not cover production economics and marketing issues. Assessing the impact of COVID-19 on shrimp industry is important for sustainability against the pandemic and the analysis of the farming economics is key to driving policy-informing tools. In this study, we investigated how production costs and market behavior in southwest Bangladesh were influenced by the COVID-19 pandemic. We

[1] Data obtained from three feed companies reveal an average price increase of between 12 and 47% following COVID-19.

Table 1 Leading shrimp-producing districts in terms of pond-based major shrimp species production in Bangladesh

District	Production (MT)		
	Major species		Total (major and other species)
	Penaeus monodon	*Macrobrachium rosenbergii*	
Satkhira	24,088	8631	37,102
Bagerhat	17,488	16,337	35,942
Khulna	**12,549**	**13,325**	27,607
Cox's Bazar	9085	180	11,619
Jashore	425	7751	8277

The bold values represent the study area

focused on small- to medium-scale shrimp farmers, hypothesizing that they would be most affected by COVID-19 and the impact on them could have implications right through to the national policy level, for example in future nutritional policy. Ensuring sustainability and resilience in the forward and backward linkages in shrimp production is an important feature as the sector emerges from the pandemic. We hereby present the challenges faced and suggest short- and long-term strategies to reshape shrimp production at this scale to create a more resilient industrial sector.

Materials and methods

Nomenclature

The reader should be aware that throughout the manuscript the use of PRE-COVID-19 and POST-COVID-19 does not reflect that the pandemic was over but a time just before COVID-19 appeared (PRE-COVID-19; before March, 2020) and just after the pandemic (POST-COVID-19; after January, 2021).

Research procedure

To investigate the impact of COVID-19 on shrimp farming in Bangladesh, a sequential survey with different stakeholders involved in the supply chain of shrimp zone was performed between January 29, 2021 and March 30, 2021. Shrimp production in Bangladesh is mainly centered in the southwest districts (Khulna, Satkhira, and Bagerhat) of Bangladesh due to favorable agro-climatic (such as suitable salinity and high temperature) and biophysical (for example, easy accessibility to agricultural land, hatchery, and natural-sourced PL and coastal rivers) conditions (Ahmed 2013). Among all three top producing districts of shrimp, only the farmers from Khulna district culture the mainstream species (*Penaeus monodon* and *Macrobrachium rosenbergii*) homogenously (Table 1) and therefore to minimize travel, this district was selected as the study area to represent the impact on the Bangladesh shrimp industry.

Before the final survey, a comprehensive list of the farmers was developed by consulting with the local Upazila[2] Fisheries Officer of the Department of Fisheries, Bangladesh. To ensure the health and safety of farmers and researchers, this list was not cross-checked using a participatory rural appraisal (PRA), rather farmers were contacted by phone to consent to participate in the survey. A previously drafted questionnaire used in our previous study (Hasan et al. 2021a), with some more questions pertinent to shrimp farming, was used as a pre-tested questionnaire. The pre-test questionnaire was piloted and validated with some selected farmers and refined based on the feedback from the pilot study (see the questionnaire provided in Online Resource 1). The face-to-face questionnaire survey was undertaken with shrimp farmers ($N=51$) from the comprehensive list who consented to give information regarding price, availability of farm logistics, and economic data resulting from the pandemic. In the survey, farmers provided information on farm management details before COVID-19 and following the onset of the pandemic. Details on the farm gate prices of product, the number of workers employed on the farm, and the non-fixed costs incurred for product generated were recorded. Non-fixed costs included the costs of water exchanges in the ponds, post-larval seed, feed, electricity, labor costs (generated from the information above) and transportation.

As a part of the sequential survey, we also investigated the COVID-19 impact on consumer empathy. For this part of the survey, we selected markets from the same survey area where the majority of harvests from the study area are traded in the adjacent retail markets. In the survey area, there were about eight big retail markets from which three were selected following the survey guidelines of (NAO 2001)[3] to make the data representative. A questionnaire was drafted to survey consumers (adopted and modified from our previous study (Hasan et al. 2021a)) and pre-tested and validated. Using the final questionnaire (see Online Resources 1 and 2), information from 62 consumers (20 from market-1 in Paikgacha, 20 in market-2 in Dumuria, and 22 in market-3 in Khulna Sadar) was collected. Random selection was followed in choosing consumers who also provided consent to share information. Consumers provided information on their purchasing behavior and they were also asked to recall

[2] The administrative divisions of Bangladesh are divided into districts which are further divided into Upazilas.

[3] For populations under 1000, a minimum ratio of 30% is advisable to ensure representativeness of the sample.

the price they were paying per kilogram for all species purchased before the pandemic (pre-COVID-19) and at the present time (post-COVID-19). Using the consumer prices, the percentage markup (here the difference between the mean consumer price and the mean farm gate price for the species) was derived.

In all situations, social distancing and other non-pharmaceutical interventions (face masks) were used to reduce risk to researchers and participants. Answers from the respondents to both parts of the survey were collected using Google Forms online platform and the data quality checked prior to analysis.

Details of shrimp farms

A total of 51 farms were surveyed in Khulna, and their locations are shown in Fig. 2. The two main species cultured were *Macrobrachium rosenbergii* and *Penaeus monodon*, with *Metapenaeus monoceros*, *Metapenaeus brevicornis*, and *Penaeus orientalis* also being cultured.

The number of farms practicing co-culture of shrimp/prawn species and/or finfish at the time of the COVID-19 outbreak in the survey are shown in Table 2. Twenty-two farms cultivated *M. rosenbergii* (11 as the main species), 41 farms cultivated *P. monodon* (40 farms as the main species), eight farms cultivated *M. brevicornis*, 14 farms cultivated *M. monoceros*, and two farms cultivated *P. orientalis*. Twenty-four farms practiced co-culture of one or more shrimp species, 41 farms practiced co-culture of shrimp and finfish, and ten did not co-culture shrimp or finfish. A total of 16 different species of finfish were recorded being co-cultured with shrimp in our survey. For those farms that were co-culturing finfish, a median of four species (mean of 4.5) was recorded per farm, with a maximum of nine different species cultured on one farm.

The shrimp farms surveyed were extensive or semi-intensive and there was a range of farm sizes in both groups. Extensive and semi-intensive farming are characterized by (1) "letting in and harvesting" with very little facilitation through little labor engagement and input providence and (2) "stocking high-quality SPF PL and feeding" by maintaining proper biosecurity to reduce disease transmission in a labor- and input-intensive manner, respectively. As expected, the median farm size for the semi-intensive farms was 140% larger than that of the extensive farms, and on average they employed 2.6 times more permanent staff to manage the farm (for details see Table 2).

Estimation of profit margins for shrimp farms pre- and post-COVID-19

Farm profit and profit margins were calculated under pre-COVID-19 and post-COVID-19 conditions using information supplied by the farmer. Production input costs included feed, seed, labor, medicines, water provision, electricity, and transport. Labor costs were calculated on an individual farm basis for permanent, seasonal, and non-technical labor. Fixed costs such as land lease were not included. As some farms did not provide costs for all product inputs, profit margins were normalized to pre-COVID-19 values as shown below. For all costs, only those farms that provided a cost pre-COVID-19 and post-COVID-19 were included in the analysis.

Farm profit and profit margins

$$\mathrm{Farmprofit} = \mathrm{GrossIncome} - \mathrm{FarmCosts} \tag{1}$$

$$\mathrm{Farmprofitmargin} = \frac{\mathrm{GrossIncome} - \mathrm{FarmCosts}}{\mathrm{GrossIncome}} \tag{2}$$

Here GrossIncome is the total income received by the farm through sales of the shrimp main crop and other co-cultured species (Eq. 5) and *Farm Costs* are the total incurred costs during the production cycle (Eq. 8).

$$\mathrm{Normalizedfarm\ profit} = \frac{\mathrm{FarmProfit}_{\mathrm{PostCOVID}}}{\mathrm{FarmProfit}_{\mathrm{PreCOVID}}} \tag{3}$$

$$\mathrm{Normalizedfarm\ profitmargin} = \frac{\mathrm{FarmProfit\ Margin}_{\mathrm{PostCOVID}}}{\mathrm{FarmProfitMargin}_{\mathrm{PreCOVID}}} \tag{4}$$

Here *Farm Profit* is the difference between income received by the farm and the costs incurred during a production cycle (Eq. 1), $Farm\ Profit_{PreCOVID}$ is the profit per production cycle before the pandemic and $Farm\ Profit_{PostCOVID}$ is the farm profit after the pandemic. Note that the normalized farm profit pre-COVID-19 is 1. Farm $Profit\ Margin_{PreCOVID}$ and $Farm\ Profit\ Margin_{PostCOVID}$ are the profit margins pre-COVID-19 and post-COVID-19, respectively.

Gross incomes of farms

$$\mathrm{GrossIncomeDifference} = \mathrm{GrossIncome}_{\mathrm{PreCOVID}} - \mathrm{GrossIncome}_{\mathrm{PostCOVID}} \tag{5}$$

Here $Gross\ Income_{PreCOVID}$ and $Gross\ Income_{PostCOVID}$ are the gross income on the farm before and after the pandemic respectively and are calculated using Eq. (6) using reported values for pre-COVID-19 and post-COVID-19.

$$\mathrm{GrossIncome} = \mathrm{GrossIncome}_{\mathrm{MainCrop}} + \mathrm{GrossIncome}_{\mathrm{Co\text{-}culturedCrop}} \tag{6}$$

Here $Gross\ Income_{MainCrop}$ is the total income generated from sales of the shrimp main crop (Eq. 7) and *Gross*

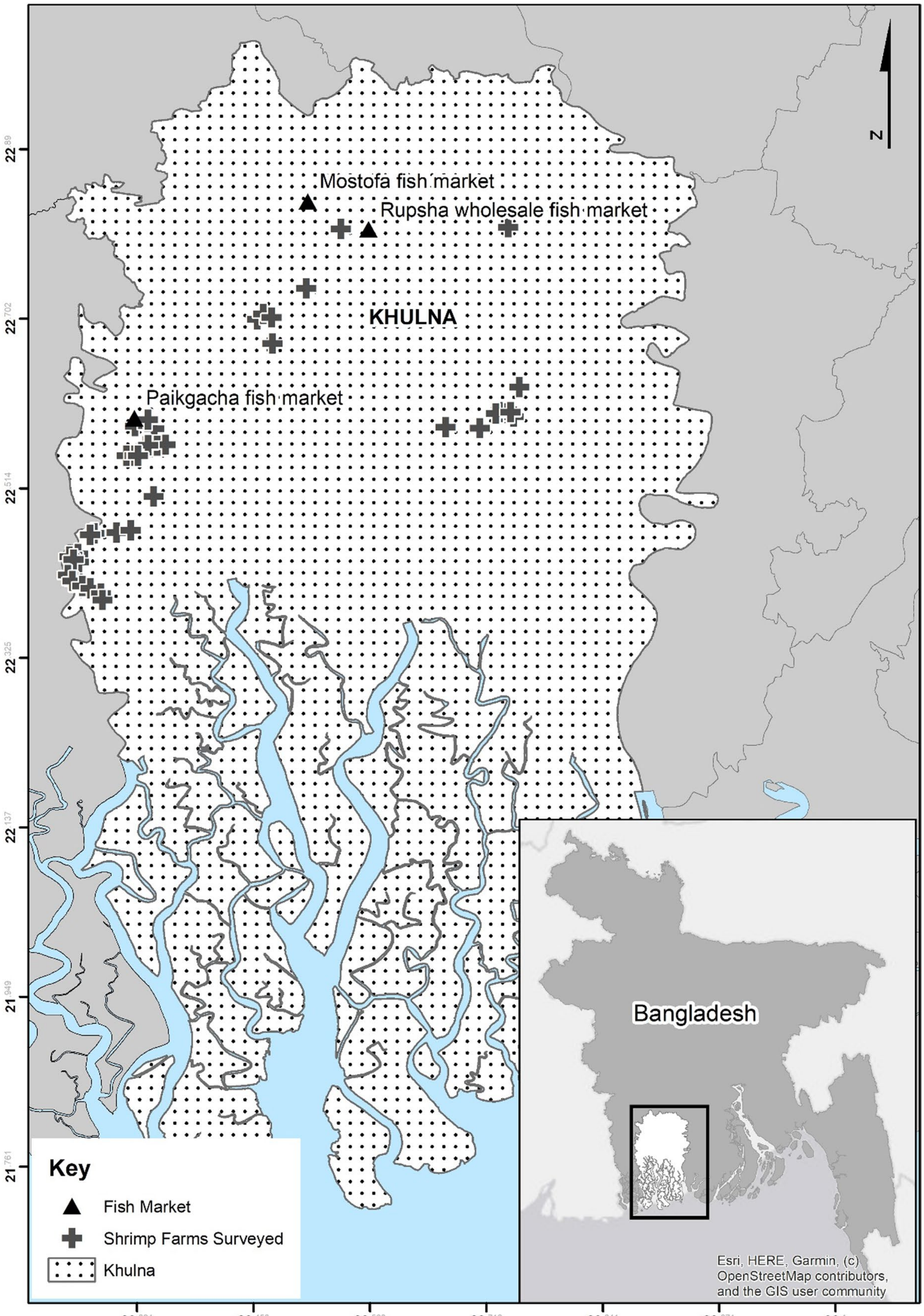

Fig. 2 Map showing the location of shrimp farms that participated in the survey

Table 2 Details of the farms that were surveyed in this study

Parameter	Shrimp main crop	Shrimp farm type[d]	
		Extensive	Semi-intensive
Number of farms	All	30	21
	P. monodon	31	9
	M. rosenbergii	11	0
Number of large farms (≥ 6 ha)	All	6	2
	P. monodon	5	2
	M. rosenbergii	1	0
Number of medium farms (> 1 ha and < 6 ha)	All	15	6
	P. monodon	14	6
	M. rosenbergii	1	0
Number of small farms (≤ 1 ha)	All	21	1
	P. monodon	12	1
	M. rosenbergii	9	0
Farms co-culturing finfish with main crop[a]	All	41	0
	P. monodon	31	0
	M. rosenbergii	10	0
Farms co-culturing shrimp and finfish with main crop[b]	All	24	0
	P. monodon	22	0
	M. rosenbergii	2	0
Farms performing no co-culture	All	1	9
	P. monodon	9	0
	M. rosenbergii	1	0
Median farm size ± MAD[c] (hectares)	All	1.0 ± 1.0	2.4 ± 1.2
	P. monodon	1.2 ± 0.88	2.4 ± 1.2
	M. rosenbergii	0.25 ± 0.18	–
Mean total number of employees ± Std Dev (pre-COVID-19)	All	3.8 ± 4.7	9.9 ± 9.1
	P. monodon	4.6 ± 4.8	9.9 ± 9.1
	M. rosenbergii	1.5 ± 3.9	–

[a]Co-culture of shrimp indicates that the farm cultivated two or more species of shrimp (farmer indicated the main crop species)

[b]Finfish co-culture included saltwater and freshwater species (for full list see Table 5)

[c]Median absolute deviation

[d]Values shown are the number of farms

$Income_{Co\text{-}culturedCrop}$ is the total income generated from sales of all other crops cultured alongside the main crop (Eq. 8).

$$\mathrm{GrossIncome}_{\mathrm{MainCrop}} = \mathrm{Yield}_{\mathrm{MainCrop}} \times \mathrm{FarmGatePrice}_{\mathrm{MainCrop}} \tag{7}$$

Here $Yield_{MainCrop}$ is the total yield of main crop reported by the farmer (in kg) and $Farm\ Gate\ Price_{MainCrop}$ is the price the farmer received for their crop (in BDT per kg) as reported by the farmer.

$$\text{Gross Income}_{\text{Co - culturedCrop}} = \sum_{i=1}^{n} \left(\mathrm{Yield}_{\mathrm{Species}_i} \times \mathrm{FarmGatePrice}_{\mathrm{Species}_i}\right) \tag{8}$$

Here, the total revenue for co-cultured crop within the pond is the sum of the revenue for each individual species co-cultured in the pond. $Yield_{Species_i}$ is the total yield from cropping of $Species_i$ co-cultured in the pond as reported by the farmer (in kg) and $FarmGatePrice_{Species_i}$ is the price the farmer received for their crop of $Species_i$ (in BDT per kg) as reported by the farmer.

Farm costs

$$\begin{aligned}\mathrm{Farmcosts} = {} & \mathrm{Cost}_{\mathrm{Feed}} + \mathrm{Cost}_{\mathrm{Seed}} + \mathrm{Cost}_{\mathrm{Labor}} + \mathrm{Cost}_{\mathrm{Medicine}} \\ & + \mathrm{Cost}_{\mathrm{Water\ Provision}} + \mathrm{Cost}_{\mathrm{Electricity}} + \mathrm{Cost}_{\mathrm{Transport}}\end{aligned} \tag{9}$$

Here $Cost_{Feed}$ is the cost of animal feed, $Cost_{Seed}$ is the total cost of shrimp post-larvae and finfish fingerlings where appropriate, $Cost_{Labor}$ is the sum of the cost of permanent, seasonal, and/or non-technical staff to perform farm operations (Eq. 10), $Cost_{Medicine}$ is the cost of medical products used in the production cycle, $Cost_{Water\ Provision}$ are any costs associated with filling and/or maintaining water levels in the pond, $Cost_{Electricity}$ are associated electricity costs, and $Cost_{Transport}$ are the transportation costs for farm operations. All cost were reported by the farmer (in BDT) and relate to a single production cycle.

$$\mathrm{Cost}_{\mathrm{Labor}} = \mathrm{Cost}_{\mathrm{Permanent}} + \mathrm{Cost}_{\mathrm{Seasonal}} + \mathrm{Cost}_{\mathrm{Non\text{-}technical}} \tag{10}$$

$$\mathrm{Cost}_{\mathrm{Labour}} = \left(\mathrm{NumberStaff}_{\mathrm{WorkCategory}} \times \mathrm{StaffWage}_{\mathrm{WorkCategory}}\right) \tag{11}$$

Here $Cost_{Permanent}$, $Cost_{Seasonal}$, and $Cost_{Non\text{-}technical}$ are the total wage costs for permanent, seasonal, and non-technical employees working on the farm, respectively. For each work category (permanent, seasonal, and non-technical), these are calculated by multiplying the number of staff on the farm for each work category ($NumberStaff_{WorkCategory}$) by the staff wage paid for each category ($StaffWage_{WorkCategory}$) as shown in Eq. (11). This assumes equal wage payments.

Data management and analysis

All data analyses were performed in R (R Core Team 2021). Survey data were extracted and analyzed using the package data.table (Dowle and Srinivasan 2019) and visualized using the package plotly (Sievert 2020). Statistical analysis of the data was performed in a R Markdown document and the survey data, lookup tables, analysis code, and markdown documents are contained in the GitHub repository (currently at https://github.com/richieheal/BangladeshCOVIDShrimp.git). For statistical analysis, mean price indications were compared using paired *t* tests and consumer data were treated as categorical data and compared using goodness-of-fit chi-squared for multiple categorical data or exact binomial tests for yes/no data.

To understand whether co-culture enabled farmers to mitigate against market price decreases, the total gross income difference was calculated and subjected to multivariate analysis using a generalized linear model. Fitting of the multi-variate analysis model to examine the effect of co-culture on the difference in farm gross income was performed using a Gaussian link function with the response variable as the difference in the total gross farm income and linear predictors of the farm size in decimals, whether the farm practiced co-culture of two or more shrimp species, and whether the farm practiced co-culture of finfish with shrimp. Post hoc analysis was performed to rule out differences in production or price differentials as co-linear response variables.

Results

COVID-19 has resulted in a decrease in the farm gate prices of shrimp

The effect of COVID-19 on the farm gate prices of shrimp is shown in Fig. 3. All species showed a decrease in product price following COVID-19. For *M. rosenbergii*, the mean percentage decrease in price was 39.1%, reflecting a decrease from a mean price of BDT 943.2 ± 172.7/kg to BDT 574.5 ± 113.6/kg. For *P. monodon*, a mean percentage decrease of 32.6% was recorded with prices dropping from BDT 802.6 ± 197.7/kg to BDT 540.7 ± 125.4/kg. Smaller, but significant, decreases were also obtained for *M. monoceros* (12.6%) and for *M. brevicornis* (10.6%). For *P. orientalis*, the price dropped from a mean of BDT 475.0 ± 106.1/kg to BDT 400.0 ± 0.0/kg, (15.8%) however, there were only two farms culturing this species so the decrease was not confirmed as significant.

Co-culture had a marginal effect on mitigating price decreases due to COVID-19

Many of the ponds investigated in this study were performing co-culture of the main crop with other species of prawn/shrimp and/or finfish, both freshwater and saltwater species at the time of the COVID-19 outbreak. We wanted to test the hypothesis that diversification of crop could affect the impact of COVID-19 on the gross income of the farm by potential access to a broader range of markets. In our study, those farms practicing monoculture were biased toward medium- and larger-sized semi-intensive farms. We therefore included other factors in the analysis including farm size, the number of ponds present on the farm, and the total reduction in staff numbers due to COVID-19. Multivariate analysis revealed that for those ponds that practiced co-culture of shrimp, there was a small but insignificant increase in the gross income difference pre-COVID-19 and post-COVID-19 (see Table 3). By contrast, co-culture of finfish species had a more marked, and significant, effect on the gross income difference, almost compensating for the loss of income due to COVID-19. The number of ponds present on the farm and

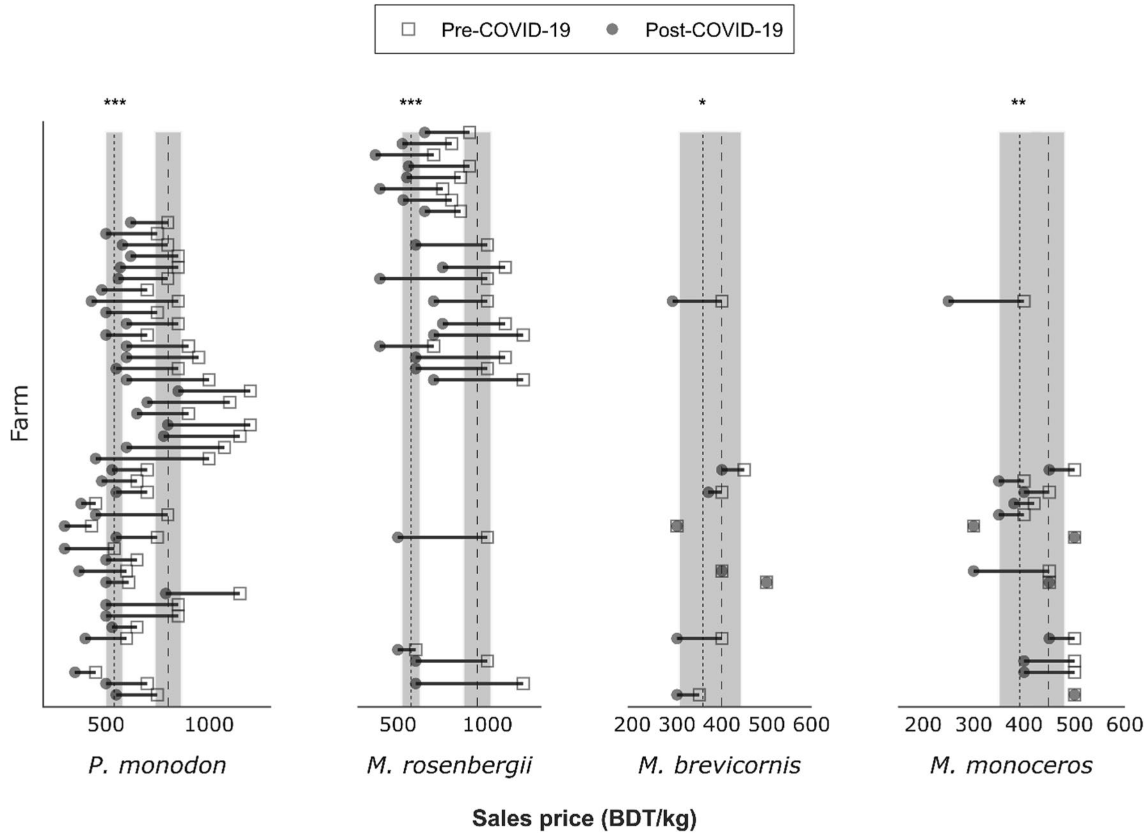

Fig. 3 Effect of COVID-19 on the farm gate prices of shrimp and prawn produce. *Horizonal lines* indicate the difference, the *dashed vertical lines* are the mean farm gate price pre-COVID-19 (*dotted*) and post-COVID-19 mean farm gate price (*dashed*); and the *shaded areas* are the 95% confidence levels. Significance of differences in farm gate prices (pre-COVID-19 versus post-COVID-19) using paired Student's *t* test are shown (***$p<0.001$; **$p<0.01$; *$p<0.05$)

Table 3 Multi-variate analysis model parameters to examine the effect of co-culture on difference on total gross income from farms

Parameter	Coefficient (std error)	*p*	Model	
			AIC[a]	R^2 captured[b]
(Intercept)	7352.975 (1194.307)	< 0.001	962	0.633
Size of farm (decimal)	− 0.038 (0.171)	0.825		
Shrimp/prawn co-cultured	− 84.781 (899.963)	0.930		
Finfish co-cultured	− 7,386.461 (1,227.042)	< 0.001		
Number of farm ponds	341.060 (200.764)	0.096		
Reduction in staff	− 21.657 (323.887)	0.947		

[a]Akaike information criterion

[b]Calculated as 1—(deviance/null deviance)

the reduction in the number of staff due to COVID-19 did not have a significant effect on the gross income difference.

This indicates that farms that were practicing co-culture of finfish at the time of the pandemic were mitigated against price falls in the main crop in the ponds but the same mitigation was not afforded by shrimp or prawn co-culture. Approximately 60% of the variance in gross income difference was described using the parameters of this model. However, caution is required, as it was clear that product volume did participate in the result. To illustrate, the multivariate analysis was repeated using the change in relative gross income due to COVID-19 (see Online Resource 3, Table S2). The co-culture of finfish remained the only significant factor ($p=0.03$), however the model was less effective, accounting for only 14% of the variance. Furthermore, our sample was biased towards semi-intensive farms that exclusively performed monoculture and extensive farms that

Table 4 Employment profile of shrimp farms in the survey pre- and post-COVID-19

Employed staff	Number of farms (Total number of employees)		Difference
	Pre-COVID-19	Post-COVID-19	
No staff employed	7 (0)	12 (0)	+5 (0)
Permanent ONLY	5 (6)	5 (6)	0 (0)
Seasonal ONLY	5 (5)	7 (8)	+2 (+3)
Non-technical ONLY	0 (0)	0 (0)	0 (0)
Permanent and Seasonal ONLY	25 (148)	18 (115)	− 7 (− 33)
Seasonal and Non-technical ONLY	0 (0)	3 (7)	+3[a] (+7)
Permanent and Non-technical ONLY	0 (0)	0 (0)	0 (0)
Permanent, Seasonal and Non-technical	9 (89)	6 (59)	− 3[a] (− 30)

[a]The changes in these groupings are the result of all permanent staff being laid off from the farms that employed permanent, seasonal, and non-technical staff

almost all performed polyculture. These factors were co-correlated in our model.

The practice of co-culture results in reduced stocking densities of the main crop as the water resource is limited in volume and has to support the other crop(s). In our study, there was a decrease in the main crop productivity of 33.1% for all farms, which dropped to 28.0% for those farms performing co-culture of shrimp and 29% for those performing co-culture of finfish. These differences were not significant (Welch's *t* test, $p = 0.22$ for productivity of farms not performing co-culture versus those performing co-culture of shrimp; and $p = 0.20$ versus farms performing finfish co-culture). This represents a revenue decrease of 55.1% for all farms, 48.4% for those farms performing shrimp co-culture, and 49.9% for those farms performing finfish co-culture. For farms performing co-culture, the productivity share (the percentage of productivity due to shrimp culture) for those performing shrimp co-culture was 1.64% compared to 2.16% for those farms performing finfish co-culture. The average price change between shrimp and finfish farm gate prices following COVID-19 decreased by 25.5 and 21.4% respectively. This supports the hypothesis that producing a second, distinct aquaculture product in the shrimp pond can reduce the farmer's exposed risk to large fluctuations in the market such as that caused by COVID-19.

Shrimp farms have reduced staff numbers due to COVID-19

Although many shrimp farms operate as family holdings with family members performing much of the work required, many farms employ part-time or seasonal labor. In our survey, seven farms did not employ staff before COVID-19, and this increased to 12 farms following the pandemic (see Table 4). Of the remaining 44 farms, 26 (59%) reduced staffing levels, 18 (41%) kept levels the same, and none (0%) employed more staff. In total, this represented a loss in staff of 53 workers, of which 29 were permanent staff, 24 were seasonal staff, with no non-technical staff reductions recorded.

For permanent staff, the employment situation was challenging. Before the pandemic there were 39 farms that employed 120 permanent staff, and this reduced to a total of 29 farms employing 91 permanent staff. Ten farms reduced their permanent workforce to zero following COVID-19. The median reduction in staff was 1 with a range from between one and five workers. Twelve farms did not employ permanent staff before COVID-19 and none of these farms took on permanent staff.

For seasonal staff, an equally challenging employment situation arose. Before the pandemic there were 39 farms that employed 116 seasonal staff, and this reduced to 34 farms employing 92 workers. Five farms reduced their seasonal workforce to zero following COVID-19. Twelve farms did not employ seasonal workers prior to COVID-19 and none of these farms took on seasonal staff.

For non-technical staff, there was no difference in staff number pre- and post-COVID-19, however the numbers of staff were one-tenth of those for permanent and seasonal staff (12 staff members in nine farms). In our results, no farms looked to employ non-technical staff to replace seasonal or permanent staff that had left or had been laid off.

When considering the mix of the workforce, the reduction of permanent staff has had the greatest effect on workforce balance. Three farms that employed permanent, seasonal, and non-technical staff prior to COVID-19 laid off their permanent staff (see Table 4). Further, seven farms with permanent and seasonal staff pre-COVID-19 reduced either their permanent staff, resulting in only seasonal staff in the employ, or laid off both permanent and seasonal staff to reduce staffing to zero. This suggests a large number of farms being deprived of permanent, well-skilled staff as a result of COVID-19.

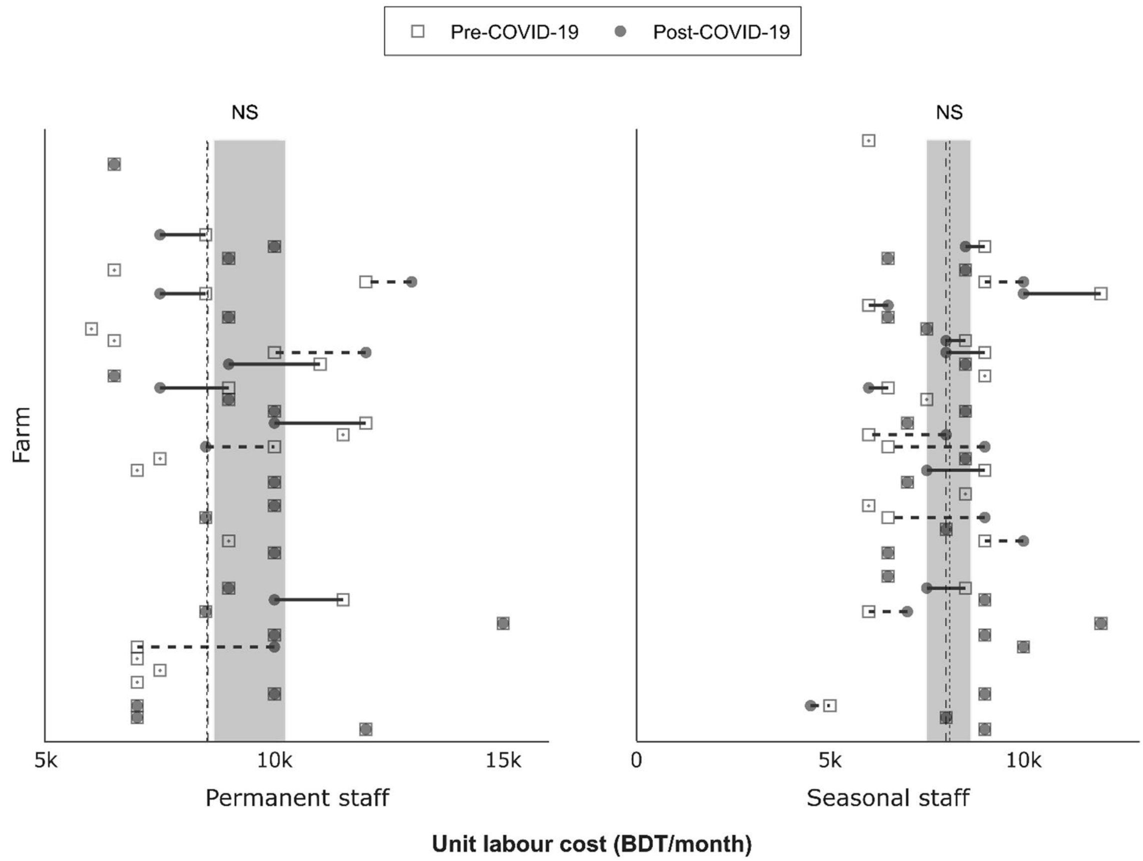

Fig. 4 Dumbbell plots showing the effect of COVID-19 on farm worker wages. In these plots, the *horizonal lines* represent farms that have decreased wages and a *dashed horizontal line* represents those that have increased wages. A single *hollow square with a dot* represents a farm that had staff pre-COVID-19 but reduced numbers to zero post-COVID-19. *NS* not significant

Wages paid to staff on shrimp farms have not decreased due to COVID-19

With farms laying off staff, and therefore an increase in the available workforce, it may be expected that the wages paid out to staff would also reduce significantly following COVID-19. However, the results indicate that this was not the case (see Fig. 4). The average unit wage for permanent workers (on farms with workers pre- and post-COVID-19) decreased from BDT 9534/month to BDT 9379/month, a decrease of 1.6%. For seasonal staff, the unit wage (farms employing seasonal workers pre- and post-COVID-19) increased from BDT 8000/month to BDT 8088/month, an increase of 1.1%. For non-technical staff, there was no change in their unit wage. Overall, the mean unit wage for all staff increased from BDT 8353/month to BDT 8526/month representing an increase of 2.1% on wage costs. Using a paired Student's *t* test, none of these increases were significant (all staff, $p=0.85$, 71 degrees of freedom (*df*); permanent staff, $p=0.43$, 28 *df*; seasonal staff $p=0.59$, 33 *df*).

Overall staff costs have reduced following COVID-19

Although COVID-19 resulted in the amount paid to workers not changing significantly, the overall unit wage bill (Unit labor cost × Number of staff) per farm decreased due to the pandemic. Prior to COVID-19, the average total unit labor cost for those farms employing staff was BDT 55,141/month and this reduced to BDT 45,141/month following COVID-19; a decrease of 18%. The mean percentage decrease in farm unit labor cost was 29.4%, although five farms cut their cost to zero and ten farms did not reduce their labor costs (see Fig. 5).

Shrimp farmers have endured a reduction in gross profit as a result of COVID-19

Using these reported values, an indication of the profitability of the farms pre- and post-COVID-19 could be made (see Table 5). As only ten farms provided complete records (cost prices pre- and post-COVID-19 for all categories), the relative gross profit and relative gross profit margin were calculated.

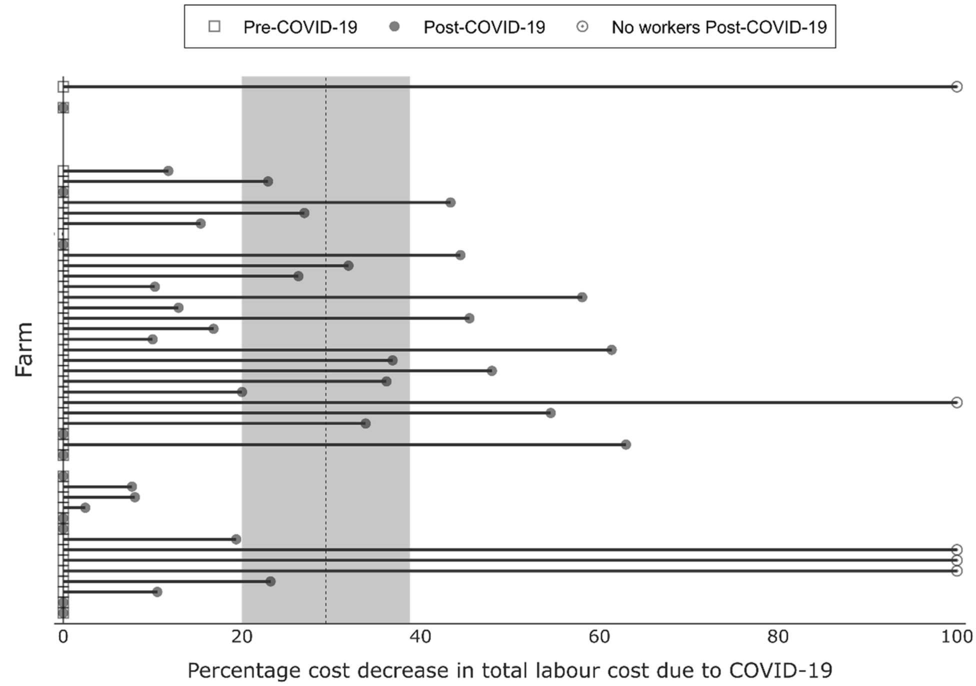

Fig. 5 Dumbbell plots showing farm total unit labor costs before and after COVID-19. In these plots, the *horizonal lines* represent farms that have decreased the total wage bill. A *hollow circle with a dot* represents a farm that reduced staff numbers to zero post-COVID-19 and therefore had a 100% drop in unit labor costs

Table 5 Impact of COVID-19 on the economics of shrimp farm management in Bangladesh

Parameter	Median costs (BDT per hectare)			Percentage change	Number of farms
	Pre-COVID-19	Post-COVID-19	Difference		
(a)Reported revenue[a]					
Total	**414,434**	**297,271**	**− 117,163**	**− 29.9**	**51**
(b) Reported production costs (non-fixed costs)					
Feed	59,405	71,287	+ 11,882	+ 14.1	45
Seed	74,887	99,850	+ 24,963	+ 33.3	51
Water supply	14,977	14,977	0	0	17
Electricity	29,087	35,553	+ 6466	+ 22.2	14
Transport	4254	5601	+ 1347	+ 19.1	22
Labor [b]	47,429	33,053	− 14,376	− 24.6	39
Medicine	9525	11,006	+ 1481	+ 15.0	45
Total	**208,823**	**231,286**	**+ 22,463**	**+ 16.2**	**51**
(c)Profit margins					
All farms					
Gross profit	248,580	65,652	182,928	− 42.8%	51
RGP[d]	1.0	0.58	0.42	–	51
RGPM[e]	1.0	0.91	0.09	–	51
Farms with complete records					
Gross profit [c]	15,218,375	7,867,475	7,349,900	− 46.2%	10
RGP	1.0	0.54	0.46	–	10
RGPM	1.0	0.81	0.19	–	10

[a]Derived from reported production and farm gate prices by the farmer

[b]Derived from reported labor costs and number of workers

[c]These farms have entered pre- and post-COVID-19 non-fixed costs for all the categories listed

[d]Relative gross profit

[e]Relative gross profit margin

The values which made bold were the total value, that need to be separated from other regular values

Table 6 Consumer prices for aquaculture products in local markets in southwestern Bangladesh

Aquaculture product	Consumer price (BDT per kg)		Price decrease (%)	Mark up difference (%)[b]	
	Pre-COVID-19	Post-COVID-19			
Shrimp and prawn [a]					
Macrobrachium rosenbergii (62)	899±105	654±68	26.9	+9.00	↑
Peneaus monodon (62)	932±65	748±81	19.8	+31.5	↑
Metapenaeus monoceros (46)	509±68	483±61	4.53	+9.82	↑
Metapenaeus brevicornis (31)	506±56	488±65	3.55	+10.1	↑
Mean	759+214	619±132	16.0	+15.1	↑
Finfish – salt water					
Lates calcarifer (37)	562±80	519±73	7.66	+29.4	↓
Mystus vittatus (29)	395±60	343±52	12.8	+15.3	↑
Labeo boga (28)	425±35	405±31	4.40	-2.21	↓
Mugil cephalus (24)	388±51	313±54	19.3	+3.02	↑
Scatophagus argus (13)	258±28	233±18	9.19	-12.3	↓
Pomadasys hasta (9)	248±18	232±17	6.40	-8.06	↓
Mean	422±115	380±111	10.1	+4.19	↑
Finfish – freshwater					
Labeo rohita (62)	251±37	237±37	4.04	+35.7	↑
Catla catla (62)	233±30	217±28	4.62	+32.3	↑
Cyprinus carpio (43)	157±26	135±22	13.9	+15.2	↑
Ctenopharyngodon idella (26)	222±69	200±54	7.52	+24.8	↑
Hypophthalmichthys molitrix (14)	144±15	115±9.4	7.58	+33.2	↑
Cirrhinus cirrhosis (26)	185±30	158±24	5.33	+18.3	↑
Puntius sarana (20)	120±6.9	105±11	6.94	+16.3	↑
Oreochromis mossambicus (22)	103±23	94±18	6.19	+56.9	↑
Pangasianodon hypophthalmus (5)	116±5.5	110±0	4.56	+6.22	↑
Mean	195±61	117±60	9.54	+25.4	↑

[a] *Penaeus orientalis* was removed from analysis due to a lack of farm gate prices

[b] The markup is the difference between the consumer price and the mean farm gate price

Decreasing product prices (discussed in "*COVID-19 has resulted in a decrease in the farm gate prices of shrimp*" section) for shrimp and prawn have severely affected revenues for shrimp farmers (see "*Farm profit and profit margins*" section of method for details on how profit was calculated). Although finfish prices have held up better, the farmers have still experienced a large drop in revenues by an average of 29% across all the farms. In addition, their total non-fixed costs of production have increased by an average of 16%, resulting in a fall in gross profit of 42.8%. Changes in staff numbers have led to a cost decrease of 24.6%, however, this has only slightly mitigated against large increases in seed prices (33.3%), and further increases in transportation (19.1%), feed (14.1%), medicine (15%), and electricity (22.2%).

Consumer prices fell but product markup increased following COVID-19

To understand the drivers for demand following the impact of COVID-19, a consumer survey was performed in three of the local markets to the shrimp farms. In total, 62 consumers from a wide range of age, education, employment, and financial status were surveyed across three markets, and the demographic of the participants can be found in Online Resource, Table S1.

Using consumer prices (presented in Table 6), before the pandemic the price of shrimp (*P. monodon* or *M. rosenbergii*) was on average 1.8 times other shrimp, 2.2 times saltwater finfish, and 4.7 times freshwater finfish species. Following COVID-19, these multiples were 1.4, 1.8, and 6.0, respectively, showing that *P. monodon* and *M. rosenbergii* became much more affordable relative to other shrimp and saltwater finfish. Consumers have taken advantage of the lower prices and higher availability (due to restricted travel movement of produce) of shrimp products by increasing the

Table 7 Results of a consumer survey into aquaculture product purchasing behavior in southwest Bangladesh

Purchasing behavior	Consumer responses			
	Shrimp		Finfish	
	Penaeus monodon	*Macrobrachium rosenbergii*	Saltwater	Freshwater
Change in amount purchased				
Increased	27	20	6	9
Decreased	0	3	5	12
No change	32	39	51	41
No response	3	0	0	0
Reason for change				
I have not changed the species purchased	32	38	51	41
I have changed the species because they are more available	15	11	5	8
I have changed the species because they are cheaper	0	1[a]	5[b]	5[c]
I have changed the species because they are more nutritious	12	12	0	1
I have changed the species because they are easier to prepare	0	0	0	0
I have changed the species because they are better for the immune system	0	0	0	0
Other	0	1	6	12

[a]From other response: "*Macrobrachium rosenbergii* was more costly than the *Penaeus monodon*"

[b]From other responses: "*Penaeus monodon* consumption has increased for being more reasonable", "Other shrimp species were available at a reasonable price" & "Purchase power reduced for margining income" (three responses)

[c]From other responses: "Other shrimp species have become reasonable", "Other shrimp species have become available and reasonable" (two responses) & "Purchase power reduced for margining income" (two responses)

amounts they have been purchasing (Table 7). For *P. monodon*, 46% of consumers increased the amount they purchased per week and their pattern of purchasing was altered due to increased availability (15 responses) and/or the perception that they are more nutritious (12 responses). For *M. rosenbergii*, 32% increased the amount purchased per week with only 5% decreasing the amount purchased, and their increased availability (11 responses) and/or more nutritious (nine responses) were the reasons given. Moreover, one consumer who commented that "prawn was more costly than the shrimp" reduced their purchase of *M. rosenbergii* in favor of *P. monodon*.

In contrast to increased purchasing of *P. monodon* and *M. rosenbergii*, finfish consumers generally did not change the amounts they purchased. For those that did alter their pattern of purchasing behavior, there was a similar number of consumers that increased or decreased the amount they purchased; 10% of consumers increased saltwater finfish purchases and 8% decreased the amount; for freshwater finfish, this was 15 and 19%, respectively. The most common reason for changing amounts purchased was more availability (87% of responses). Furthermore, there were four open responses suggesting that shrimp was being favored over finfish due to their more reasonable pricing level.

Although the decrease in farm gate price was passed on to the consumer, there was an increase in the markup of 16 out of 19 of the products (4/4 for shrimp and 12/15 for finfish). Interestingly, despite being the most affordable, the freshwater finfish species attracted the largest increase in markup (25.4%), whereas saltwater finfish markup was only around a 4% increase and shrimp 15.1%. The three species that displayed a decrease in markup were all saltwater fish species, specifically *Labeo boga*, *Scatophagus argus*, and *Pomadasys hasta*.

Discussion

National and international movement restrictions due to the COVID-19 pandemic have disrupted world trade (Love et al. 2021) impacting many lives and livelihoods across the globe. In Bangladesh, the export-led shrimp industry was hit by reduced international and national demand for product (Love et al. 2021; Mandal et al. 2021; Belton et al. 2021) coupled with increases in production input costs. In this study, we have analyzed the effect of COVID-19 on the shrimp farmer, a pivotal player in the shrimp production value chain. Using financial and production data provided by the farmers, we have shown that the farmers are experiencing a squeeze on their finances from the forward (product price) and backward (input costs) elements of the value chain (see Table 5). We have shown that farmers have followed remedial strategies including reducing labor costs through a decrease in staff numbers, and diversification of farm products has helped some farmers, especially the adoption of co-culture of finfish. Though these measures mitigated against price fall to some extent, all the farmers surveyed experienced a significant fall in income. Similar impacts were evident in shrimp farming in India (Kumaran et al. 2021), finfish farming in Bangladesh, Myanmar, India, Egypt, Nigeria, Malaysia (Waiho et al. 2020; Sunny et al. 2021; Belton et al. 2021; Hasan et al. 2021a), and in seafood trade across the globe (Coll et al. 2021; Love et al. 2021). However, the financial support for aquaculture has varied, and while the farmers of Malaysia, India, and Myanmar enjoyed access to government interventions and stimulus packages (Waiho et al. 2020; Kumaran et al. 2021; Belton et al. 2021), those in Bangladesh did not have the level of assistance.[4] In addition, a consumer survey was performed by visiting three markets adjoining to the surveyed shrimp farms under challenging conditions.

As reported by shrimp farmers in southwestern Bangladesh, we have shown that COVID-19 resulted in a reduction in the farm gate prices for the shrimp main cropping species *P. monodon* by 48.4% and *M. rosenbergii* by 62%, representing a significant adjustment to market value. A major cause of the price drop was the closure of processing factories, ice mills, and depots in Khulna, Satkhira, and Bagherhat regions (Hossain 2021) due to reduced international demand, labor non-availability due to movement restrictions, and travel reticence (Habib 2020; CGIAR 2020; Bashar et al. 2022), and cessation of transport chains (Ma et al. 2021). It would be expected that cheaper product availability in the local markets, coupled with the easier processing of shrimp compared to finfish, would increase the national demand, and therefore stabilize product prices. Indeed, we observed an increase in consumer demand for shrimp products in our survey. However, a concurrent reduction in the price of finfish, and the apparent preference for finfish by low-income households (Mandal et al. 2021; Hasan et al. 2021a) seems to have prevented this, thus driving down shrimp prices further.

It is likely that the high international demand for shrimp pre-COVID-19 resulted in less national exposure of the product (Islam et al. 2016) and therefore, a reduction in the diet of most people in Bangladesh (only 2.43 g/person/day according to Biswas et al. (2021)). This made the product more vulnerable to a change in the international position. It is interesting to speculate that the non-main crop shrimp cultivated (*M. monoceros*, *M. brevicornis* and *P. orientalis*) have remained in the local and national diet and therefore, their price drops were not as dramatic. However, this could also be due to much lower volumes of these species being produced. Hasan et al. (2021a) and Kumaran et al. (2021) recorded price falls of 13% for carps and catfishes in Bangladesh and by 35% for shrimps in India, whereas Belton et al. (2021) reported an at most 35% fall in Asian and African countries. Unfortunately, due to potential disease outbreaks or environmental challenges, shrimp farmers were unable to hold on to their stock until better market conditions (Kabir et al. 2020; Talukder et al. 2021). This led to 'panic harvesting and forced marketing', as referred to by Kumaran et al. (2021), where stock was harvested early and sold on before the harvest could be ruined. Moreover, although we report here drops in product prices and farm gate prices, we also revealed an increase in product markup, a feature observed in the finfish supply chain in Mymensingh (Hasan et al. 2021a). However, in Mymensingh, the consumer paid extra for some of the aquaculture products, but in the markets of southwest Bangladesh all shrimp and finfish products saw a price decrease. Therefore, the shrimp farmer appears to be shouldering more of the supply chain cost increases due to COVID-19 placing further economic strain on the businesses.

In response to potential economic hardship caused by depressed demand, shrimp farmers reduced their labor force. Permanent staff were subjected to the largest decline (24.17%) followed by seasonal staff (20.69%), which is a different scenario to that observed in the response of finfish farms to COVID-19 where seasonal staff reduction was preferred (Hasan et al. 2021a). It is likely that some of this reduction is down to an exodus of migrant employees at the start of the pandemic due to worries about being paid and a lack of health and social security (Harper et al. 2020), and the subsequent travel restrictions (Belton et al. 2021). The Bangladeshi shrimp sector has seen a gradual shift from extensive farming patterns, where 'one man fits all'[5] is practiced, to semi-intensive culture patterns, which follows a 'one man for one pond' strategy to reduce the risk of horizontal transmission of pathogens (Hasan et al. 2020). This inevitably resulted in a higher requirement for permanent staff and therefore an increased farm wage bill in comparison to extensive farms. However, as a consequence, this allowed these farms to mitigate against falling incomes by reducing

[4] Only 2% of the BDT 50 billion stimulus package budgeted for the agriculture sector was used to assist 78,074 fish, shrimp, and crab farmers (along with eel collectors) from 75 subdistricts in Bangladesh.

[5] 'One man fits all' refers to the fact that the farmer does all the tasks for all ponds on their farm, whereas 'One man for one pond' refers to a single custodian of each pond, thus reducing potential transmission between ponds.

the staff wage bill, however it is unclear whether this will have a knock-on effect for future harvests.

In our study, we report an average wage reduction of 1.6% for permanent workers, an increase of 1.1% for seasonal workers and no change for non-technical workers. Overall, this translated as an increase in the average wage of 2.1% following COVID-19. This small wage rise may be the result on extra working pressure imposed on the workers due to the smaller workforce on many farms. As reported by Hasan et al. [19], in finfish aquaculture, wage reduction by over 10% occurred in all three groups and non-technical staff bore the largest decrease. The different strategy employed in the shrimp sector may be due to the higher risks associated with disease outbreak and natural disasters (Kabir et al. 2020; Talukder et al. 2021), which necessitate retention of technical and skilled laborers on farms. Therefore, farms in the shrimp sector adapted to revenue pressures by retaining a smaller number of skilled and semi-skilled staff, thus reducing the overall wage bill by an average of 18% while retaining the best staff with consistent wages.

Although co-culture of species is common in semi-intensive and extensive systems, its use as a mitigation strategy against large fluctuations in product prices has not been considered. The practice has widespread use as a mitigation tool for prevention of severe disease outbreaks in monocultured crops, and therefore at the time of the COVID-19 outbreak some farmers in our survey were observed to co-culture other shrimp or prawn, finfish or a combination of both. Our results suggest that co-culture of the main crop with another shrimp or prawn species did not provide a significant mitigation strategy against large falls in the main crop price. Farms co-culturing shrimp were observed to suffer a smaller decrease in productivity following COVID-19, however this did not translate into a mitigation against revenue loss. This contrasts with the co-culture of finfish which also resulted in a smaller productivity loss, similar to that under shrimp co-culture, but attracted a significantly smaller reduction in total farm revenue. Due to the small sample size, however, the influence of some other factor of semi-intensive production cannot be ruled out as the mitigating factor and more work is needed to resolve this issue.

The fact that co-culture of the main crop with finfish acted as a useful mitigation tool suggests the value of farmers diversifying by production of a different commodity type. Why this is the case is a complex situation, but with most farmers co-culturing at least four different species of finfish, it is certain that this allows increased flexibility in harvest cycles to achieve best prices for the products. This is clearly an area for further study. It is also likely due to a smaller demand for shrimp in the local markets and the inherently larger costs associated with shrimp farming in terms of feeding and health maintenance (Ahmed et al. 2018). Finfish are farmed on natural food items and, with the availability of low-priced fingerlings, they require little cost and therefore attract better returns. While this did not overcome the financial hardship induced by COVID-19, as there was also a concurrent reduction in farm gate price of finfish, better disease resistance meant they could remain in ponds longer until prices improved. Our results suggest product diversification through co-culture of finfish with shrimps can reduce economic risk and be considered as a resilience measure against future challenges. Similar indication with integrated multitrophic aquaculture (IMTA) was concluded by Sarà et al. (2021) as a coping strategy against COVID-19 and other anthropogenic crises.

Before COVID-19, most of the shrimp farms operated with tight budgeting to maintain a small profit while incurring high economic and biological risks (Hasan et al. 2020). For the farms in our study, overall economic loss from COVID-19 was in the margin of 42–46% on gross profit, higher than the findings with finfish and other seafoods by Hasan et al. (2021a), Kumaran et al. (2021) and (Belton et al. 2021). Among the obstacles faced, disruption of transportation directly increased production costs by 19.1%. However, it also indirectly affected other production costs, such as feed, seed, and medicines, which was reflected by increases in these items. For example, interruption of trawling to collect berried shrimps during the COVID-19 ban on fishing (Belton et al. 2021), the shortage of skilled labor, restriction on transport facilities, and disrupted hatchery production (Mamun et al. 2021) pushed the price of seed up; in our survey, seed cost rose by 33%. Interestingly, Indian hatcheries also faced similar problems from an inadequate labor force and specific-pathogen-free brood stocks were adversely affected (Kumaran et al. 2021). Feed costs rose 14% due to feed companies being unable to meet farm demands because of limited cargo shipments, national logistic interruption, and labor shortage. Waiho et al. (2020) and Kumaran et al. (2021) reported an equivalent situation in Malaysia and India, respectively. In our survey, medicinal costs rose by 15% most likely the result of lower availability due to transport restrictions, in addition to a high level of use in the previous season; a result of higher-than-normal rainfall and abrupt temperature changes increasing the incidence of disease outbreak (Hasan et al. 2020, 2021a). Surprisingly, COVID-19 also increased electricity costs, possibly due to ghost billing, where consumption was assumed by the Bangladesh Power Development Board without visiting farms amid the pandemic (Shitu 2020).

It is unclear what the effect of reduced profitability, farmers laying off an engaged workforce, and altered patterns of culture will be on production sustainability in the near and longer term. A key concern is whether the large impact of COVID-19 on revenue has driven shrimp farmers to a level of debt that leaves insufficient capital to budget for the next production cycle. Many farmers in Bangladesh lease their farmland and, faced with no alternative cropping patterns, have no other option but to restock to pay debts; a sentiment expressed by shrimp farmers from Khulna (Haque and Belton 2021). In India, 27% of shrimp farmers reported an inability, or aversion, to start the next production cycle because of poor demand prediction and difficulties in getting the necessary inputs (Kumaran et al. 2021). A similar tendency was reported in Thailand, Malaysia, Myanmar, and Vietnam (Dao 2020; FAO 2021) and the slow rebound of demand for imported seafood in China and the EU (Love et al. 2021) further hampers rejuvenation of the industry. Finally, reduced skills in the sector through unemployment has the potential to leave a legacy of poor production and product quality. It also puts into jeopardy the aspiration of the aquaculture industry creating jobs for 25% of the unemployed in Bangladesh by 2023 (BSFF 2018).

Conclusions and recommendations

Travel restrictions imposed due to COVID-19 have placed the shrimp farmers of southwest Bangladesh in financial jeopardy through elevation of the price of farming inputs and depression of demand in the national and international markets. Farmers have adapted to challenging times by altering their labor force and species being cultured and sold. Of concern is the future collapse of segments of the shrimp sector, which would resonate on food security, livelihoods, and sustainability of farming in the region.

Results from our study reveal that there is a key requirement for monetary support for the sector in the short term to shore-up the supply chain and ensure setting of future production cycles. It would be helpful to declare farming activities, and their associated movements, under 'indispensable activities', while not undermining necessary sanitary provisions, and for the national stimulus package to operate on a 'sliding scale' for shrimp farmers rather than on an equitable basis[6] (Belton et al. 2021). Variations in farm size, investment, and culture patterns can be large in the shrimp sector and by taking this into account survival of all shrimp farmers, including those operating extensively, would be more likely in the region.

National consumption of shrimp products should be promoted, similar to initiatives undertaken by the Ministry of Fisheries and Livestock to promote egg and dairy products (UNB 2021). Despite the economic shockwave, quality control and inspection by the Department of Fisheries must not compromise good aquaculture practice (farm level) and good manufacturing practice (processing level). A premium-quality product should be ensured to retain international trust in the product as the markets improve. Organic certification can be promoted to produce shrimp by adopting a low-cost extensive system, which has been experienced by many farmers in southwest Bangladesh. Finally, this paper proposes longer-term research on mitigation strategies with a view to building a sustainable and resilient sector to ensure future prosperity.

Limitations

Our survey was performed soon after the first lockdown occurred in Bangladesh when traveling to the shrimp farms and getting agreement from the farmers to participate was challenging. As this limited the number of surveys that could feasibly be carried out, we decided to have a more in-depth survey with the 51 farmers that agreed to COVID-secure face-to-face interviews. The data used in this study was gathered through self-reporting and is therefore vulnerable to bias. For example, respondents may be inclined to give answers that they believe to be desired by the researcher (social desirability response). As such, this study may overestimate the economic impact of COVID-19 because the responses given fit a narrative of perceived negative impacts. The extent of this bias could not be evaluated. At present, there are no audited indicators on local costs and retail prices for the extensive and semi-intensive shrimp sector in Bangladesh. Future studies should address this limitation either through data gathering or by more detailed case studies.

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Data availability Data sharing is not applicable to this article. The data that support findings of the study will be available on request.

Declarations

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

[6] The 'sliding scale' approach weights support in favor of smaller boats or farms, whereas the 'equitable' approach allocates a flat fee per unit area or size.

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