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CLIMATE CHANGE EFFECTS ON THE SMALL-SCALE FISHERIES IN THE NORTHERN PART OF BANGLADESH AND ASSOCIATED ADAPTATION MEASURES

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Abstract

Bangladesh is the sixth-most climate-vulnerable nation in the world. As a result, scientists have focused more on studying the connections between aquaculture, adaption techniques, and the effects of climate change in recent decades. This paper aims to evaluate the degree of awareness and perception regarding climate change, as well as the adaption tactics used by small-scale aquafarmers. Data for the study were gathered through focus groups, key informant interviews, household surveys, and exploratory surveys. The results of the study demonstrate that there have been considerable changes in temperature and rainfall patterns. Fish farmers exhibit considerable knowledge about climate change, drawing information from several sources such as newspapers, television, extension workers, and the internet. Fish farmers have implemented several adaptation strategies, including netting, pond irrigation, long dikes, aerators, fish density reduction, crop rotation, feed management, and feeding, to combat the impacts of floods, cyclones, droughts, and cold waves. In the face of changing environmental conditions, the emphasis should shift towards adapting climate-resilient culture fisheries as part of a climate-smart aquaculture strategy to enhance nutritional security for the growing population. There are already established integrated farming systems in operation, including agri-aquaculture-based systems, livestock-based aquaculture systems, and agri-aqua-livestock integration. A number of cutting-edge technologies, such as community-based aquaculture, cage/pen culture, high dike cropping, aquaculture liners, species diversification, and greenhouse aquaculture, have also been developed as a result of scientific advancements in the integrated farming concept. These practices contribute significantly to improving production, reducing the impacts of climate change, and avoiding contributions to climate change.

Keywords: Marginal fishermen, Natural disasters, Climate-smart aquaculture, Coping strategy, Adaptive capacity

Introduction

Climate change is a worldwide occurrence impacting various sectors of human activity. As noted by Adger et al. (2003), the ramifications of this phenomenon are evident in aquaculture, agronomy, horticulture, and other sectors crucial to the livelihoods of rural populations in developing nations. In Bangladesh, the significance of fish and fisheries cannot be overstated, owing to their substantial contribution to exports and revenue. However, despite the extensive benefits derived from freshwater aquaculture in the country, concerns regarding climate change have recently emerged in relation to pond-fish culture. Climate change stands out as one of the most defining challenges of this century, necessitating a global response. Bangladesh is widely acknowledged as one of the most climate-vulnerable countries globally. Frequent natural disasters, including tropical cyclones, storms, coastal erosion, monsoon winds, evaporation from monsoon rains, floods, and droughts, lead to loss of life and property, especially affecting poor communities in remote or ecologically vulnerable areas like river islands and cyclone-prone coastal belts (Afjal et al., 2012). Anticipated climate variability and the increased frequency of extreme weather events due to global climate change have positioned the country as the second most climate-vulnerable in Asia for freshwater

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aquaculture, with the lowest adaptive capacity for brackish water aquaculture (Falconer, 2018). Almost every year, the country experiences various disasters that significantly impact life, goods, and development activities (Mamun et al., 2007). Predicted climate changes also induce physiological, ecological, and operational shifts in global aquaculture, impacting production, livelihoods, and influencing the sector indirectly. All of these modifications have an indirect effect on aquaculture but a direct impact on livelihoods depending on aquaculture and productivity (Crozier et al., 2021; Huang et al., 2021; O'Connor and Booth, 2021). However, a comprehensive, multidisciplinary, and multi-method approach is essential to understand local perceptions and the intricate interrelationships between the biophysical and social components of risk (Lorenzoni et al., 2007).

The northern region of Bangladesh, covering an area of 16,320.26 KM2, is a land of contrasts. It lies between the latitudes of 25°20' and 26°37' north and longitudes of 88°50' and 89°53' east. Key districts in this area include Dinajpur, Kurigram, Rangpur, Nilphamari, Sirajganj, Gaibandha, and Jamalpur. Summers in this region are dry, marked by scorching westerly winds, while the rainy season is exceptionally wet, with annual rainfall ranging from 2,000 to 3,000 millimeters. Monsoon-related flooding remarkably affects this part of the country. The Teesta River, a perennial river fed by rain and snow, traverses the five northern districts of Bangladesh, namely Gaibandha, Kurigram, Lalmonirhat, Nilphamari, and Rangpur, which fall within the Rangpur Division. In 2011, the estimated population of this region was 9.15 million, made up of 5,427 villages and 35 upazilas (Prasai et al., 2015). Due to its unpredictable nature, flooding of the Teesta River causes considerable, unforeseen damage to standing dry-season crops and properties. Farmers view floods as the most significant threat to a complete harvest failure since abrupt or extended floods often result in physical harm to ponds. While northern Bangladesh holds significant potential for aquaculture development, inland aquaculture is highly susceptible to flooding (Islam et al., 2017). This vulnerability arises from the difficulty of preventing the escape of fish from the ponds and predatory fish from the wild entering the ponds during flood events (Conway and Waage, 2010; Islam et al., 2019). Additionally, the region experiences cold waves in January and February, approximately every two years, further impacting the livelihoods of the most vulnerable communities.

While numerous studies have explored the impact of and adaptation to climate change in aquaculture broadly, few have specifically delved into the perceptions of climate change held by small-scale fishermen. Additionally, there is a noticeable absence of studies investigating the adoption rate of weather forecasting in fisheries, particularly in the northern areas. In this paper, we conducted an analysis of the perceptions of climate change among small-scale fishermen and their attitudes toward weather forecasts in the northern regions of Bangladesh. The hypothesis guiding this study is that farmers are aware of climate-related risks and are willing to take action to adapt to the effects of climate change. Consequently, the study specifically aims to determine the fishermen's perception of climate variability and change, their attitudes toward weather forecasts, and the adoption rate of weather forecast usage, along with identifying factors influencing its adoption. Furthermore, this study offers recommendations for several climate-resilient culture fisheries as part of a climate-smart aquaculture strategy, with the aim of improving nutritional security for the growing population.

Materials and Method

An overview of the research areas

The study adopted a participatory and interactive approach involving the target groups and other stakeholders to identify, elaborate upon, discuss, and consolidate the socio-economic status of stakeholders engaged in aquaculture, catching fish, and fish marketing systems in both rural and rural-urban areas across various disaster-prone regions in the northern part of Bangladesh. Three upazilas, namely Raiganj, Saidpur, and Palashbari, situated in the districts of Sirajganj, Nilphamari, and Gaibandha, respectively, were selected for this study (Figure 1).The study incorporated both descriptive and analytical approaches, utilizing a participatory methodology for gathering information.

After an initial reconnaissance and project inception meeting, a comprehensive review of existing knowledge from previous studies was conducted to establish a detailed sectoral overview, forming the backdrop of this study. The review process combined desk-based research with supplementary field visits to address any informational gaps. Notably, emphasis was placed on examining relevant work conducted in other parts of the country and the Southeast Asian region.

Data collection

The information was gathered using various participatory methods, which included Focus Group Discussions (FGD) with primary stakeholders, individual case studies involving semi-structured or structured questionnaire surveys, and market surveys. The surveys were divided into four sections, each of which focused on demographic data, views of adaptation, views of the environment and climate change, and basic information on the fishing profession.

Primary data collection

The questionnaire was used to gather primary data through in-person interviews with the respondents. The purpose of the questionnaire was to give a thorough picture of both the consequences of climate change on aquaculture and present practices. It comprised both open-ended and close-ended questions, allowing for statistical analysis based on the closed questions and qualitative data collection based on the open-ended questions to elicit detailed information and personal opinions on specific issues. The appropriateness of the questions was verified through a pilot test that involved a limited number of participants. The final questionnaire was structured logically to enable the fishers to respond in chronological order. Primary data were collected through questionnaires from approximately 100 participants across three districts.

Additionally, key informant interviews were conducted with members of the fisher community, such as fisher leaders, stakeholders, and experienced fishers, as well as relevant authorities, including the Upazila Fisheries Officer. Key informants, including District and Upazila Fisheries Officers and NGO workers, were subjected to cross-check interviews in order to verify the accuracy of the data gathered. Three Focus Group Discussion (FGD) sessions, each comprising 10-15 fish farmers, were also conducted.

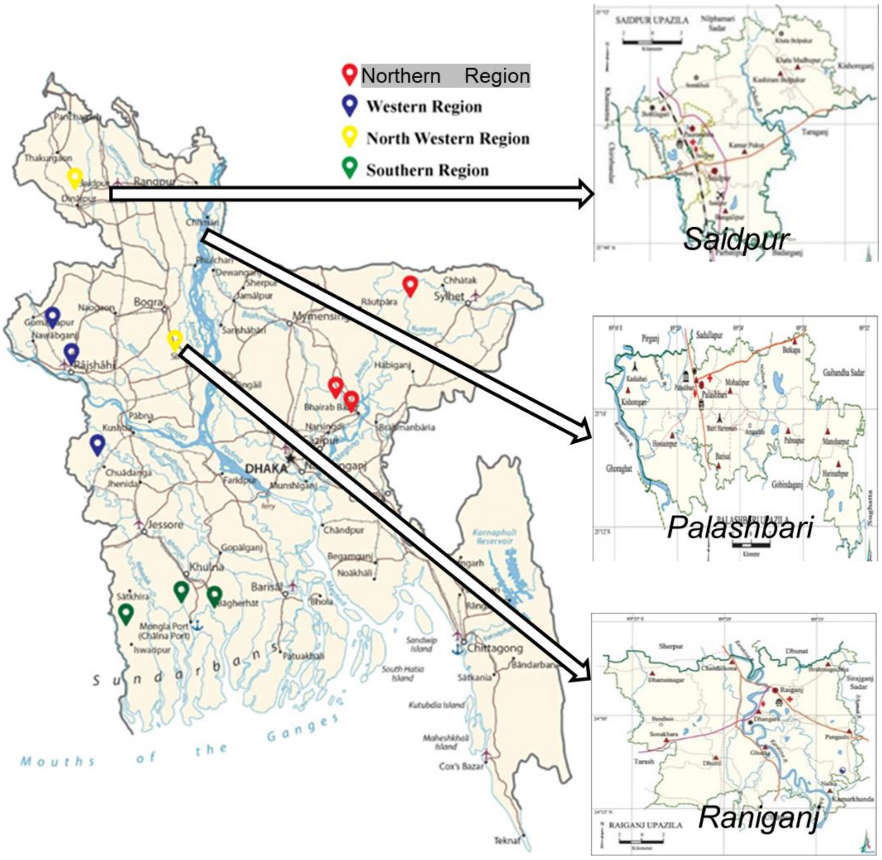


Figure 1. Map showing three upazilas (Raiganj, Saidpur, and Polashbari under Sirajganj, Nilphamari, and Gaibandha districts) of northern areas of Bangladesh

Secondary data collection
The internet and published papers served as primary sources of secondary data. Meteorological data, including temperature, rainfall, and extreme weather events such as drought, floods, cold waves, and precipitation, were obtained from the meteorological department and online sources (https://www.worldweatheronline.com/).

Data processing and analysis
The data was examined using Microsoft Excel (2010) edition to determine the frequency distribution, percentage, mean, and standard deviation using descriptive statistics. Tables, frequencies, figures, and percentages were used to display the data that had been examined.

Results and discussion
Metrological data
Average temperature and rainfall trend are important to predict the changing weather pattern. Every year, the rate of temperature increase slows, increasing the likelihood of drought in the area. In northern region, between 2012 and 2021, there have been gradual rises in temperature. (Fig. 2).The lowest average temperature was observed in 2012-13 (27.66℃) and the highest average temperature in 2018-19 (29.16℃).The dashed line in Fig. 2 represents the linear trend of temperature change. Given its positive left-to-right slope, it is clear that climate change is probably to blame for the rising temperatures in the northern region. This increase in temperature might have an impact on aquaculture production. It has been observed that in last 22 years' time scale (2009 to 2021) the annual mean temperature of northern districts is increased by nearly 0.44℃.

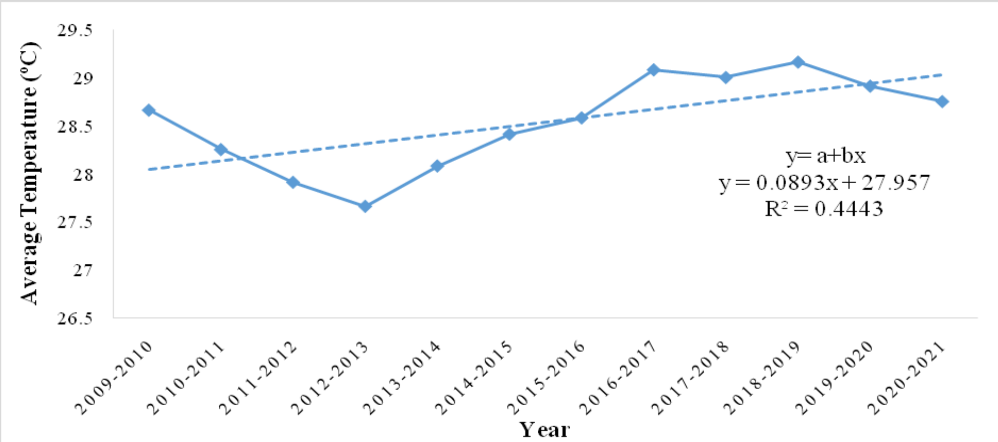


Figure 2. Maximum, minimum and average annual temperature in the northern region of Bangladesh (2009-2021)

The trend of precipitation is not as distinct as temperature in the northern region, shows slight increase by 0.1 in last 22 years (2009 to 2021). The average rainfall of the northern region is highest in 2020-21, which is 319.43mm (Fig. 3). The linear trend of precipitation change is depicted by the dashed line in Fig. 3. It shows that precipitation is increasing in the northern region, most likely due to climate change, as it slopes positively from left to right. While a sharp drop in rainfall can result in drought in the area, an increase in rainfall can cause floods. Thus, variations in precipitation may have an effect on aquaculture production.

Bangladesh will continue to warm as a result of ongoing greenhouse gas emissions, according to an assessment done by the Intergovernmental Panel on Climate Change (IPCC, 2014). Projections indicate that mean temperatures across the country are likely to increase by 1.4°C and 2.4°C by 2050 and 2100, respectively. This warming trend is anticipated to be more pronounced during the winter months from December to February. In Bangladesh, Mahmud et al. (2021) observed a rise in protected temperatures during the monsoon season from June to August, indicating a general increase in temperature. The average maximum and minimum temperatures during the monsoon season show an annual increasing trend at rates of 0.05°C and 0.03°C, respectively (Mahmud et al., 2021). The rise in temperatures is expected to lead to more intense and unpredictable rainfall during the monsoon season, increasing the likelihood of catastrophic cyclones and higher tidal inundation. Bangladesh, with a population density of over one thousand people per square kilometer and an annual population increase of 2 million, is highly vulnerable to the impacts of climate change on surface and groundwater resources. This vulnerability became evident during the recent super-cyclone Amphan in 2020, when heavy monsoon rains caused widespread flooding in various parts of the country. Over one-third of Bangladesh was affected, impacting more than 4.9 million people and resulting in the loss of 42 lives.

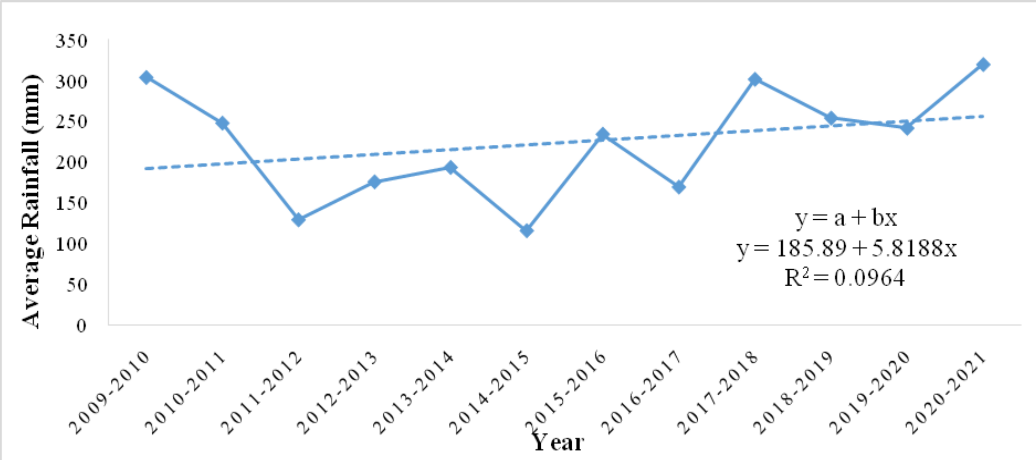


Figure 3. Maximum, minimum and average annual precipitation in northern of Bangladesh (2009-2021)

Socioeconomic characteristics of fishermen and their perception on climate change

Climate change poses a serious threat to Bangladesh, especially in light of the predicted effects, which include rising sea levels, hotter weather, more rainfall and runoff from the monsoon, decreasing precipitation during the dry season, and more frequent and intense cyclones in this region (Agrawala et al., 2003). Environmental catastrophes, such as floods and cyclones that occur as a consequence of climate change directly influence coastal socio-economic foundation, land-use standard, natural resources, and costal people's lifestyles and livelihoods (Shaw and Krishnamurthy, 2010). To determine the socio-economic status of marginal fishermen, demographic data, such as age, gender, marital status, income sources, literacy, employment, religion, family type or size, education, training exposure, and so on were gathered considered in the northern districts of Bangladesh (Table 1).

In Bangladesh, age is one of the basic aspects that supports the fishing effort since, at a productive age, one can execute the job to the best of one's ability. According to the Bangladesh Job Market, productive age ranges from 15 to 60 years. Age structure is a crucial aspect in determining the position and functions of a fisherman in his society, as well as their behavior. Responsibilities, privileges, rights and obligations, hardworking, and so on are all strongly connected to age. Therefore, in the fishermen communities, male contributed more (94%) than women. Most of the fishermen in the inspected locations were between the ages of 18 and 60 years. Working as a fisherman involves a great physical resilience due to the unpredictable hazards of natural environment. Islam et al. (2017) observed that the majority of fish farmers (33.3%) in Sadar Upazila, Meherpur, belonged to the 31–40 age group, with the lowest percentage (3%) in the 10–20 age group. These findings are mostly consistent with the findings of the current study.

Family size is an important socioeconomic indicator since it influences household income, food consumption, and socioeconomic well-being of families. Six persons make up the typical family size, and 80% of the respondents are married. All the members of a family who dependent upon the family's head are counted as dependents. Fishermen can employ a family member to help them with their fishing business and earn money from other jobs. Among the farmers, more than 80% were married. As can be noticed in the findings, Muslims made up the vast majority of the fishermen in the research locations.

Table 1. Demographic data of disaster-prone areas in the northern districts

Category	Characteristics	Percentage (%)	Category	Characteristics	Percentage (%)
Gender	Male	94	Education	Higher	8
	Female	6		Islam	80
Age (yrs.)	> 18-60	90	Religion	Hindu	20
	13-18	10		Others	0
	<13	0		Aquaculture	82
Marital status	Married	82	Income source	Agriculture	8
	Unmarried	18		Business	3
Education	Illiterate	22		Husbandry	7
	Primary	15	Experience (yrs.)	<5	33
	SSC	30		5-15	48
	HSC	25		>15	19

Individual preferences and behavioral habits are heavily influenced by educational qualifications. Pond fish farmers' education can be extremely important for good fish production as well as efficient administration and operation. The academic qualifications of the fishermen in the study areas have been classified into five groups in this study: (i) illiterate, (ii) primary, (iii) SSC, (iv) HSC, and (v) higher education. Secondary education was detected to be the greatest degree of education (30%), followed by higher secondary education (25%). Considerable fishermen were found as illiterate (22%) in the study area. Islam et al. (2017) conducted a study in Sadar Upazila, Meherpur in a fishermen community where they noticed the similar pattern of academic qualifications of the people engaged in small scale aquaculture. Academic qualifications are necessary not just for present-day farming, but also for protecting fish farms from natural calamities.

Since experience has an impact on business management, engaging in fishing activities is a way for fishermen to learn about managing their profession. A field survey indicates that the majority of the fishermen have a great deal of experience with aquaculture. Based on their experience, fishermen are distributed into three groups, as shown in Table 1: first, fishery fishermen with experience ranging from 0 to 5 years; second, fishermen with experience ranging from 5 to 15 years; and third, fishermen with experience range from 15 to more years. It was discovered that 48% of fish farmers in the research area had between five and fifteen years of aquaculture experience. A significant proportion of fish farmers—nearly 19%—has more than 15 years of experience, whereas 33% have more than 5 years. Our research supports the findings of Islam et al. (2016), who found that the age group of 10 to 15 years old made the most contributions to aquaculture in Bangladesh's southern districts. In communication with fish farmers, we came to know that fish farmers received several aquaculture related trainings from the Department of Fisheries and different NGOs.

Carp polyculture was the most preferred (about 80%) by the northern communities where variety of carp species are stocked in the culture ponds (Fig. 4). After carp, tilapia was the second highest favored species followed pangas, shingh, koi, magur and tengra. The similar scenarios are also observed in other areas in Bangladesh (Rahman, 2014). On the other hand, farmers prefer shrimp with or without white marine fish and crab in the southern parts of Bangladesh due to close proximate of the coastal zone.

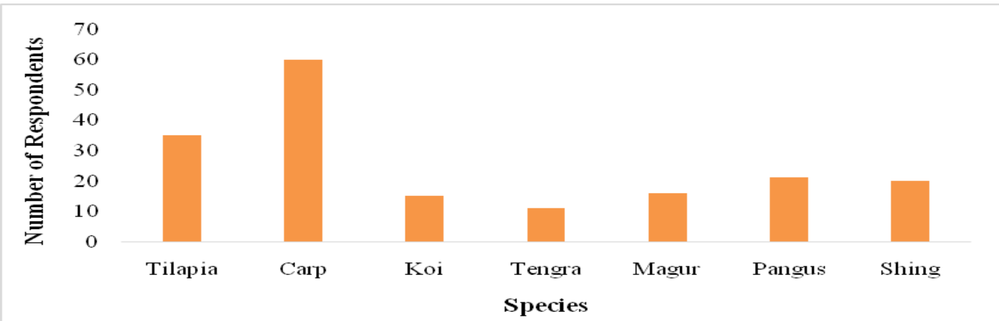


Figure 4. Types of species cultured in northern part of Bangladesh

Fishermen's perception on climate change

In the study area, about 65% farmers responded that they believed that there was a change in the climate, while about 25% farmers responded that there was no change in the climate (Fig. 5). The remaining 10% are ignorant of how climate change affects ecosystems. The most respondents (58%) confirmed that flood was the main reason for the losses of aquaculture during summer. Farmers also noticed that cold wave and drought further destroyed the aqua-business in the locality during winter and summer respectively (Fig. 6). According to a study conducted in the Nilphamari area by Roy et al. (2018), the majority of respondents (57%) said that decreasing rainfall intensity and unpredictable and delayed rainfall were the main ways in which agricultural output was negatively correlated with climate change. There was a moderate influence on agricultural productivity, according to 43% of the remaining respondents. Furthermore, a vast majority of respondents (93.65%) in both regions felt that the number of winter days had reduced over the previous 20 years. In Kurigram, most respondents (43.65%) thought that the frequency of floods had increased, whereas most respondents (40.48%) said that there had been no change in the flood condition in Nilphamari over the previous 20 years. More than 40% of the participants in Kurigram and Nilphamari reported feeling that the intensity of the drought has risen throughout the previous 20 years (Roy et al., 2018).

The degree to which meteorological data and forecasting sources are accessible in Bangladesh's disaster-prone locations is depicted in Fig. 5. Questionnaire interview confirmed that more than 80% fish farmers in all areas have well access to weather forecasting (Fig. 7a). The majority farmers obtained weather news from newspaper followed by TV, internet, and extension works (Fig. 7b).

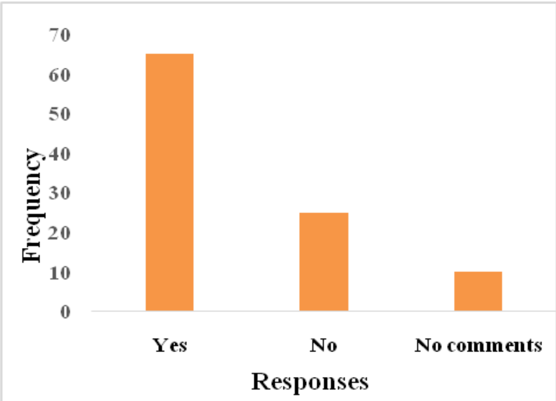


Figure 5. Fishermen's perception on climate change

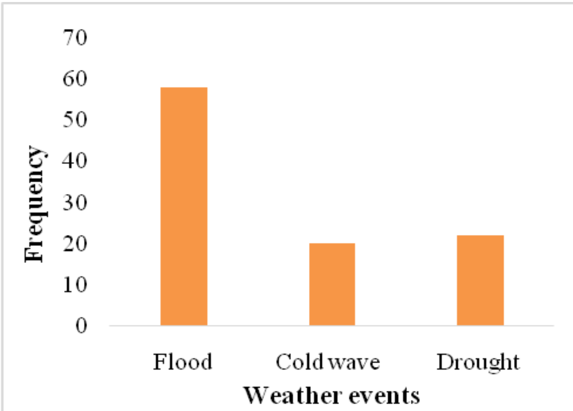
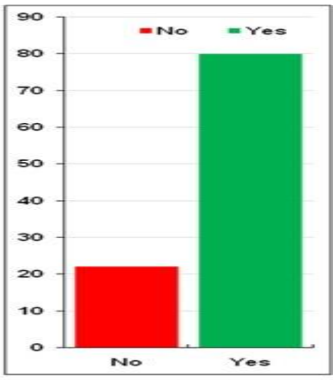
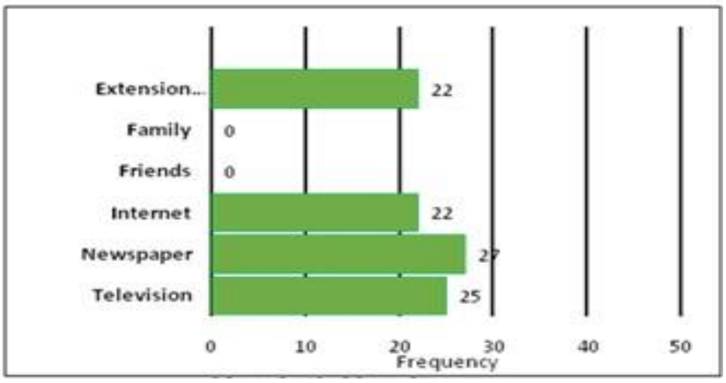


Figure 6. Extreme weather events that affect aqua-business in the northern districts



Access (a)



Forecasting(b)

Figure 7. Access (a) and sources of fore casting (b) by the fish farmers in the surveyed areas

All interviewed fishers' demonstrated awareness of variations in climatic conditions in their respective areas. In Fig. 8, the damages experienced by fishermen are depicted based on their understanding of climate change indicators. Fishermen in the surveyed regions reported various losses, encompassing reduced fish yield, crop damage, harm to fishing craft and gear, loss of livelihood, and biodiversity decline attributed to climate change. According to the fishermen, the ability to adapt was hindered by factors such as limited access to credit facilities, lack of awareness, insufficient land availability, inappropriate gear materials, lax law enforcement, absence of affordable freshwater facilities, and high dependence on natural stock. They proposed several interventions to address these constraints, including the provision of low-interest credit facilities, increased awareness, affordable fish feed, quality seed, embankment development, and stricter enforcement of existing laws and regulations. A study by Jahan et al. (2018) reported that major constraints in Dinajpur districts included financial problems, technical challenges, and physical issues.

Impacts connected to climate change can be held responsible for about 25% of the loss and damage that occurred in the agriculture, fisheries, and aquaculture sectors in developing nations between 2003 and 2013 (Shelton, 2014). In Bangladesh, a single extreme weather event, such as the cyclone "SIDR," resulted in damages amounting to USD 6.71 million in aquatic food systems. This damage was caused by the washing away of fish, shrimp, and fingerlings, as well as the destruction of infrastructure, gears, and equipment (GoB, 2008). Similar to this, fish farms lost USD 5 million due to infrastructural damage and fish and fingerlings being washed away in a single flood event that occurred in 2020 (Saha, 2020).

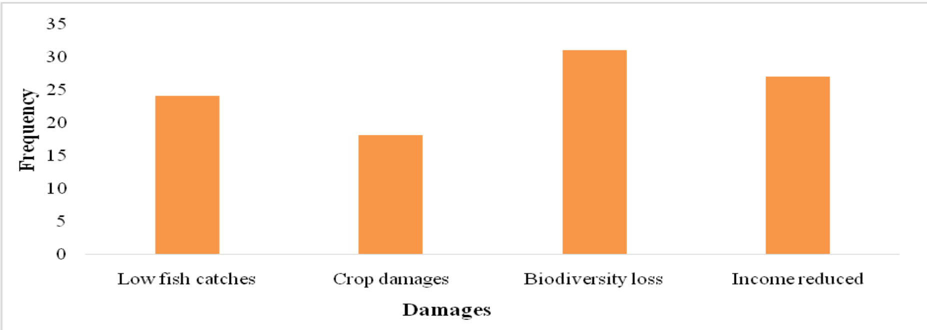


Figure 8. Common damages farmers experience due to extreme weather events

The focus group participants brought up the fact that household food security is directly impacted by the numerous changes. Such disasters not only reduce income or business but also the increase the probability of burrowing money with high interest. Finally, fishermen seek alternative job to come with these losses due to climate change (Fig. 9).

Evidence from various studies further confirms that freshwater ecosystems, home to many crucial species, are among the most threatened habitats on the planet (Döll and Zhang 2010). Both a direct and an indirect effect of climate change are expected on aquaculture production (Handisyde et al., 2006; De Silva and Soto, 2009). Changes in the physiological and anatomical characteristics of fish and shellfish stocks in production systems are considered direct effects. Conversely, indirect effects may take the form of altered primary and secondary productivity, altered ecosystem structure, disrupted input supplies, or impacted product prices, including those of fishmeal and fish oil, among other essential goods and services for aquaculture and fishing businesses. However, despite the significant benefits offered by freshwater aquaculture in Bangladesh, concerns regarding climate change have recently arisen in relation to pond-fish culture.

The study identified a number of climate factors that negatively impact pond fish culture in the research location. Flooding is the primary climatic variable that affects pond-fish culture, followed by drought, variations in rainfall, and temperature swings, according to Ahmed and Dina (2016). Concerns over the impacts of these climatic elements were voiced by almost all of the farmers questioned. According to the field survey, cyclones, cold waves, floods, droughts, and heavy rains all have a detrimental impact on fish stocking because they cause poor water quality, which increases the risk of fry mortality.

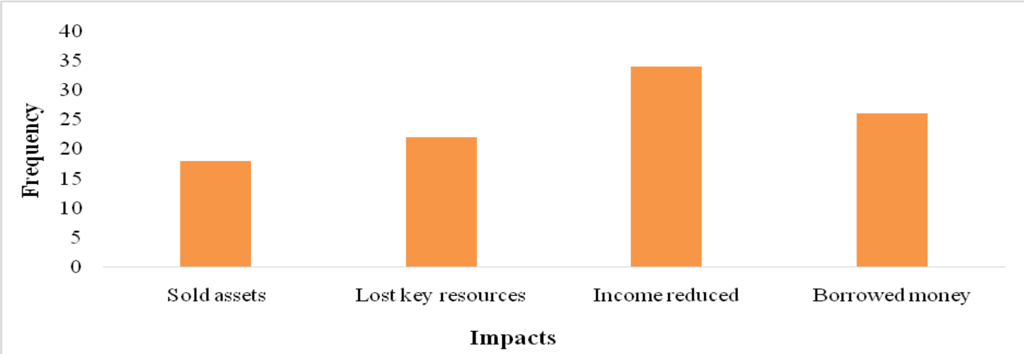


Figure 9. Impact of livelihood due to climate change in the surveyed areas

In the northern regions of Bangladesh, floods are increasingly frequent within fish farming communities. Farmers report a significant rise in unusual flooding in recent years, particularly during the peak aquaculture season, attributable to heavy monsoon rainfall. Pond-fish culture proves highly susceptible to flooding, with farmers perceiving floods as the primary threat to total harvest loss, given the physical damage inflicted on ponds during sudden or prolonged flooding. Even with high dikes, preventing fish escape during floods remains challenging for farmers, compounded by the large amounts of garbage and sedimentation carried into ponds during heavy rainfall, reducing water clarity and limiting sunlight penetration (Hossain et al., 2021). These factors restrict plankton availability and hinder oxygen production through photosynthesis (Tucker and Hargreaves, 2004). Furthermore, heavy precipitation might drop the pH of the water, which can have adverse ecological consequences, as the ideal pH range for fish growth is 7.5 to 9 (alkaline) (Jadhav, 2008). Consequently, fish growth and output are impacted by ecological shifts resulting from rainfall variations, allowing for the introduction of parasites that cause fish pond epizootics (Marcogliese, 2001).Variations in meteorological conditions have rendered fish more susceptible to illnesses such as black spot, white spot, and epizootic ulcerative syndrome (EUS). Climate change has increased the risk of EUS infections (Marcos-Lo´pez et al., 2010).

In winter, the gradual temperature drops in the northern part of Bangladesh results in cold waves, which negatively impact fish growth and increase the likelihood of fish mortality. Cold spells may also alter pH levels and disrupt dissolved oxygen and carbon dioxide balances, leading to prolonged periods at shallow levels and reduced feeding behavior. Moreover, severe or prolonged droughts often lead to temporary fish cultivation, rendering year-round fish farming impractical due to water scarcity. During the dry season, most ponds dry up, creating unfavorable conditions for fish, leading to overcrowding and stress in limited water volumes. Droughts also affect pond-dike cultivation and decrease fish consumption due to low yields, causing food shortages in fish farming areas during severe droughts. According to the Flood Plan Management Unit (FPMU, 2013), Bangladesh's food productivity is projected to decrease by 30% by 2100 due to climate change.

Copping strategies by the fish farmers

Farmers in climate-affected areas have devised a number of creative solutions to offset the loss of fish output during the lean season (Fig. 10). Farmers manage fish ponds in flood and cold prone areas with netting (25%, pond dike (22%), aerator (17%), reduce fish stocking (15%), crop rotation (11%) and food management (8%). Drought-stricken farmers in the locality rely on irrigation and groundwater (22%).

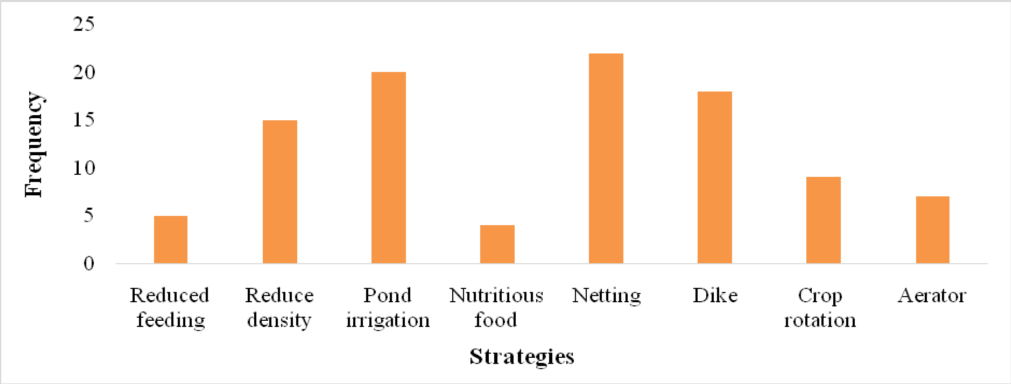


Figure 10. Farmer's strategies to cope with the constraints

Household adaption measures are still falling short of expectations, which are especially crucial in the northern region, even if extreme weather occurrences are common in the research areas (Roy et al., 2021). Fishers lack awareness of experts' predictions regarding climate change, and their understanding of the causes of climate change does not align with expert opinions. Fishers express the belief that they can adapt to the changing climate through measures such as securing low-interest loans, obtaining fish seeds, establishing fish reservoirs, regulating the water flow of barrages, and receiving comprehensive training on climate change.

Key informants' comments on the management choices and operations of climate-sensitive aquaculture

This study also considered the viewpoints of resource personnel (key informants) engaged in various climate-affected areas. High temperatures, cold, dry spells, and heavy precipitation were noted by key informants as important weather phenomena that could have an impact on a range of aquaculture activities, including feeding, stocking fingerlings, harvesting, and water quality management (Table 2). Key informants stressed that high temperatures have a major impact on managing water quality because they lower pH levels, which result in basic or acidic water, cause imbalances in dissolved O2 and CO2, and hasten the production of NH3 and H2S gases. These alterations in the parameters that determine the quality of the pond's water might cause fish to experience physiological stress, which can impair their ability to digest food and survive. Agricultural lime applications are often suggested as a possible solution for these problems. Furthermore, the use of disinfectants, a "horra" (a locally made instrument for cleaning the bottom of ponds), zeolite application, water addition, and artificial O2 supply through aeration can all help maintain the quality of the water. In hot weather, fish should be fed less or not at all in the afternoon, and in the morning, a vitamin C supplement should be given.

To prevent shock, responders advised against stocking fingerlings during the high-temperature afternoon periods. Conversely, cold periods were noted to elevate pH levels and create imbalances in dissolved O2 and CO2, leading to prolonged periods at shallow depths and reduced food intake. In such scenarios, key informants recommended limiting lime use, implementing irrigation, providing O2 through an aerator or oxygen-promoting aqua-medicines, reducing feeding, and, if necessary, conducting partial harvesting to decrease fish stock density. Heavy rains can cause decreases in dissolved O2 levels and pH. When coupled with sudden temperature drops, this can lead to reduced food intake and potential mortality. Aeration and spreading lime after heavy rains can help mitigate these risks by enhancing the availability of dissolved O2.

Heavy rains can cause ponds to overflow and fish populations to escape from fences. As a preventive measure, key sources advised farmers to raise pond embankments and utilize nets to prevent losses. Dry periods, on the other hand, were described as conditions where water supply diminishes due to evaporation from high temperatures, leading to impaired feeding behavior and, in some cases, creating ideal conditions for disease outbreaks. To address these issues, respondents suggested that farmers could use pumps to supply water to ponds from groundwater or adjust the timing and volume of fingerling stocking. Additionally, farmers could consider partial harvesting to reduce stock density while modifying feed distribution. The key informants' insights regarding climate-sensitive choices and operations in aquaculture are summarized in Table 2.

Table 2. Climate-sensitive aquaculture operations and management decisions

Climatic variables	Operations	Potential impacts	Management
Heavy rain/flood	Pond water quality management	Decreased dissolve O_2 level; Decreased pH level; Sudden temperature drops	Artificial oxygen supply using aerator or oxygen; Enhancing aqua-medicine; Lime application after the rain
	Feeding	No food intake	Stop feeding
	Stocking	High mortality rate	Stop fingerling stocking
	Harvesting	Flooding; Fish escape	Heighten the pond banks; Protect the fish to escape using nets
Cold spells	Pond water quality management	Increased pH level; Imbalance between dissolved O_2 & CO_2 levels	Restrict lime application; Pond irrigation to increase water depth; Aeration to enhance dissolve oxygen; Oxygen enhancing aqua-medicine
	Feeding	Less food intake	Reduced feeding
	Harvesting	Abnormal behavior of fish (floating near the water surface)	Reduce fish stock density through partial harvesting

Modified from Hossain et al., 2021

Advanced climate resilient aqua-farming practices

The implementation of advanced technologies through scientific interventions in the integrated farming concept has yielded numerous practical benefits. Employing a comprehensive adaptation strategy is key to alleviating the influences of climate change on aquaculture. The investigation of climate-resilient adaptations in farmed fish for climate-smart aquaculture is one method to improve food security for the world's growing population under changing climatic circumstances. Because fish are the main source of protein and money for people all over the world, the aquaculture industry is expanding quickly and now accounts for almost half of the fish supply worldwide. In a time when there is a growing need for animal protein and global climate change, it is essential to increase fish production using environmentally friendly and sustainable methods. The development of climate-smart aquaculture can provide practical management techniques to sustain the aquaculture sector in an ethical manner. In times of calamity, a number of strategies have been proposed to protect aquatic resources (Table 3).

Table 3. Climate change adaptation tactics for freshwater aquaculture

Climatic variable	Adaptation strategy
Flooding	Cage/pen culture; Netting and fencing of ponds; Construction of higher pond-dikes; Community-based floodplain aquaculture; Small size pond
Drought	Community-based irrigation facilities; Pump-out groundwater; Micro-irrigation for pond-dike cropping; Adjusting fish culture during monsoon; Hydroponics; Aquaculture liners; Species diversification (first growing, heat tolerance)
Cold wave	Greenhouse aquaculture; Explore cold tolerance species; Dike cropping

(Modified from Ahmed and Diana, 2016)

In flood-prone areas, the installation of cages or enclosures can serve as a viable short-term solution when floods are imminent. To adapt to climate change, open-water cage culture has been implemented (Shelton, 2014), encompassing the cultivation of various types of shellfish and finfish species in freshwater, brackish, and marine environments. Potential locations for cage culture in Bangladesh include rivers, irrigation canals, oxbow lakes, and haors (Golder et al., 1996). This allows small-scale farmers to make better use of their limited resources by adding high-value species to their cages, which improves their income and standard of living. Ponds can be made more secure by using fencing and netting to keep stocked fish contained and to discourage predatory fish during floods. In cases where pond embankments are insufficient to withstand inundation, farmers use fine-meshed plastic nets to enclose ponds and prevent fish from escaping. During periods of seasonal flooding, natural materials such as bushes and branches are utilized to construct flood traps, and traditional bamboo traps are modified to reduce catch per unit effort, while also providing habitats for small indigenous fish species.

Constructing higher pond embankments is identified as a key strategy for flood management. The embankments are typically built tall and wide to withstand the force of floodwaters. To minimize land erosion, the embankment sides are turfed immediately after construction, and further protection is provided by planting vegetation such as plantain, pulses, betel-nut, and lemon on the embankments. Some aquatic weeds, such as duckweed, azolla, water hyacinth, and water spinach, can also be grown in ponds to provide shade for fish during hotter months (Ahmed and Diana, 2016). In addition, community-based flood control structures like embankments and dams can lessen flooding. According to key informants, open-water bodies could be converted into viable floodplain aquaculture through community-based water embankments. Community members are involved in decision-making, planning, technology implementation, control, maintenance management measures, and activity evaluations in community aquaculture. This ensures the sustainable exploitation of resources, fair profit distribution, resolution of conflicts, and adherence to established terms and conditions. This strategy helps villages' environmental conditions while also giving rural populations access to food security, income, and self-employment opportunities.

Over the past 70 years, there has been a significant transformation in aquafarming equipment, transitioning from wooden cages to polyethylene and steel cages. Considering the significance of water quality, the use of aquaculture liners, certified for potable water, has become common. These liners are fish and plant-safe, do not leach additives, and contribute to an overall improvement in water quality, resulting in higher crop densities and healthier fish. Aquaculture pond liners made of reinforced polyethylene can be an effective option for drought-prone areas as they eliminate the risk of chemicals and additives leaching into the water and damaging fish crops. To enhance water temperature during colder periods of the year and promote proper fish growth, greenhouse ponds serve as a viable alternative to open ponds. When compared to outside tanks, the water temperature in open and enclosed greenhouses during the winter months can increase from 3.58 to 6.79°C, indicating the impact of water temperature on fish growth (Tribeni et al., 2006).

Diversifying the aquaculture industry through the introduction of climate-resilient species and varieties is a crucial step towards implementing climate-smart aquaculture. This effort involves optimizing existing species, generating sustainable choices for novel species, and assessing socio-ecological influences, considering the dynamic trade-offs. Some climate-resilient species, such as air-breathing fish, catfish, eel, Tilapia, Pangas, and Snakehead, have demonstrated the ability to survive dry seasons, increased temperatures, limited water, and poor water quality. Rearing air-breathing catfish, known for its high tolerance to adverse conditions, along with edible vegetables in the form of hydroponics, not only yields additional crops but also provides shelter for fish during droughts and high temperatures.

Bangladesh boasts around 260 indigenous freshwater fish species, out of which 143 are classified as Small Indigenous Fish Species (SIS). These species are acknowledged for being a great source of vital protein, vitamins, minerals, and macro- and micronutrients. As such, they are important in helping to compensate for dietary inadequacies in humans. Due to their ability to tolerate fluctuating environmental conditions and their short growth cycle, SIS species are seen as additional opportunities for marginalized communities, including men, women, and household members. In addition to the aforementioned interventions, the strategic stocking and harvesting of fish of different sizes, with appropriate monitoring, can help reduce losses during disasters. There are several small shrimp species with short life cycles that are easy to rear and hold potential in the local market.

Conclusion

Aquaculture holds a significant position in Bangladesh's economy, serving as a vital source of sustenance, income, livelihood, and export revenue. Findings from field surveys and literature reviews reveal that the small-scale household aquaculture sector in the northern region of Bangladesh is under threat from various climatic factors, such as floods, droughts, cold spells, and temperature fluctuations. These variables have had a substantial impact on pond ecosystems, affecting the survival, growth, and reproduction of fish. Although fish farmers possess substantial knowledge regarding climate change through sources like television, newspapers, the internet, mobile communications, and friends, sudden climate-induced natural disasters lead to numerous losses, including decreased fish yield, crop damage, destruction of fishing equipment, disruptions in livelihoods, and harm to biodiversity. Despite this, several adaptation strategies are employed by fish farmers to mitigate the effects of climate change. These strategies include effective water and feed management, the construction of boreholes, strategically locating farms near water bodies, adjusting the timing and size of fish stocking, adopting alternate cropping, implementing pond shading, and constructing embankments to prevent floods, temperature fluctuations, and cold waves. Moreover, the integration of scientific interventions in the form of advanced technologies, such as community-based aquaculture, cage/pen culture, aquaculture liners, pond netting/fencing, and the use of plastic sheets to cover pond bottoms, alongside the cultivation of heat-tolerant and fast-growing species, as well as greenhouse aquaculture, have significantly enhanced the productivity of the aquaculture industry. These practices not only improve production but also contribute to reducing the hostile impacts of climate change and prevent further contributions to it. Finally, the importance of fostering good coordination among various government organizations involved in water resource management activities was strongly emphasized during the group deliberations of this project. These conclusions and suggestions provide insightful information for developing, organizing, and putting into practice policies meant to strengthen the fisheries sector's capacity for adaptation and to support sustainable livelihoods in Bangladesh's disaster-prone areas.

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