Asian J. Med. Biol. Res. 2022, 8 (2), 103-114; https://doi.org/10.3329/ajmbr.v8i2.60083

Asian Journal of Medical and Biological Research
ISSN 2411-4472 (Print) 2412-5571 (Online)
https://www.ebupress.com/journal/ajmbr/

Article

Constraints to climate change adaptation and livelihood challenges: perspectives from the Sundarbans fishers' community in Bangladesh

Md. Nagim Uddin[1], Tutul Kumar Saha[1], Myiesha Rayzil Hossain[2], SM Fakrul Islam[3] and Zakir Hossain[1,*]

[1]Department of Fisheries Biology and Genetics, Faculty of Fisheries, Bangladesh Agricultural University, Mymensingh - 2202, Bangladesh
[2]Faculty of Arts and Science, University of Toronto, Scarborough Campus, Toronto ON M1C 1A4 Canada
[3]Department of Human Resource Management, Jagannath University, Dhaka-1100, Bangladesh

*Corresponding author: Zakir Hossain, Department of Fisheries Biology and Genetics, Faculty of Fisheries, Bangladesh Agricultural University, Mymensingh-2202, Bangladesh. Phone: +8801724-939693; E-mail: zakir.fbg@bau.edu.bd

Received: 06 May 2022/Accepted: 15 June 2022/ Published: 27 June 2022

Abstract: Fishers' are first-line observers of changes in the Sundarbans region and are among the first to be affected by the changes that occurred. In the Sundarbans fishers' communities, transformations of society have always been a part of life. In contrast, environmental changes were always interim and reversible, allowing them to understand and identify with the Sundarbans ecosystems as food and life providers. In this study, fishers' observations on climate change impacts and their livelihoods were compiled and analysed using a structured questionnaire in accordance with the tenets of grounded theory. The observations of fishers from the region of the Sundarbans demonstrated a rise in the frequency of extreme weather events caused by rising temperatures and changes in the weather pattern. Physical components such as rainfall, coastal erosion, sea-level rise, siltation alterations in fish species distribution ranges, and migratory spawning behaviours were also affected by changes in the region's weather and climate. As salinity levels rose, the diversity and productivity of river ecosystems were affected, particularly in the most vulnerable areas. As a result, river freshwater flow decreased over time. A high rate of siltation in rivers and river mouths was considered another major concern that led to seasonal flooding due to its low freshwater upstream flow rate. The Sundarbans region provides a vast array of resources for diversifying fishers' livelihoods, but climate change is diminishing these alternatives due to more frequent catastrophic events. Specifically, climate change limits the resilience of fishers' communities, restricting opportunities for diversification or forcing them to leave their homes or villages. Climate change generated an environment that was generally unfavourable for all fishing communities. In order to survive in an unfavourable environment, the social well-being of fishers (mostly women and children) was negatively impacted by a variety of challenges, including disease, lack of potable water, malnutrition, sanitary difficulties, lack of electricity, lack of food and clothing, lack of proper medical care, and so on. To evaluate the effects of climate change on fisheries in the study area, the biodiversity, abundance, and production of most freshwater species are drastically reduced due to the destruction of spawning grounds, a transition in the spawning season, and the obstruction of fish migration. The findings of this study show that the climate and livelihood conditions of fishers in the Sundarbans region have changed significantly over the past few decades. Regardless of GOs and NGOs taking the required steps, proper implementation of interdisciplinary adaptive policy and regular monitoring in the Sundarbans fisher's community in Bangladesh could effectively reduce climate change impacts and improve livelihood conditions.

Keywords: mangrove forest; climate change; weather events; primary productivity; livelihood

1. Introduction

The Sundarbans are the only contiguous and most extensive mangrove forest system globally, with over 10,000 square kilometres (Gopal and Chauhan, 2006). Bangladesh comprises above 60% of the Sundarbans, located on the northern boundaries of the Bay of Bengal and the recently departed Ganges delta (Islam, 2003). The Ganga, Brahmaputra, and Meghna river systems are connected by a dense network of smaller rivers, canals, and creeks (Hossain *et al.*, 2021). This mangrove helps maintain coastal livelihoods by providing essential ecosystem services and critical socio-economic and environmental functions (Agrawala *et al.*, 2003). However, in the coastal areas of Bangladesh, export-oriented aquaculture industries have grown up that have used the Sundarbans as their main source of production. As a result, an unfavourable environmental situation has resulted for the fishing communities (Bir *et al.*, 2015).

In Sundarbans, climate change is a virtual event as many fish species in this area are declining due to climate change, exploitation, habitat alteration, as well as pollution (Agrawala *et al.*, 2003). Physical and biogeochemical aspects of aquatic ecosystems, such as pH, temperature, and oxygen concentration, can be affected by climate change (Tumpa *et al.*, 2020), wind patterns and flow, and upwelling activity. These changes immediately impact aquatic nutrient enrichment and the ecophysiology and ecology of underwater creatures (Dasgupta *et al.*, 2017; Rahaman *et al.*, 2020). As a result, modifications in species distribution, ecological functions, phenology, species assemblages, and trophic interactions occur. As environmental conditions in Sundarbans rivers deteriorate, intertidal fish groups can transition from competitive to facilitative associations. Climate change would affect the water temperatures in Sundarbans aquatic habitats to rise to suboptimal or catastrophic levels for resident fishes with limited dispersion capabilities. In contrast, the detrimental effects of disease are expected to accelerate as pathogens prefer high temperatures over their hosts (Harvell *et al.*, 2002).

The fisheries sector supports the livelihoods of several fishing communities in the Sundarbans (Giri *et al.*, 2007), and it also contributes significantly to the national economy (Islam *et al.*, 2018). More than 3.5 million people in the Sundarbans area either directly or indirectly depend on ecosystem services (Biswas *et al.*, 2007). Sundarbans fishers are already experiencing the consequences of these changes caused by rising global atmospheric temperatures. For example, rising ocean temperatures have resulted in increased storm frequency and saline water penetration into the coastal areas of Bangladesh (Unnikrishnan *et al.*, 2006). The impacts of climate change on the fishing sector are currently being researched (Barros *et al.*, 2014). There have been comparatively fewer studies of the effects of climate change on fisheries resources and fishers in developing countries, particularly in Bangladesh. This study aims to identify the effects of climate change on fisheries resources, primary productivity, water quality, physiology of fishes, and livelihood of fishers of Sundarbans in Bangladesh.

2. Materials and Methods

2.1. Study area

This study was conducted in the Khulna Sadar, Bagerhat Sadar, Mongla, Digrajbazar, Shatkhira, Shemnagar, Koira, Paikgacha, Goroikhali, and Mongla ports of the Sundarbans area (Figure 1) from October 2017 to November 2018. The Sundarbans (largest mangrove forest of the world) is located south of the Tropic of Cancer and northwest of the Bay of Bengal (21° 30'–22° 30' N, 89° 12'-90° 18' E).

2.2. Fishermen data collection

The data were obtained from a comprehensive study on fisher communities that compiled observations of climate change impacts and adaptive responses by Sundarbans fishers. In this context, "observation" refers to a preliminary observation cited or asserted in the source material by persons or groups described as subsistence-oriented fishers (i.e., fishers depending on the fishery for subsistence) (Savo *et al.*, 2016). A total of 120 fishers were surveyed using a structured questionnaire in their residences, boats, markets, and local places to discover their livelihoods and the impact of climate change on them. The fisher folk survey took place in Bogakochua, Andarmanik, Tripoltola, Bojragram, Itampur, and Dangmari are in the Bagerhat district; Noakati, Goraikhali, Boalia, Mamudkati, Srikantopur, Koira, Beyara, and Sadar are in the Khulna district; and Shemnagar, Asasoni, Debduar, and Durgapur are in the Shatkhira district. The final questionnaire considered age, gender, religion, marital status, types of family, family members, education, housing status, medical facilities, sanitary facilities,

drinking water sources, land status, current facilities, safety, and security. It also contained socio-economic questions such as income sources, daily or monthly income (peak and restricted seasons), loan facilities, loan amount, interest rate (percentage), source of the loan, savings, government organisations (GOs), and non-government organisations (NGOs) facilities, and so on. Some particular questions were included in the questionnaire to identify the causes of vulnerability and highlight the role of fisheries in fishers' livelihoods and food security in the country to assess the possible impact of climate change on Sundarbans fisheries and fishers. Consequently, a questionnaire section comprised local temperature, rainfall, wind direction, cyclones, flooding, droughts, rising sea levels, salinity, soil degradation, freshwater flow, siltation, fishing status, fish productivity, and factors affecting fish productivity levels.

All observations were classified into four categories: (a) changes in weather and climate; (b) changes in the physical components of the environment; (c) changes in fisheries resources; and (d) impacts on the well-being of fishers, particularly women and children. We further subclassified all four groups, e.g., changes in weather and climate, changes in the physical components of the environment, changes in the fisheries resources, and impacts on the well-being of fishers, especially women and children, into 8, 7, 11, and 15 sub-groups respectively. Each sub-group was characterized as a rare, occasionally, high, moderately high, or extremely high event based on its frequency of occurrence in the study area, which was determined by a ranking within 1 to 5 categories.

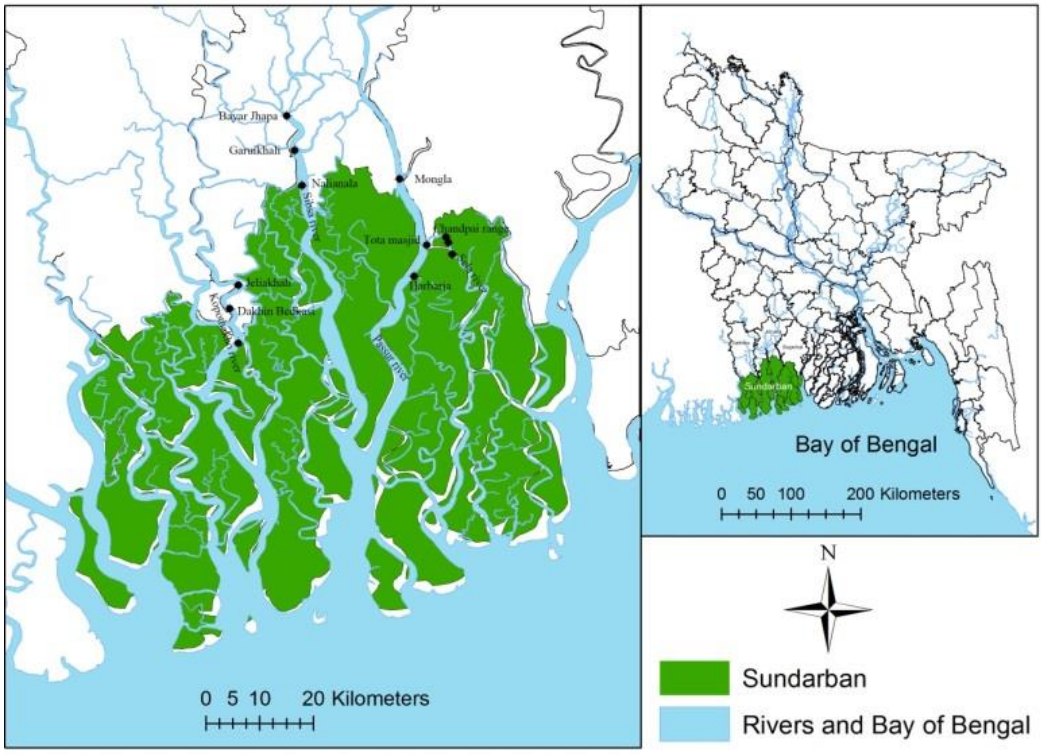

Figure 1. Study area and sampling stations (Sundarbans regions).

2.3. Data analysis

Instead of relying on preexisting assumptions, the collected fisher data from the study areas was examined using grounded theory concepts to detect and clarify emergent patterns. After that presented in textual and graphical forms to understand the impact of climate change on the status of fisher livelihood and the constraints of fisher folks. GIS software consisted of an interface from Mapinfo and digitised maps from ArcView v3.2. The GIS software was used to view the statistical results and map of the Sunderbans mangrove forest. Other statistical data were analysed using Microsoft office 2016 and SPSS v26 and then presented in textual and graphical views.

3. Results

3.1. Weather and climatic variable perception of fishermen

Under this observation, eight sub-categories were taken to evaluate the changes in weather and climate in the Sundarbans region (Figure 2). A total of 100% fishers agreed that increased air temperature, thunderstorms, and extreme weather events frequently occurred. All three sub-categories were reported more frequently in the Sundarbans zone, considered extremely high events (rank-5). Decreased rainfall and changes in weather patterns/seasonality in Sundarbans were agreed by 87.4% and 87.3% of fishers, respectively. It was also considered an extremely high event (rank-5). Water temperature also increased due to increased air temperature, and 58.6% of fishers agreed with it. Water temperature was an essential sub-category in the fisheries sector, and it was also considered a moderately high event (rank-3). A total of 44% of fishers accepted wind direction and intensity changes, and it ranked as an occasional event (rank-2). Fog was considered as an occasional event (rank-2) also, and 68% of fishers admitted it.

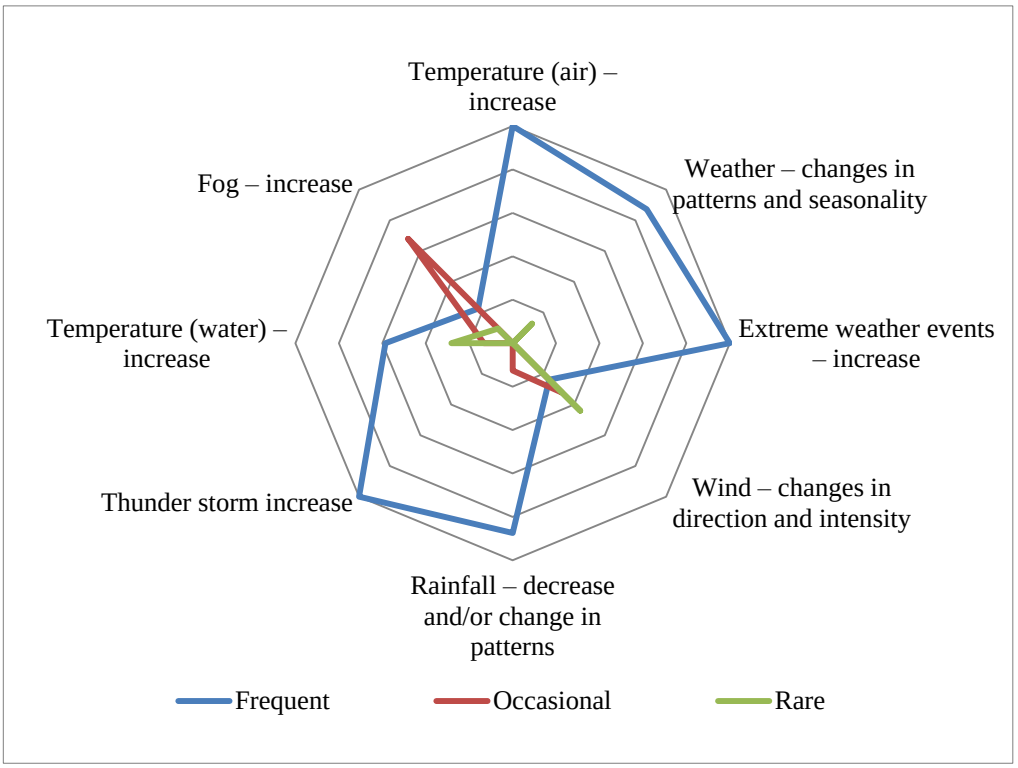

Figure 2. Observations by fishers of changes in weather and climate in the Sundarbans region by frequency and rank.

3.2. Physical components variable perception of fishermen

Under this observation, seven sub-categories were taken to evaluate the impacts of climate change on physical components in the environment of fishers (Figure 3). Most fisher communities occasionally experience increased soil erosion, according to 57.1 % of fishers. Increased soil erosion was deliberated as rare event (rank-1) in most of the areas of fishers' communities.

However, river freshwater flows were gradually decreased, and 100% of fishers disclosed it. Therefore, decreased river freshwater flow was apprehended as an extremely high event (rank-5). The decreased upstream freshwater flow was the main reason for introducing a high rate of saline water in these areas. In this study, it was found that the rate of saline water intrusion gradually increased. 77.3% of fishers agreed to the saline water intrusion. Therefore, saltwater intrusion was considered as a high event (rank-4). The other reasons for saltwater intrusion were rising sea levels and ocean tidal effects. About 57.8% of fishers admitted the rising sea level, and it was deliberated as a moderately high event (rank-3).

On the other hand, ocean tidal effects were a frequent problem for 42.4% of fishers in their communities. Therefore, it was apprehended as a moderately high event (rank-3). Siltation was another serious problem where

72% of fishers agreed with this, which was considered a high event (rank-4). Flood was also increased by a high rate of siltation in rivers and rivers mouth. Flood problem was faced by 82.3% of fishers frequently in their communities. Therefore, increased flood was considered an extremely high event (rank-5).

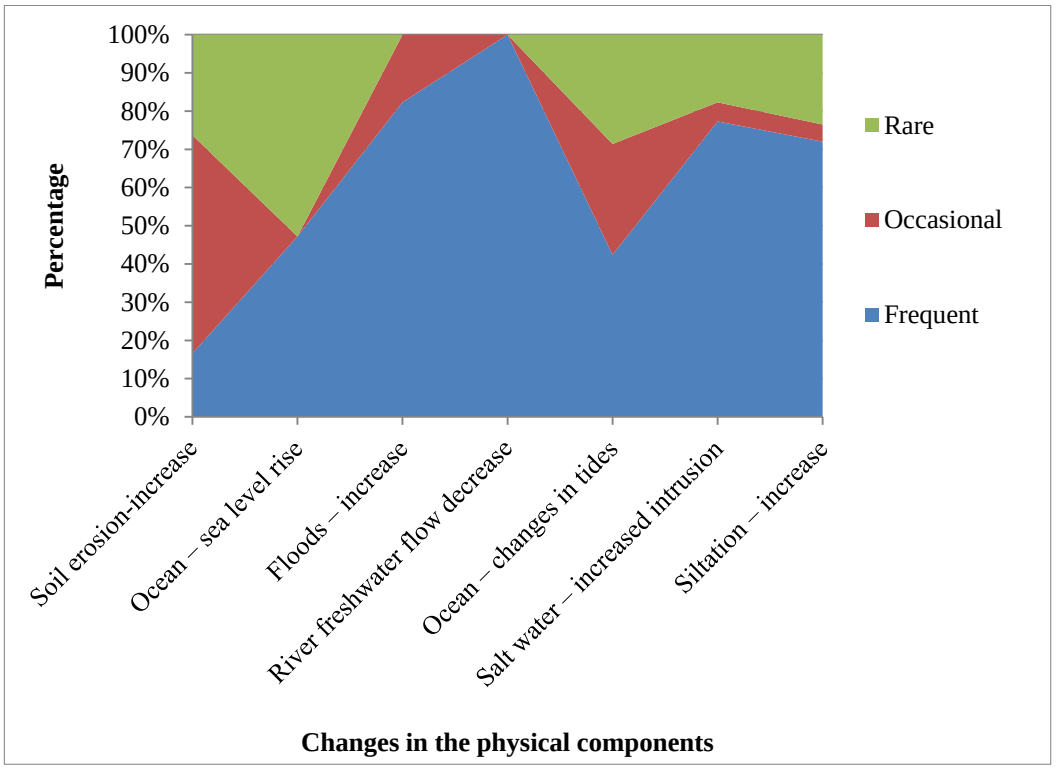

Figure 3. Observations by fishers of changes in the physical components of the environment of fishers' community in the Sundarbans region by frequency and rank.

3.3. Impacts of climate change on the well-being of fishers (women and children)

Under this observation, 15 sub-categories were taken to evaluate the impacts of climate change on fishers' social well-being, especially women and children (Figure 4). All fisher communities were located more or less in an unfavourable environment which is created by climate change. However, this unfavourable environmental condition was frequently faced by 66.1% of fishers. Unfavourable environmental condition was considered as a high event (rank-4). In order to live in an unfavourable environment, the social well-being of fishers was affected by several problems; disease, lack of drinking water, malnutrition, sanitary problem, electricity, lack of food and clothes, lack of proper treatment, and so on. Among them, diseases were rapidly occurring and considered a severe problem. A total of 87.3% of fishers agreed with this problem. Diseases were considered as an extremely high event (rank-5). Besides, fishers rarely received proper treatment, and 67% of fishers agreed that. Only 11.3% of fishers were able to get proper treatment, and it was deliberated as a rare event. Disease spread quickly owing to a shortage of drinking water, sanitation issues, hunger, and other factors. Most fishers did not have the facilities to get pure drinking water and about 91.2% of fisher families frequently suffered this severe problem. Lack of drinking water was apprehended as an extremely high event (rank-5). Another significant concern in the study area was the hygienic situation, which was regularly encountered by 63.6% of fishing households. A sanitary problem was regarded as a major event (rank-4).

Malnutrition condition also influenced the incidence of disease. The majority of the children and women were malnourished, affecting 77.4% of the fishing families. Therefore, it was considered as a high event (rank-4). The education qualification of fisher families was significantly less in the study area. Only 22.7% family of fisher frequently gets education facilities. The illiterate and primary level dropped fisher families were 70.7% and 13.6%, respectively. These illiterate fisher communities did not aware of the disadvantage of early marriage. A high rate of early marriage had occurred in the study area.

Due to a lack of educational qualification, most fishers did not move to any other activities from fishing, and 55.8% of fishers admitted that. Only 6.4% of fishers got the chance to move other activities from fishing. During banned seasons, some other activities related to fisheries, such as making nets and traps, and making and repairing boats, had been done by 37.8% of fishers. However, most of the fishers (64.4%) who did not have facilities to do any other activities during banned seasons took loans frequently from Mahajan, agencies, and banks to maintain their livelihood. Any direct help from GOs and NGOs did not reach 86.2% of fishers in the study areas. Therefore, information and training were not accessed by 78.9% of fishers to become well in their profession. Although, the Government took proper steps to ensure electricity and safety in a large proportion of the study area. Electricity and safety facilities from Govt. were enjoying 57.4% and 77.4% fishers, respectively (Figure 5).

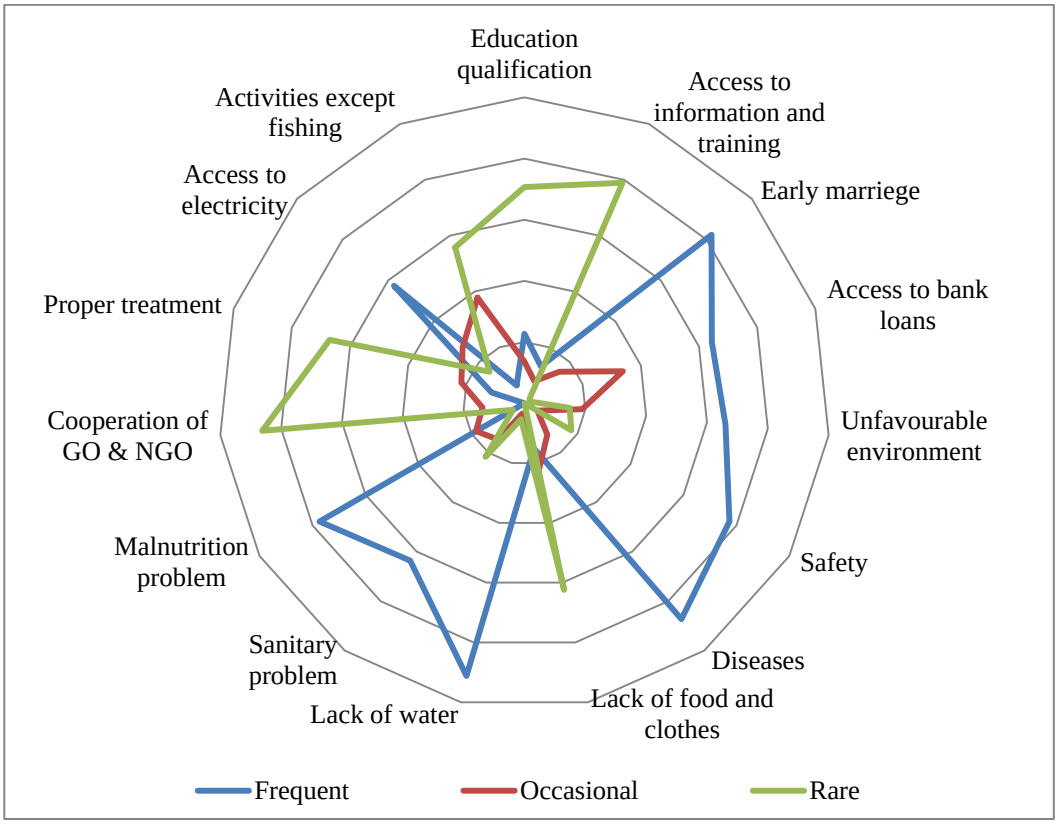

Figure 4. Observations by fishers of changes in the well-being of fishers (especially women and children) in fishers' community by frequency and rank.

3.4. Fisheries resources variable perception of fishermen

Under this observation, 11 sub-categories were taken to evaluate the impacts of climate change on fisheries in the study area (Figure 5). Fish production was immensely reduced in the rivers of the Sundarbans, and 95.4% of fishers admitted it. Most of the fishers did not get enough fish as they had captured before. Besides, some of the species of the Sundarbans were not available in rivers. In 87% of fishers agreed, fish biodiversity was damaged. Most freshwater species biodiversity, abundance, and production were significantly reduced, and 62.2% of fishers agreed that. In accordance with 74.2% of records of fishers, nursery ground was gradually damaged in rivers of the Sundarbans. However, following 42.1% of fishers, these migration routes were blocked with small mesh-sized nets. In the case of a few fishes, spawning seasons were also slightly changed, confirmed by only 17.3% of fishers. However, according to most of the fishers (62.7%), spawning seasons occasionally change. Therefore, people constructed many polders in a large proportion of the study area to expand shrimp and aquaculture. Shrimp and aquaculture were increased near communities of 72.2% fishers.

On the other hand, fish storage was not enough in local areas. Fishing materials cost was increased occasionally in a year. Nevertheless, according to most of the fishers, the fish price in the market was reasonable (82.3%). Sometimes, fish price was reduced in the local market in the study areas (Figure 5).

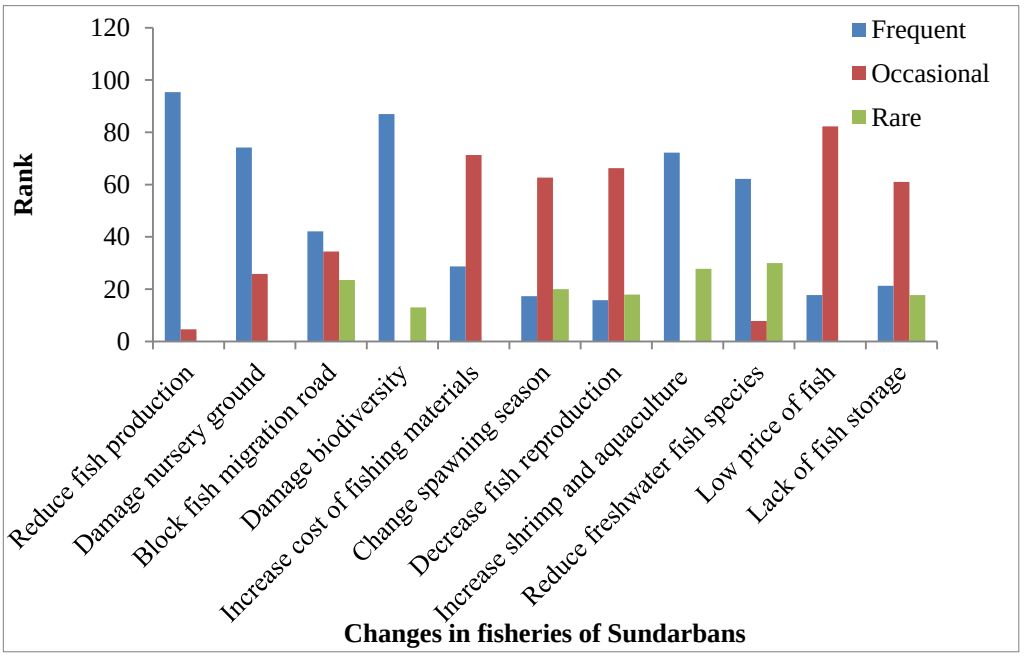

Figure 5. Observations by fishers of changes in fisheries of Sundarbans region by frequency and rank.

4. Discussion

4.1. Perception of weather and climatic condition variable in the Sundarbans regions

The majority of observations in Sundarbans revealed some of the most frequently reported phenomenons. Among them, increased air temperature (17.3% of records of the weather and climate change observations), changes in weather patterns/seasonality (15.1% of records of the weather and climate change observations), increased thunderstorms (17.3% of records of the weather and climate change observations) and increased extreme weather events (17.3% of records of the weather and climate change observations) were the most commonly discussed. These changes had adverse effects on fishers and their communities. Among them, freshwater fish species were mainly damaged than others. Some previous studies suggested the changes included in these sub-categories can have a variety of adverse effects on the coastal environment (Harley *et al.*, 2006), local economy (Allison *et al.*, 2009), society and culture (Adger *et al.*, 2005). The monthly maximum mean average temperature was gradually increased due to climate change recorded by Mongla station (1989-2016) (Figure 6).

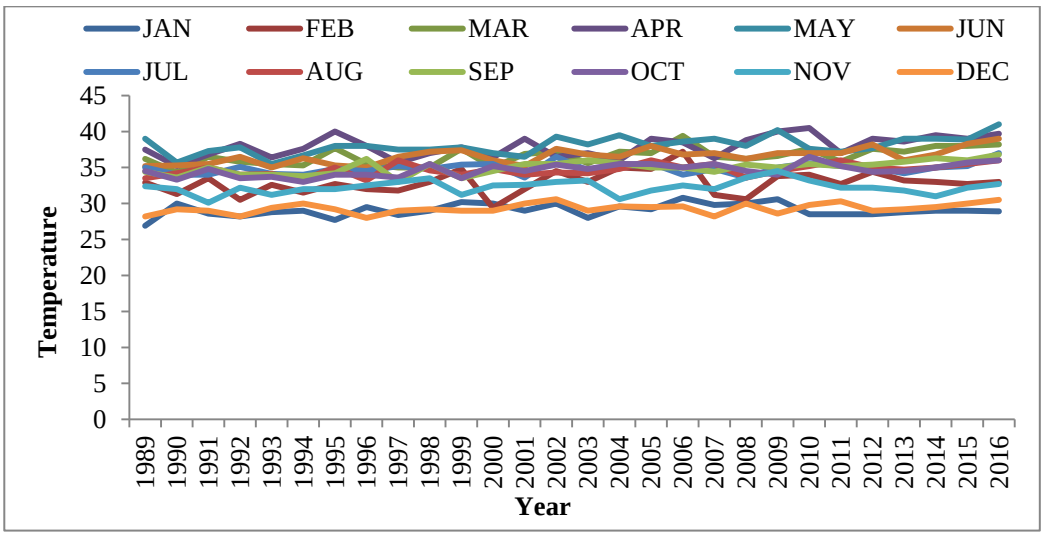

Figure 6. The monthly maximum average temperature of Sundarbans recorded by Mongla station (1989-2016) (Rahman, 2017)

Fishers had got heat stock and dehydration problems during fishing by high temperatures. Increased air temperature also created a northwester disaster in the study area, where many physical structures of fisher communities were destroyed during pre-monsoon. In previous years, Sundarbans' terrestrial resources and ecosystems were devastated by cyclones or hurricanes (Uddin *et al.*, 2021). Understanding, reading, and recording weather is crucial for fishers' safety and was of particular concern in the Sundarbans, where weather conditions are going extreme day by day. More unpredictable storms endanger fishers at sea and force changes in seasonal fishing schedules (Turunen *et al.*, 2009; Fisher, 2011), which may, in turn, affect catch availability and the local economy. Fog was another important sub-category during the winter season in the study area, which was also influenced by climate change. Fishers were also reported decreases, increases and/or changes in the duration and timing of rainfall (15.1% of records of the weather and climate change observations) occurred dramatically in Sundarbans, where changes in rainfall were the most commonly reported type of observation by fisher communities. Besides, changes in rainfall patterns and weather patterns/seasonality were also often observed in this area frequently by fishers. The yearly average rainfall gradually decreased during monsoon in the Sundarbans recorded by Mongla station (1991-2013) (Figure 7). Previous research suggested that rainfall shifts were essential to monitoring because many fishes and shellfish depend on seasonal precipitation fluxes during monsoon that can generate significant nutrient transport from freshwater rivers to marine and estuarine environments (Doney *et al.*, 2012).

Weather predictability was reduced by changes in wind direction and intensity (4.1% of records of the weather and climate change observations) in Sundarbans which was observed by fishers. Different wind directions were generally associated with specific weather patterns (e.g., rain, storms) known to subsistence fishers based on their long-term knowledge of particular areas (King *et al.*, 2008; Bunce *et al.*, 2010). Unpredictable winds can hinder fishers' ability to read signs of incoming storms, which critically affects ocean navigation and safety, particularly given the small vessels typically used by subsistence fishers (Grant and Berkes, 2004; Glaeser and Glaser, 2010). Increases in river water temperature (10.1% of records of the weather and climate change observations) were also noted by fishers in several communities. The rise in water temperatures was especially relevant for fishers because of the expected changes in fish distribution and abundance (Perry, 2011; Cheung *et al.*, 2013; Weatherdon *et al.*, 2016).

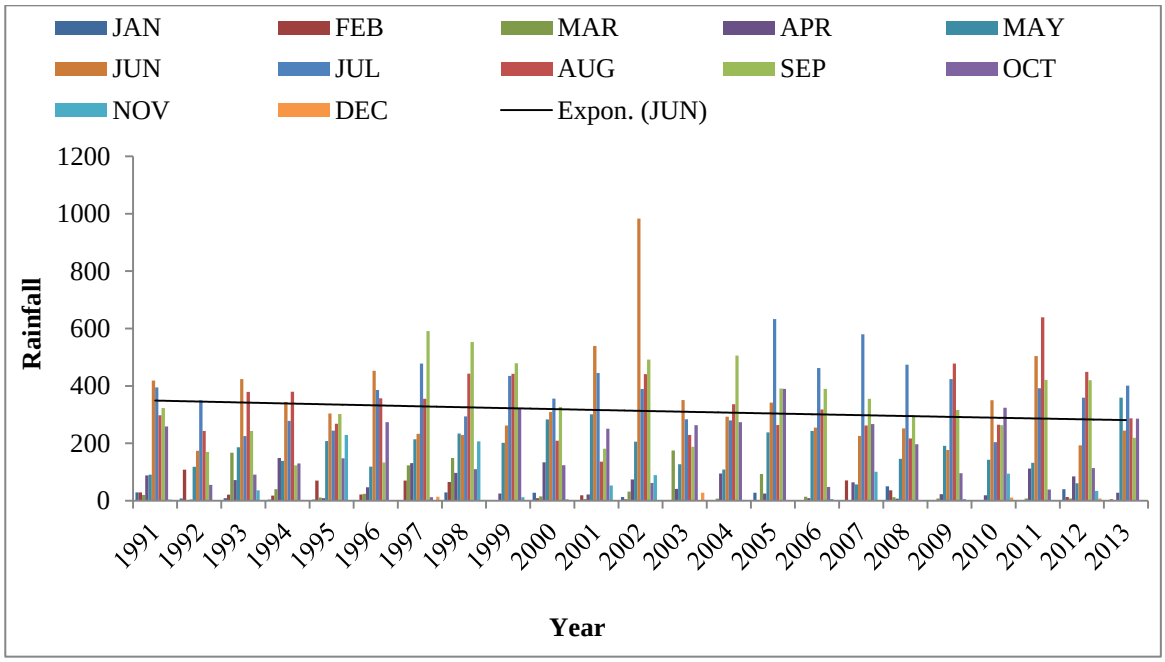

Figure 7. The yearly average rainfall of Sundarbans recorded by Mongla station (1991-2013). (Source: climate.barcapps.gov.bd)

4.2. Perception of physical components variable of the environment

In the study area, changes in the physical components of the environment observed by fishers occurred frequently. Fishers most often report three linked phenomena in the physical environment category; (a) decreased river freshwater flow (22.9% of records of the physical environment observations), (b) increased saltwater intrusion (17.7% of records of the physical environment observations) and, (c) increased siltation

(16.5% of records of the weather and climate change observations). The saltwater intrusion was the crucial problem that frequently occurred in the study area. Fishers relate increased saltwater intrusion and siltation to decreased freshwater flow and concurrent phenomena such as higher tides (9.7% of records of the physical environment observations), more frequent storm surges, and increased sea-level rise (10.8% of records of the physical environment observations) in Sundarbans. According to Wahid *et al.*, (2007), the freshwater flow had declined almost 60% since 1973 due to the construction of the Farakka Barrage on the Ganges in India, and that had silted up most of its distributaries in Bangladesh and impacted the carrying capacities of rivers in Sundarbans. As a result, the dry season and the wet season flow of freshwater in many rivers was reduced. Soil erosion (3.4% of records of the physical environment observations) also occurred due to sea-level rise, floods (18.8% of records of the physical environment observations), and concurrent phenomena such as higher tides and more frequent storms surges. Fishers understand that floods were exacerbated by changing weather patterns that produced more frequent heavy rainfall events and increased siltation in the river (Agrawala *et al.*, 2003; Mataki *et al.*, 2006; Vlassova, 2006). These physical changes can make fishing more challenging and lead to loss of land/property, coastal vegetation, and reduced access to fresh water (Barnett and Adger, 2003). Indeed, a reduction in freshwater availability was often combined with saltwater intrusion into local groundwater sources.

4.3. Impacts of weather and climatic variable perception of coastal fishers

Climate change mainly hampered the environmental condition of fisher communities in the study area. Fishers lived in an unfavourable environment (9% of records of impacts of climate change on well-being). They continued their life with various problems, e.g., lack of drinking water (12.4% of records of impacts of climate change on well-being), malnutrition (10.5% of records of impacts of climate change on well-being), sanitary problems (8.6% of records of impacts of climate change on well-being), electricity (3.1% of records of impacts of climate change on well-being), lack of food and clothes (2.1% of records of impacts of climate change on well-being) and lack of proper treatment (13.3% of records of impacts of climate change on well-being). Drinking water was not available in the fisher communities. Rain's or pond's water was drunk by most fisher families. Few fishers had tubewell facilities in their communities achieved by Government. However, the groundwater level was gradually reduced due to increased salinity intrusion.

Sanitary was another big issue in the study area. Few fishers had a well-facilitated sanitary system. Nevertheless, most fishers also used unhealthy sanitary, and some used river banks. Children and women of the communities suffered malnutrition problems due to a lack of nutritious foods. As a result, various diseases (11.7% of records of climate change affect well-being), such as skin diseases, waterborne diseases, nutritional disorders, and other health threats, commonly occur in communities. Some fishers communities were also observed health effects, such as skin rashes, burns, and waterborne diseases, especially after extreme events such as floods and hurricanes found by Furgal and Seguin, (2006). Even if not numerous, these observations supported the research of Patz *et al.*, (2005); Islam *et al.*, (2020a); and Saha *et al.*, (2021), which suggested an increase in some diseases due to climate change. Because of the reduction in fish production, fishers did not earn enough money to maintain their family appropriately. As a result, most fishers took vast amounts of loans with 5-7% interest per month from local money lenders to maintain their families during banned seasons and release fishers from the Sundarbans pirates. They did not get enough financial help from Govt. and non-government organisations. In fact, they did not have the scope to move other activities due to their illiteracy. In that case, women became a burden in the fishers' community, and the community took early marriage as their solution, which was an alarming problem in society.

4.4. Fisheries resources variable perception of fishermen

By comparing observations of different fisherman with previous research, it was clear that fish production (17.9% of records of changes in fisheries) was significantly reduced, and the biodiversity (16.3% of records of changes in fisheries) was reduced. Fishes were affected by elevated water salinity, pH, temperature, and DO (Moyle and Cech, 2004). Freshwater fish diversity and production were mainly hampered than others due to increased salinity intrusion rates and other physic-chemical parameters (Akter *et al*., 2020; Ema *et al.*, 2020; Hossen *et al*., 2014; Jahan *et al*., 2019; Jahan *et al*., 2021; Rakhi *et al*., 2015). Most of the freshwater aquatic habitats in Sundarbans regions were altered into the saline environment, which was the reason for reduced freshwater fish species (11.7% of records of changes in fisheries). Changes in water circulation, ocean water volume, and more severe marine intrusion were causing increased eutrophication, hypoxia, and anoxia in the estuary and coastal systems, resulting in the loss of marsh and intertidal ecosystems (Officer *et al.*, 1984; Kennedy, 1990). Most of the northern parts of the Sundarbans were converted into shrimp and aquaculture (13.5% of records of changes in fisheries) farms for some particular species by making a folder to retain saline

water. Small mesh-sized nets destroyed different fish fry while collecting shrimp fry for culture from wild sources. Besides, fish fry was also destroyed due to blocking the fish migration route (7.9% of records of changes in fisheries) by small mesh-sized nets in the rivers in different places. Fish migration route was also blocked due to siltation in the rivers. The Sundarbans was considered as nursery (13.9% of records of changes in fisheries) and spawning ground (3.3% of records of changes in fisheries) for many fish and crustaceans. However, these essential grounds were hampered due to changes in water qualities, especially salinity. As a result, fish reproduction (3% of records of changes in fisheries) and survival rates were gradually reduced. Climate change-related influences significantly impact fishes and their populations (Islam *et al*., 2020b; Rahaman *et al*., 2019 Roessig *et al.*, 2004).

5. Conclusions

The Sundarbans is the largest mangrove forest with many plants and animals and an economic zone. Nevertheless, now, it is vulnerable due to climate change, which may severely impact its fisheries resources, water quality, natural productivity, breeding and nursery ground. Decreased Ganges river flow and sea-level rise due to global warming accelerate the high rate of salinity intrusion in the rivers of Sundarbans day by day. As reported, climate change impacts on the fishers community increased many serious problems such as diseases, lack of fresh drinking water, food, lands, economic support, and lack of other facilities. Flood, cyclones, siltation, erosion, and windstorm are joined in Sundarbans regions. As a result, many fishers getting lower livelihood conditions as they lose their habitat, life, land, and properties every year. The Government and other organisations should take necessary steps to support the fishers communities during the banned season and natural calamities. With greater use of targeted information, fisheries sectors can be better placed to adapt to future changes and take advantage of opportunities associated with climate change. Efforts to reduce these barriers and synthesise learning from continued research will be critical to improving, or at least preserving, adaptive capacity for the future sustainability of fisheries resources of Sundarbans.

Acknowledgements

Authors acknowledge to the Project Implementation Unit, National Agricultural Technology Program-Phase II Project (NATP-2), Bangladesh Agricultural Research Council (BARC), Farmgate, Dhaka-1215, Bangladesh for funding the project (no. CRG-718).

Data availability

All data are available within the manuscript.

Conflict of interest

None to declare.

Author contributions

Tutul Kumar Saha: methodology, data collection, analysis and manuscript writing; Md. Nagim Uddin: data collection, analysis and manuscript writing; Myiesha Rayzil Hossain, SM Fakrul Islam: reviewing and editing; Zakir Hossain: supervision, conceptualization, reviewing and editing. All authors have read and approved the final manuscript.

References

Adger WN, TP Hughes, C Folke, SR Carpenter and J Rockstrom, 2005. Social-ecological resilience to coastal disasters. Science, 309: 1036-1039.

Agrawala S, T Ota, AU Ahmed, J Smith and M Van Aalst, 2003. Development and climate change in Bangladesh: Focus on coastal flooding and the Sundarbans. OECD, Paris, pp70.

Agrawala S, T Ota, J Risbey, M Hagenstad, J Smith, M van Aalst, K Koshy and B Prasad, 2003. Development and climate change in Fiji: Focus on coastal mangroves. OECD, Paris, pp. 56.

Akter R, NS Ema, MS Hossain and Z Hossain, 2020. Effects of dietary polyunsaturated fatty acid on reproduction and developmental biology of Gangetic Mystus (*Mystus cavasius*) (Hamilton-Buchanan, 1822). Asian J. Med. Biol. Res., 6: 641-649.

Allison EH, AL Perry, MC Badjeck, W Neil Adger, K Brown, D Conway, AS Halls, GM Pilling, JD Reynolds and NL Andrew, 2009. Vulnerability of national economies to the impacts of climate change on fisheries. Fish Fish., 10: 173-196.

Barnett J and WN Adger, 2003. Climate dangers and atoll countries. Clim. Change, 61: 321-337.

Barros VR, CB Field, DJ Dokken, MD Mastrandrea, KJ Mach, TE Bilir, M Chatterjee, KL Ebi, YO Estrada and RC Genova, 2014. Climate change 2014 impacts, adaptation, and vulnerability part b: Regional aspects: Working group ii contribution to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press. pp. 1-1820.

Bir J, MS Sumon and S Rahaman, 2015. The effects of different water quality parameters on zooplankton distribution in major river systems of Sundarbans mangrove. IOSR J. Environ. Sci., Toxicol. Food Technol., 11: 56-63.

Biswas SR, JK Choudhury, A Nishat and MM Rahman, 2007. Do invasive plants threaten the Sundarbans mangrove forest of Bangladesh? For. Ecol. Manag., 245: 1-9.

Bunce M, S Rosendo and K Brown, 2010. Perceptions of climate change, multiple stressors and livelihoods on marginal African coasts. Environ. Dev. Sustain., 12: 407-440.

Cheung WW, JL Sarmiento, J Dunne, TL Frölicher, VW Lam, M Deng Palomares, R Watson and D Pauly, 2013. Shrinking of fishes exacerbates impacts of global ocean changes on marine ecosystems. Nat. Clim. Change, 3: 254-258.

Dasgupta S, I Sobhan and D Wheeler, 2017. The impact of climate change and aquatic salinisation on mangrove species in the Bangladesh Sundarbans. Ambio, 46: 680-694.

Doney SC, M Ruckelshaus, J Emmett Duffy, JP Barry, F Chan, CA English, HM Galindo, JM Grebmeier, AB Hollowed and N Knowlton, 2012. Climate change impacts on marine ecosystems. Ann. Rev. Mar. Sci., 4: 11-37.

Ema NS, MS Hossain, MN Uddin, MM Rahman and Z Hossain, 2020. Study of the climate change impact on fishers' livelihood near the Padma river in Munshiganj, Bangladesh. Asian J. Med. Biol. Res., 6: 777-784.

Fisher PB, 2011. Climate change and human security in Tuvalu. Glob. Change Peace Secur., 23: 293-313.

Furgal C and J Seguin, 2006. Climate change, health, and vulnerability in Canadian northern aboriginal communities. Environ. Health Perspect., 114: 1964-1970.

Giri C, B Pengra, Z Zhu, A Singh and LL Tieszen, 2007. Monitoring mangrove forest dynamics of the Sundarbans in Bangladesh and India using multi-temporal satellite data from 1973 to 2000. Estuar. Coast. Shelf. Sci., 73: 91-100.

Glaeser B and M Glaser, 2010. Global change and coastal threats: The Indonesian case. An attempt in multi-level social-ecological research. Hum. Ecol. Rev., 135-147.

Gopal B and M Chauhan, 2006. Biodiversity and its conservation in the Sundarbans mangrove ecosystem. Aquat. Sci., 68: 338-354.

Grant S and F Berkes, 2004. One hand can't clap": Combining scientific and local knowledge for improved Caribbean fisheries management. In: Commons in an Age of Global Transition: Challenges, Risks and Opportunities," the Tenth Conference of the International Association for the Study of Common Property, Oaxaca, Mexico, August. pp. 9-13.

Harley CD, A Randall Hughes, KM Hultgren, BG Miner, CJ Sorte, CS Thornber, LF Rodriguez, L Tomanek and SL Williams, 2006. The impacts of climate change in coastal marine systems. Ecol. Lett., 9: 228-241.

Harvell CD, CE Mitchell, JR Ward, S Altizer, AP Dobson, RS Ostfeld and MD Samuel, 2002. Climate warming and disease risks for terrestrial and marine biota. Science, 296: 2158-2162.

Hossain Z, MS Hossain NS Ema and AW Omri, 2021. Heavy metal toxicity in the Buriganga river alters the immunology of Nile tilapia 2 (*Oreochromis niloticus* L). Heliyon, 7: e08285.

Hossen MS, AHMM Reza, SF Rakhi, MM Rahman, MA Alam and Hossain Z. 2014. Observation of embryonic and early larval development of striped gourami, *Trichogaster fasciata* (Perciformes: Osphronemidae). EurAsian J. BioSci., 8: 61-70.

Islam A, A Habib, NM Uddin, JM Hossain, IJ Tumpa, ATU Haque and Z Hossain, 2018. Effects of stocking density on growth and survival of thai pangas (*Pangasius hypophthalmus* Sauvage, 1878) fry in net cages in a commercial fish farm in Noakhali, Bangladesh. Fundam. Appl. Agric., 3: 586-590.

Islam A, MS Hossain and Z Hossain, 2020b. Impacts of climate change on fishers´ livelihood in Kishoregonj haor region, Bangladesh. Asian J. Med. Biol. Res., 6: 408-417.

Islam A, SS Basak and Z Hossain, 2020a. Fish and plankton biodiversity in the Kishoreganj haor, Kishoreganj, Bangladesh. Genet. Aquat. Org., 4: 39-48.

Islam MS, 2003. Perspectives of the coastal and marine fisheries of the Bay of Bengal, Bangladesh. Ocean Coast. Manag., 46: 763-796.

Jahan H, MA Pervin, R Akter and Hossain Z. 2019. Effects of soybean meal on new muscle generation and growth of silver barb, *Barbonymus gonionotus*. Int. J. Agric. Environ. Bio-Res., 4: 102-110.

Jahan H, IJ Tumpa, AQ Wafaa, M Moniruzzaman, MA Pervin, R Akter, AW Omri and Z Hossain, 2021. Evaluation of the partial replacement of dietary fish meal with fermented or untreated soybean meal in juvenile silver barb, *Barbonymus gonionotus*. Front. Nutr., 8: 733402.

Kennedy VS, 1990. Anticipated effects of climate change on estuarine and coastal fisheries. Fisheries, 15: 16-24.

King D, A Skipper and WB Tawhai, 2008. Māori environmental knowledge of local weather and climate change in Aotearoa–New Zealand. Clim. Change, 90: 385-409.

Mataki M, K Koshy and V Nair, 2006. Implementing climate change adaptation in the pacific islands: Adapting to present climate variability and extreme weather events in navua (fiji). Assessments of Impacts and Adaptations to Climate Change (AIACC), Florida, USA.

Moyle PB and JJ Cech, 2004. Fishes: An introduction to ichthyology. 5th Edn.: Prentice-Hall, Englewood Cliffs, New Jersey.

Officer CB, RB Biggs, JL Taft, LE Cronin, MA Tyler and WR Boynton, 1984. Chesapeake bay anoxia: Origin, development, and significance. Science, 223: 22-27.

Patz JA, D Campbell-Lendrum, T Holloway and JA Foley, 2005. Impact of regional climate change on human health. Nature, 438: 310-317.

Perry R, 2011. Potential impacts of climate change on marine wild capture fisheries: An update. J. Agric. Sci., 149: 63-75.

Rahaman MJ, MS Hossain, MM Rahman and Z Hossain, 2019. Fish biodiversity and plankton communities in the Meghna, Laukhati and Galachipa river in Bangladesh. EurAsian J. BioSci., 13: 1705-1717.

Rahaman MJ, MS Hossain, MM Rahman and Z Hossain, 2020. Impacts of climate change on livelihood of the fishers´ at the Meghna, Gauhati and galachipa river in Bangladesh. Asian J. Med. Biol. Res., 6: 81-92.

Rahman MA, 2017. The Anomaly of Maximum Temperature in South-West Part of Bangladesh. Int. J. Sci. Eng. Res., 4: 123-126.

Rakhi SF, AHMM Reza, MS Hossen and Z Hossain, 2015. Embryonic development and growth performances of an endangered fish species *Nandus nandus*: effects of dietary polyunsaturated fatty acids supplementation. Iran. J. Fish. Sci., 14: 1029-1052.

Roessig JM, CM Woodley, JJ Cech and LJ Hansen, 2004. Effects of global climate change on marine and estuarine fishes and fisheries. Rev. Fish Biol. Fish., 14: 251-275.

Saha TK, J Hosen and Z Hossain, 2021. Fish culture in net cages improves the livelihood of Charland population: A case study from Padma (Ganga) River, Mmunshiganj, Bangladesh. Asian J. Med. Biol. Res., 7: 174-181.

Savo V, D Lepofsky, J Benner, K Kohfeld, J Bailey and K Lertzman, 2016. Observations of climate change among subsistence-oriented communities around the world. Nat. Clim. Chang., 6: 462-473.

Tumpa IJ, SM Hossain, NM Uddin and Z Hossain, 2020. Spawning and developmental biology of Pabdah Catfish, *Ompok pabda*. Asian J. Med. Biol. Res., 6: 449-459.

Turunen J, J-P Snäkin, J Panula-Ontto, H Lindfors, H Kaisti, J Luukkanen, S Magistretti and C Mang, 2009. Livelihood resilience and food security in Cambodia. In: ideas. pp. 2010.

Uddin MN, IJ Tumpa and Z Hossain, 2021. Diversity of Biological Communities Along the Major Rivers of Sundarbans in Bangladesh. Asian Fish. Sci., 34: 127-137.

Unnikrishnan A, KR Kumar, SE Fernandes, G Michael and S Patwardhan, 2006. Sea level changes along the Indian coast: Observations and projections. Current Sci., 362-368.

Vlassova T, 2006. Arctic residents' observations and human impact assessments in understanding environmental changes in boreal forests: Russian experience and circumpolar perspectives. Mitig. Adapt. Strateg. Glob. Chang., 11: 897-909.

Wahid SM, MS Babel and AR Bhuiyan, 2007. Hydrologic monitoring and analysis in the Sundarbans mangrove ecosystem, Bangladesh. J. Hydrol., 332: 381-395.

Weatherdon LV, Y Ota, MC Jones, DA Close and WW Cheung, 2016. Projected scenarios for coastal first nations' fisheries catch potential under climate change: Managem.Challeng. opport. PloS one, 11: e0145285.