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Perceived Impacts of Climate Change on Coastal Aquaculture in the Cyclone Prone Southwest Region of Bangladesh

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ABSTRACT

The southwest region of Bangladesh is particularly vulnerable to a range of climatic threats, including cyclones, prolonged flooding, sea level rise, saltwater intrusion, drought, and riverbank erosion. The study investigates how these different drivers affect aquaculture systems and aims to provide critical insights for sustainable management. The survey work focused on the problems, vulnerabilities, migration, and adaptive strategies of communities of the southwest region of Bangladesh, that rely heavily on shrimp, fish, and crab production for their livelihoods. Data were collected from the 80 respondents across four unions (Atulia, Burigoalini, Gabura, and Bhurulia) in Shyannagar Upazila, Satkhira District, using a structured questionnaire survey and focus group discussions. Findings reveal that climate change events have significantly changed shrimp farming in enclosures, pond aquaculture, and crab point management, and negatively impacted livelihoods. Pond aquaculture appeared to be the most vulnerable to climate change conditions, followed by shrimp farming in enclosures and crab points. Furthermore, the adverse effects of climate change compelled human migration within the study area, primarily driven by the search for employment. This study provides evidence of the effects of various climate change stressors on shrimp, fish, and crab production systems and the adaptive difficulties of the communities dependent on aquatic ecosystems. As the natural calamity like cyclone cannot be prevented, understanding the impact of previous events may help people of the affected area as well as the policy makers to plan for better survival.

1. INTRODUCTION

Over the past two decades, discussions of the effects of climate change and related impacts have become common in national and international forums. Scientists, environmentalists, and even politicians have stated various opinions and findings regarding the changing climate and its current and anticipated impacts. The impact of global climate change is being researched by the Intergovernmental Panel on Climate Change (IPCC) and the United Nations Framework Convention on Climate Change (UNFCCC). Climate impacts could be confined to a single location or affect the entire planet and could happen in terms of average weather conditions or the distribution of weather events around an average (Yazdi and Shakouri, 2010). Humans have been recognized as the major contributors to climate change through the use of fossil fuels such as coal, oil, and gas (Doubleday et al., 2013; Gao et al., 2016; Palmer and Stevens, 2019) as well as deforestation and forest degradation (Khaine and Woo, 2015) that emit greenhouse gases (GHGs) into the atmosphere.

Bangladesh is highly exposed to natural disasters and vulnerable to the effects of climate change (Kabir et al., 2016; Alam et al., 2020; Sarker et al., 2020; Rahaman et al., 2021). Bangladesh was ranked sixth among the nations most adversely affected by climate change between 1997 and 2016 by the Global Climate Risk Index 2018 (Naser et al., 2019). Global climate change-related problems, such

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as saltwater intrusion, sea level rise, drought, and riverbank erosion, significantly impact Bangladesh's southern region (Alam et al., 2010; Khan et al., 2011; Rana et al., 2011). Around the Indian subcontinent, the IPCC expects sea levels to rise between 15 and 38 cm by 2050 and 46 and 59 cm by 2100. By noting the percentage of inundation for the Sundarbans, the World Bank Report 2000 estimated the sea level rise for those areas step by step (Das, 2022).

Human activity and climate change have directly impacted coastal aquaculture. This human intervention directly forces human migration (Naser et al., 2019). Islam et al. (2022) showed that people in southwest areas of Bangladesh were particularly exposed to climate stressors such as riverbank erosion, salinity intrusion, temperature increase, salinity increase, and drought.

Shyamnagar Upazila (sub-district) of Satkhia District covers an area of 1,968 km^2, located between 21°36' and 22°24' north latitudes and in between 89°00' and 89°19' east longitudes. A total of 19,997 ha of land of Shyamnagar Upazila is currently used for fish, shrimp, and crab farming, which is 10.5% of the total area of the Upazila. The Bay of Bengal is on the south of Shyamnagar Upazila. So, it is prone to almost all the cyclones originating in the Bay of Bengal that traverse to the Bangladesh Coast. The major cyclones since 2007, namely Sidr, Aila, and Amphan, caused widespread damage in Shyamnagar Upazila (Tajrin and Hossain, 2017).

Due to Shyamnagar's significance as a fish, shrimp, and crab farming area and the threat posed by climate change on Bangladesh's Southwest Coast, we investigated how residents of Shyamnagar Upazila perceive the effects of climate change on fish, shrimp, and crab farming. This study also provides new information on the geographical human movement and vulnerability of Bangladesh's southwest shore.

2. METHODOLOGY

2.1 Study areas

The study was conducted in Shyamnagar Upazila in the Satkhira District of Bangladesh. As of the 2011 census, Shyamnagar Upazila had 72,279 households and a population of 318,254. Shyamnagar Upazila has 12 Unions. We collected data from four Unions (the smallest rural administrative and local government unit in Bangladesh comprising several villages): Atulia, Burigoalini, Gabura, and Bhurulia (Figure 1). The GPS coordinates of all four locations were recorded. Atulia union is located between 22°20'59" and 22°21'19" N latitude, and 89°12'14" and 89°11'47" E longitude; Burigoalini union is located between 22°28'27" and 22°26'17" N latitude and 89°20'27" and 89°19'07" E longitude; Gabura union is located between 22°24'07" and 22°22'17" N latitude and 89°27'15" and 89°25'05" E longitude; Bhurulia union is located between 22°09'29" and 22°08'19" N latitude, and 89°13'11" and 89°12'01" E longitude.

2.2 Secondary data review

We collected secondary data from the Department of Fisheries (Bangladesh), Bangladesh Bureau of Statistics, and existing literature. We also collected secondary data on annual sea level rises and occurrences of floods in Shyamnagar Upazila from the Bangladesh Meteorological Department (BMD) in Dhaka.

2.3 Collection and analysis of primary data

We developed a questionnaire that included the socio-economic information of the respondents, fish farmer types, names of fish/shellfish/mollusk species used for farming, trend in the production and profitability of fish, shrimp, and crab, and the driving forces behind the changes, threats to these production systems, livelihood opportunities, and trends in human migration. We obtained a list of people involved in fish/shrimp/crab farming from the Shyamnagar Upazila office of the Department of Fisheries of the Government of Bangladesh. We then randomly selected and interviewed 20 respondents from the four selected unions. 59% of participants were between 20 and 40 years old, with 30% above 40 years old and 11% under 20 years old. We performed four Focus Group Discussions (FGD), one in each of the four study unions with randomly selected group members. FGD participants included fish farmers, shrimp farmers, crab point owners, and community members. Based on the gathered information, we categorized the farms in the study area into three types: small (less than 0.8 ha), Medium (0.8 to 1.6 ha), and large (greater than 1.6 ha).

2.4 Vulnerability assessment

We measured the vulnerability of location based on Exposure (E), sensitivity (S), and adaptive capacity (AC) by the following equation (Yohe et al., 2002):

$$\text{Vulnerability} = E + S - AC$$

Where Exposure = Likelihood of threats × Magnitude of the impacts

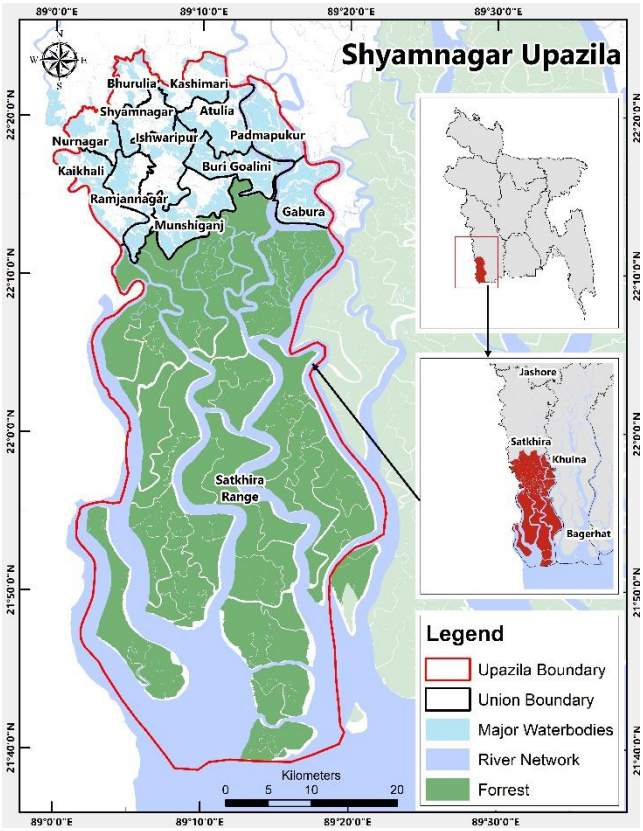

Figure 1. Map of Bangladesh showing the study area. The names of the Unions are shown in the map.

Threats and impacts are floods, erratic rain, salinity, sea level rise, temperature, and storm surge.

2.5 Quantifying the vulnerability assessment factors

1) Likelihood of flood (number of times): 5=very high (more than three times in a year), 4=high (3 times in a year), 3=moderately high (2 times in a year), 2=medium (1 time in a year, and 1=Low (flood with no impact)

2) Magnitude of the impacts of the flood (Duration of flood): 5=very high (more than 15 days), 4=high (10-14 days), 3=moderately high (7-9 days), 2=medium (4-6 days), and 1=low (2-3 days)

3) Likelihood and magnitude of the impacts of erratic rain, sea level rise, salinity intrusion, temperature rise, and storm surge: 5=very high, 4=high, 3=moderately high, 2=medium, and 1=low

4) Sensitivity (S): Sensitivity means the degree to which fish/shrimp/crab farmers depend on aquatic resources as a primary livelihood strategy, and are therefore susceptible to any change in the sector. 25=very high (80% or above people impacted), 20= high (70-79% of people impacted), 15=medium (50-69% of people impacted), and 10=low (50% or less of people impacted).

5) Adaptive Capacity (AC): Adaptive capacity is determined based on poverty status, literacy, access infrastructure in the form of community support, roads, educational institutes, medical facilities, government and NGO assistance during emergencies, electricity coverage, drinking water facilities and presence of other amenities. 50=excellent, 30=very good, 20=good, 10=moderate, 5=poor, 2=very poor, 1=extremely poor.

6) Migration: Community perceptions of permanent, temporary migration, and non-migrants were analyzed based on a questionnaire survey and FGDs. The values indicate the percentages of the respondents who agreed with the statement that natural hazards forced people to migrate.

All collected data were processed and analyzed by using MS Excel 2021, version 2107 (Microsoft Corporation, NY, USA).

3. RESULTS AND DISCUSSION

Bangladesh, due to its geographical location, receives about 40% of the total impacts of global climate change (Dasgupta et al., 2010). We analyzed the perceived impacts of climate change on the production systems of fish, shrimp, and crab farms and the livelihoods, vulnerability, and coping strategies of

the fish, shrimp, and crab farmers of Bangladesh's natural calamity-prone southwest region. The education level of respondents in the study area appears to be very poor: 24% were illiterate, 40% could sign only, 20% had primary level education, and only 6% had above secondary level education. Most respondents (56%) had small-sized farms (less than 0.8 ha), 18% had medium-sized farms (between 0.8 and 1.6 ha), and 16% had large-sized farms (greater than 1.6 ha). We analyzed the perceived impacts of climate change on the production systems of fish, shrimp, and crab farms and the livelihoods, vulnerability, and coping strategies of the fish, shrimp, and crab farmers of Bangladesh's natural calamity-prone southwest region.

3.1 Perceptions of the respondents on the aquaculture systems

Cultured species varied in the three systems (Shrimp farming enclosure, Crab point, and fish ponds). The most preferred cultivable species for livelihoods ranked according to the focus group discussions of the respondents are listed in Table 1. In shrimp farming enclosures, the black tiger prawn (*Penaeus monodon*) was the most cultured species. *P. monodon* is a marine species and can grow well in normal seawater. The growth and production rate of *P. monodon* is higher than other shrimp species farmed in Bangladesh. As the salinity in the shrimp farming enclosures is high, no freshwater species can grow well in these enclosures. From July 2021 to June 2022, 24,802 metric tonnes of *P. monodon* were produced in Satkhira District, whereas the total production of all finfish species was 38,474 metric tonnes (FRSS, 2022). The high price of *P. monodon* in the local and international markets also inspires farmers to culture this species. Brown shrimp (*Metapenaeus monoceros*), Giant freshwater prawn (*Macrobrachium rosenbergii*), and Indian white prawn (*Metapenaeus affinis*) were also cultured with the black tiger shrimp. Mud crab (*Scylla serrata*) was the only cultured species in crab points. Several species were cultured in fish ponds, including Nile tilapia (*Oreochromis niloticus*), barramundi (*Lates calcarifer*), rohu *(Labeo rohita*), catla (*Catla catla*), mrigal (*Cirrhinus cirrhosus*), and pangasius (*Pangasianodon hypophthalmus*).

Post larvae (PL) of *P. monodon* are readily available in hatcheries and local rivers and estuaries. Brown shrimp (*Metapenaeus monoceros*), mud crab (*Scylla serrata*), and barramundi (*Lates calcarifer*) were the second, third, and fourth-ranked cultured species, respectively, because these species were sold rather than consumed for subsistence, due to their high market value. Nile tilapia ranked fifth because of its low demand and lower market price. Pangasius, rohu, catla, Indian white prawn andsilver barb (*Barbodes gonionotus*) were the sixth, seventh, eighth, ninth, and tenth-ranked cultured species, respectively (Table 1). All these species are cultured due to availability, high demand, and reasonable price.

Table 1. Important cultured fish, shrimp, and crab species, ranks and reasons of importance

Mean rank	Local name	Common English name	Scientific name	Reasons	Production trend
1	Bagda	Black tiger shrimp	*Penaeus monodon*	High price and market demand, cash crop	Increasing
2	Horina chingri	Brown shrimp	*Metapenaeus monoceros*	High market demand, easily cultivable with Bagda, medium price, available	Stable
3	Kankra	Mud crab	*Scylla serrata*	High market demand, high price, available, cash crop.	Increasing
4	Bhetki	Barramundi	*Lates calcarifer*	High market demand, less available	Decreasing
5	Tilapia	Nile Tilapia	*Oreochromis niloticus*	Market demand, available, cheap	Increasing
6	Thai Pangas	Thai Pangas	*Pangasianodon hypophthalmus*	Available, high growth rate, sold	Increasing
7	Rohu	Indian Major carp	*Labeo rohita*	Available, high demand, eaten	Stable
8	Catla	Indian Major carp	*Catla catla*	Available, high demand, eaten, sold	Stable
9	Chaka Chingri	Indian white prawn	*Metapenaeus affinis*	Available, good price, sold	Decreasing
10	Sarpunti	Thai barbs	*Barbodes gonionotus*	Good price, eaten, sold	Decreasing

The first four species (*P. monodon, M. monoceros, S. serrata*, and *L. calcarifer*) are marine or brackishwater species and are the most preferred species for culture in this region. *P. hypophthalmus* has become one of the cheapest protein sources in Bangladesh because of its wide range of environmental tolerance, excellent growth, and survival rate. Pangasius can be cultured at four ppt salinity with a desirable growth rate similar to freshwater (Mandal et al., 2020). Hasan et al. (2023) reported that the pangasius fingerlings can be cultured in salinities up to 10 ppt without negatively affecting growth and survival rate. Nile tilapia is another important aquaculture species in Bangladesh. *O. niloticus* can tolerate brackish water conditions and can be grown in intensive farming systems. De Alvarenga et al. (2018) recommended salinity between 4 and 8 ppt (6 ppt) salinity to improve the growth performance of tilapia in the initial culture phase of biofloc. The final weight and specific growth rate of tilapia fingerlings were reported to be higher in shrimp farming enclosure at salinities of 4 and 8 ppt compared to 0 ppt under biofloc systems (Khanjani and Alizadeh, 2024) and recirculating aquaculture systems (RAS) (Dawood et al., 2023). Mirera and Okemwa (2023) state that *O. niloticus* could fully acclimate to seawater.

The present study indicates that the farmers of Shyamnagar upazila also culture the Indian major carp to some extent, and efforts have been made to assess the potentiality of these species in inland saline-affected areas. The Indian major carp rohu can tolerate salinity up to 10 ppt, but it is expected to perform well in less than six ppt salinity (Kumar et al., 2018). However, with an increase in salinity, the survival rate, growth, and tissue ascorbic acid level in *L. rohita* decreases, which indicates that it is vulnerable when exposed to salinity for a long durations (Sarma et al., 2020). An increase in salinity level significantly impacted the growth and physiology of the Indian major carp. This species can be reared in low-saline areas for some time, which will not only help in the utilization of salt-affected areas but also help generate employment and income (Ahirwal et al., 2021). The salinity of inland ponds in the coastal region varies over time, even having 0 ppt salinity during periods of extreme rainfall. Diversification of cultured species may help farmers cope with the impact of calamities linked to climate change.

3.2 The productivity of different systems

The respondents identified the key factors affecting productivity in each aquaculture system in the study area, and the main impacts and responses.

In shrimp farming enclosures, collected data included i) the size of the farming enclosure, ii) species composition (number of species and abundance of each species), iii) input costs (seed, fertilizer, and other chemicals), and iv) profitability as the critical factors affecting changes in productivity (Table 2). Profitability has changed due to increased production costs, unavailability of good quality seed (shrimp post-larvae and juveniles), and the incidence of bacterial and viral diseases.

According to the respondents, the siltation of shrimp farming enclosures due to cyclones including Sidr in 2007, Aila in 2009, Amphan in 2020, and many other climate change adversities are the critical factors in the negative changes in shrimp farming enclosures.

The key factors reported for the crab points included productivity (kg/unit area), the average size of the crab point, species composition, input costs (seed, feed), and profitability (Table 2). The significant changes in the crab culture system were- a) Sidr, Aila, and Amphan destroyed a substantial number of crab points; b) natural catch of crab used for stocking the crab points decreased substantially; and c) over the last 2-3 years (post-Amphan), hundreds of people became involved in crab fattening; d) crab consumption by villagers of all religions and castes followed an increasing trend.

The significant changes reported for freshwater fish ponds were; a) Sidr, Aila, and Amphan destroyed all the valuable freshwater wild fish species people used to catch for their household consumption; b) tilapia increased slightly during the pre-Amphan period, and a considerable increase was observed in the culture ponds afterwards; and c) stocked culture fish (Indian major carps) not growing well (Table 2).

3.3 Major changes in coastal aquaculture systems

The respondents in the FGDs identified the major events over the last 20 years that shaped their aquaculture systems regarding farm design and practice, species selection, and use of inputs (Table 3). The participants reported that cyclones Sidr (2007) and Aila (2009) caused the devastation of cereal crops, vegetables, fruits, and timbers, salinized the land and water, and lowered soil and water fertility. Several years after Sidr and Aila, the villagers had difficulty

growing plants in the soil and farming freshwater fish in the ponds. Therefore, among others, Sidr (2007), Aila (2009), and Amphan (2020) cyclone were considered in almost every response by the villagers concerning the changes in the culture practices and species over the selected period.

Table 2. Changes in productivity and profitability in different systems (shrimp farming enclosure, crab point, and fish pond) compared to 5/10 years back

System	Changes in productivity	Changes in profitability	Realized impacts		Livelihood responses
			From climate change action	From management	
Shrimp farming enclosure	Size (+) Species richness (+) Input costs (+) Water depth (−)	Profitability increasing or sometimes the same or decreasing	- Silt increase - Unviability of Post-larvae/juvenile - Salinity levels are increasing extremely	- Decrease in farming enclosure size - Increasing stocking density - Do not follow - Good Aquaculture Practice (GAP) - Shrimp disease	Diversification of species
Crab point	Size (+) Input costs (+) Water depth (−)	Profitability increasing	- Reducing natural catch - Devastation of crab points by cyclone	- Feeding crabs small pieces of tilapia	- Newcomers to crab fattening - Increased intake of crab
Fish pond	Water depth (−) Species composition (−) Input costs (+)	Profitability decreasing	- Salinity intrusion in pond water - Decreasing wild stock	- Tilapia increase - Stocked culture fish decrease	- Re-excavate ponds - Regular change of pond water

Table 3. Major events over the last 20 years affecting aquatic systems productivity

Factors	2002	2012	2022
Farm design and practice	- Large farm area - Proper water depth in shrimp farming enclosure, crab point, and fish pond	- Large farm area - Due to siltation, the depth of the water in shrimp farming enclosures and ponds dropped - Due to siltation and Sidr, the depth of the water in shrimp farming enclosures and ponds further dropped	- Smaller and divided farm area - Due to siltation, Aila, Amphan, and other factors, the water depth in shrimp farming enclosures and ponds further dropped.
Species abundance	- Rich in species diversity of freshwater wild fishes in ponds - No aquaculture done in fish in ponds	- River species diversity decreased - Exotic craps stocked in ponds - Introduction of tilapia (*Oreochromis niloticus*) in ponds and shrimp farming enclosures	- Wild fish decreased extensively from ponds - Ponds stocked with native and exotic carps, poor production
Input used	- No feed in the farm area - No fertilizer in the farm area	- No feed and fertilizer in fish ponds - Feeding shrimp with snail meat, using a yeast-molasses mixture, lime, and other fertilizers in shrimp shrimp farming enclosure - Chopped tilapia and eel fish for crab	- No feed and fertilizer in fish ponds - Many shrimp farming enclosure owners attempt to prepare the enclosure by removing bottom mud, liming, and feeding shrimp with feed pellets. - Chopped tilapia and other low-value fish for crab

3.4 Driving forces behind the changes

Many actors in the study area have changed productivity and livelihood. Shyamnagar Upazila is very vulnerable and influenced by climate change effects. The major threats related to climate change, as reported by respondents in the study areas, include increased salinity, sea level rise, drought, storm surge, long-term floods, riverbank erosion, and lack of finance (Table 4).

Drought (due to increased temperature or reduced rainfall) was found to be the most hazardous environmental factor for the three aquaculture systems (shrimp farming enclosure, crab point, and fishpond). Kabir et al. (2016) studied Baliatali and Ghopkhali villages of Amtali Upazila of Barguna District and found similar results.

Table 4. Driving forces behind the changes

Effects	The Magnitude of effects on different systems			Impact on coastal aquaculture
	Shrimp farming enclosure	Crab point	Fish pond	
Increased salinity	H	M	VH	- Disease outbreaks in different systems - Production is gradually decreasing.
Drought	VH	H	VH	- Loss of wild and cultured stock. - Increased production costs - Loss of opportunity as production is limited.
Storm surge	H	VH	VH	- Loss of aquaculture stock and damage to or loss of aquaculture facilities and fishing gear. - Additional cost for designing new facilities. Increased insurance cost.
Long time flood	VH	VH	VH	- Disease outbreak - Cultured area is flooded.
Riverbank erosion	VH	VH	VH	- Reduced area available for culture - Increased system management costs
Sea level rise	H	M	VH	- Reduced area available for freshwater aquaculture. - Shifts in species abundance, distribution and composition of fish stocks and aquaculture seed. - Reduced freshwater availability for aquaculture and a shift to brackish water species. - Reduced seed for aquaculture. Worsenede Exposure to waves and storm surges and risk that inland aquaculture becomes inundated.
Finance	VH	VH	VH	- Problem in management

VH=Very High, H=High, M=Medium

In shrimp farming enclosures, long floods and riverbank erosion cause very high adverse effects, and drought and salinity intrusion cause high and medium adverse effects on production, respectively. Anzum et al. (2023) also reported that increased temperature, reduction in rainfall, long summers, floods, and cyclones affected the farmers. People in the study area expressed interest in traditional methods rather than modern aquaculture practices. Howlader and Akanda (2016) reported the same outcomes in Galachipa and Patuakhali Sadar upazila under the Patuakhali District of Bangladesh. In crab points, drought, riverbank erosion, and longtime floods affected the study area highly, and salinity intrusion and storm surges affected moderately and highly, respectively. Hossain et al. (2018) also reported similar findings in their Atulia Union of Shyamnagar Upazila study. In fishponds, salinity intrusion, sea level rise, long duration flood, riverbank erosion, and drought affected the study area very highly. Shaibur et al. (2017) also observed the same facts for Shyamnagar, Satkhira. Chowdhury et al. (2012) reported that, on average, there are five storms per year or once every 9.5 weeks, and if the increasing trend continues, the cyclonic frequency may reach eight storms per year or once every 6.5 weeks by 2050 in Shyamnagar upazila.

3.5 Vulnerability and human migration in the study area

Natural hazards such as cyclones, long-duration floods, and droughts force humans to migrate from one place to another, temporarily or permanently, to take up employment or establish residence. We identified both temporary and permanent migration in the study area. The present study showed that the highest level of permanent (not returning to the place of origin) human migration (40%) occurred in the Bhurulia Union, where only 5% of people did not practice any form of migration. On the contrary, 40% of respondents were nonimmigrants in Atulia Union. The rates of permanent migration of Atulia, Burigoalini, Gabura, and Bhurulia Union were 10%, 25%, 35%, and 40%, respectively.

On the contrary, the rates of temporary migration (migration to avoid calamities but returning to the place of origin) in Atulia, Burigoalini, Gabura, and Bhurulia Union were 50%, 60%, 55%, and 55%, respectively. Searching for new jobs was found to be the most common cause of human migration (60%), followed by avoiding climate disasters (26%). In the last several years, people in the study area have lost wage-earning and livelihood opportunities due to climate-induced disasters and have become poor. They migrated to nearby and faraway districts for

laborious jobs like rickshaw pulling, brick field labour, and seasonal labour. This study revealed that migrations were mainly limited to the male population. Most of the people who migrated (seasonal or permanent) were unskilled. Climatic disasters were cited as the reason for migration in 26% of cases. Besides, 14% migrated for various other reasons (for a better lifestyle, opportunities, and study).

The present study's findings also aid in our understanding of the adaptive strategies available to achieve ecological and livelihood sustainability. Recent studies assessed the adaptive capacity of coastal aquaculture to cope with climate change (Melnychuk et al., 2014; Leith et al., 2014). Based on the findings of the present study and the body of current literature (Das, 2010; Chowdhury et al., 2012; Didar-Ul Islam et al., 2015; Akhter et al., 2016; Hossain and Hasan, 2017; Anzum et al., 2023) and South Asian countries (SA) contexts', primary adaptive reactions identified to the vulnerability of various coastal aquaculture systems are rising human migration, and diversifying livelihoods.

Due to its unique geographical features, Bangladesh suffers from regular natural hazards, including floods, tropical cyclones, storm surges, and droughts. These hazards lead to loss of life, damage to infrastructure, adverse impacts on livelihoods, and often displace individuals and communities from their places of residence. Khatun et al. (2021) reported that the people of the alluvial lands of the three major rivers of Bangladesh, namely -the Padma, the Jamuna, and the Meghna, remain under threat of erosion. They migrate seasonally or even permanently to neighbouring areas as an adaptation strategy to reduce risks and uncertainties. According to Mallick et al. (2022) and Black et al. (2013), climate-induced migration has somewhat stagnated in theorizing the concept of "migration as adaptation" and investigating the causes, drivers, factors, and dynamics of decision-making concerning migration or displacements. Migration to the cities not only creates an opportunity for temporary/alternative solutions for resettlement and livelihoods but also creates tremendous challenges for urban policies to adapt (Vinke, 2020).

Notably, the government of Bangladesh has initiated short-term, mid-term, and long-term development planning strategies, which include Five-Year Plans, Vision 2041, Second Perspective Plan, and Bangladesh Delta Plan 2100, along with the UN Agenda 2030 for achieving the sustainable development goals (SDGs). These plans mainly focus on thematic/sectoral and hotspot-specific strategies, policies, and programs, ignoring the regional imbalance and disparities in development and resource distribution, population size (Nahar et al., 2019), the occurrence of natural disasters, and production of climate/environmental migrants (Jones et al., 2016).

Shyamnagar Upazila is area in the Khulna division that produces the most migrants, and the study showed that the level of migration in the four Unions of Shyamnagar Upazila is similar to that reported in previous reports (Wiig et al., 2023; Akhter et al., 2016; Didar-Ul Islam et al., 2015). Since 2008, the number of disasters and internally displaced persons has increased enormously. The number of disasters recorded between 2008 and 2021 strongly correlates with the number of displaced persons in Bangladesh (Sakapaji, 2023).

3.6 Livelihood opportunities in the study area

There are limited livelihood opportunities in the study area (Figure 2). Most of the respondents were agriculture farmers/labourers (67), migrant workers (72), or brick kiln labourers (53). Other livelihoods are government service, rickshaw puller, NGO worker (trainers and micro credit providers), auto-rickshaw driver, wood collector, shopkeeper, motorcyclist, pseudomedicine practitioner, street vendor, cooking fuel collector, and palm-leaf collector/seller.

People of this locality have very few options for livelihood diversification. Most people are attached to farming or labouring (Hossain and Hasan, 2017). Climate change makes life miserable for this locality's people and forces them to abandon their family occupations (shrimp farming, crab fattening, and fish culture). Moreover, the scope of their work opportunities could be bigger. Most farmers opt for day labour, van or rickshaw pulling, and working in brick kilns for their livelihood diversification (Rahaman et al., 2021).

Fishers are firmly attached to their work, and diversifying has associated costs (Shaffril et al., 2017). So, the appropriate agencies should establish programs to intensify the promotion of non-fishing, non-natural resource dependent income-producing activities among small-scale fishers, which in turn should reduce their dependency on fishing and diversify their income (Shaffril et al., 2017). Examples of such mechanisms include diversification of livelihoods, such as switching between farming and fishing in response to seasonal and inter-annual

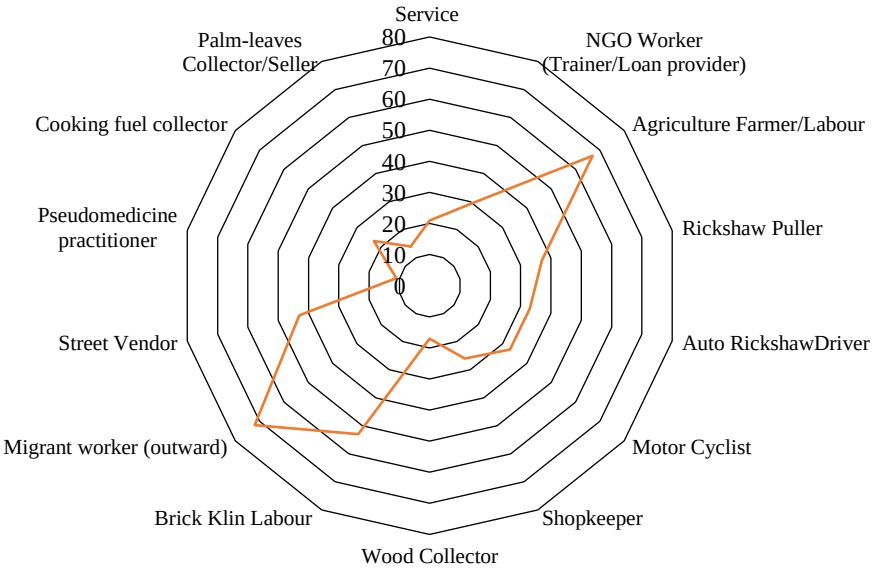

Figure 2. Livelihood opportunities other than aquaculture in the study area. The values indicate the number of respondents who opted for the opportunities. Each respondent opted for multiple livelihood opportunities.

variation in fish availability, providing opportunities with training, and taking up alternative income-generating activities.

One example of a growing activity in the study area is crab fattening. As indicated by participants in the focus groups, crab fattening is potentially profitable and a feasible fishery venture in and around the Satkhira Coast. The mud crab, *Scylla serrata* is widely distributed in the Pacific and Indian Oceans, including the Bangladesh Coast. The crabs produced in the crab fattening farms are quite healthy (nearly half of the total harvest), and the production is scaling up rapidly in the coastal areas. Several factors hinder the crab sector's sustainable development, including the supply of crablets. The collection of crablets from wild sources like rivers and estuaries is becoming risky for the environment, and the natural stock has already suffered overexploitation. In order to support the crab fattening industry, it is essential to establish crab hatcheries in the southwest region of Bangladesh.

3.7 Vulnerability of production systems in the study area

The respondents said fish ponds were the most vulnerable among those three systems. Freshwater species like pangasius, rohu, catla and tilapia are cultured in fishponds and cannot tolerate high salinity. Vulnerability levels of crab points, shrimp farming enclosures, and fishponds were 15.01, 23.05, and 30.99, respectively (Figure 3).

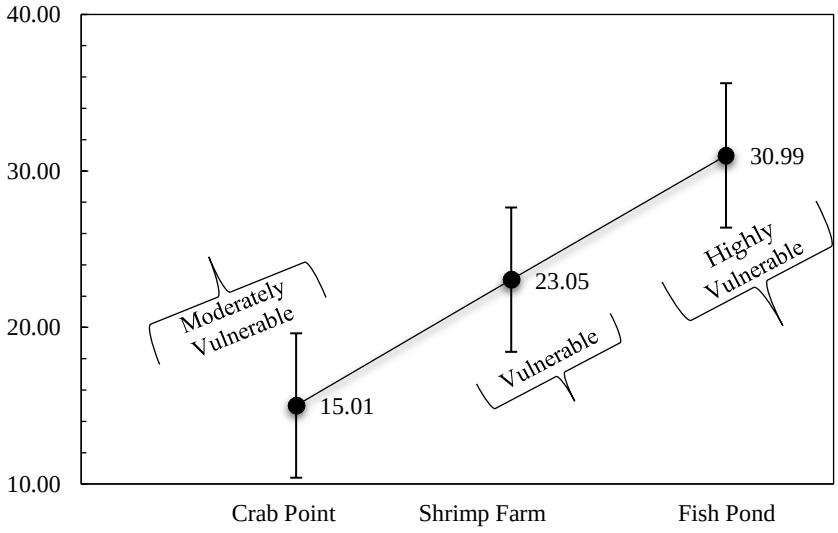

Figure 3. System-wise vulnerability of the study area

Salinity intrusion, sea level rise, long duration floods, riverbank erosion, and storm surges are the major problems contributing to coastal vulnerability. The participants of the FGD raised these issues and considered significant barriers to sustainable livelihoods and adaptation in the area. Hossain and Hasan (2017) stated that the Shyamnagar Upazila is highly vulnerable. Several natural calamities affect this study area every year. Climate change directly or indirectly affects people in this locality (Anzum et al., 2023). With the increased salinization of groundwater, fish, shrimp, and crab production faced many difficulties in this area (Rahaman et al., 2021). Kabir et al. (2016) studied the impact of cyclone Sidr on the Amtali Upazila of Barguna District, and cyclone Aila affected the Koyra Upazila of Khulna District and reported that they had severe consequences for the livelihood patterns of the affected population and their overall health status. Broadly, there is difficulty in gaining sufficient drinking water, which makes households very vulnerable to impacts in aquatic systems and exacerbates poverty (Hossain et al., 2018). The present study's findings suggest that bridging the different approaches to adapt vulnerable livelihoods to the more severe impacts seen in the aquatic system is crucial.

4. CONCLUSION

The southwest coast of Bangladesh is highly prone to cyclones and other natural calamities, the frequency of which has increased significantly due to climate change. Climate change impacts have challenged the sustainability of the pond fish culture, shrimp culture, and crab fattening. We assessed the perceptions of the fish, shrimp, and crab farmers on the impacts of climate change on the production systems, livelihoods, and vulnerability of the region's households. The southwest coast of Bangladesh experienced the significant economic losses in the aquaculture sector due to storm surges, long duration floods, salinity increases, sea level rise, droughts, and river bank erosion. Building the capacity of fish farming communities is necessary to apply the suggested adaptation measures. The government should implement a pragmatic program to support the region’s inhabitants during natural calamities and reduce temporary or permanent human migration.

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