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EDITED BY
Amiya Sahoo,
Central Inland Fisheries Research Institute (ICAR), India

REVIEWED BY
Marcia Moreno-Baez,
Tufts University, United States
Piyashi Debroy,
Central Inland Fisheries Research Institute (ICAR), India

*CORRESPONDENCE
Mohammad Mojibul Hoque Mozumder
mohammad.mozumder@helsinki.fi

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Climate change adaptation strategies for small-scale Hilsa fishers in the coastal area of Bangladesh: social, economic, and ecological perspectives

Mohammad Mojibul Hoque Mozumder[1]*, Petra Schneider[2], Mohammad Mahmudul Islam[3], Dibash Deb[4], Mehedi Hasan[4], Md. Abdulla Monzer[5] and As-Ad Ujjaman Nur[6]

[1]Fisheries and Environmental Management Group, Helsinki Institute of Sustainability Science (HELSUS), Faculty of Biological and Environmental Sciences, University of Helsinki, Helsinki, Finland, [2]Department for Water, Environment, Civil Engineering and Safety, University of Applied Sciences Magdeburg-Stendal, Magdeburg, Germany, [3]Department of Coastal and Marine Fisheries, Sylhet Agricultural University, Sylhet, Bangladesh, [4]Department of Oceanography, Faculty of Marine Sciences and Fisheries, University of Chittagong, Chattogram, Bangladesh, [5]Department of Fisheries, Faculty of Marine Sciences and Fisheries, University of Chittagong, Chattogram, Bangladesh, [6]Department of Fisheries and Marine Science, Noakhali Science and Technology University, Sonapur, Bangladesh

This study examines social, economic, and ecological adaptation strategies for small-scale Hilsa fishers in Bangladesh's coastal areas in response to the impacts of climate change. The Hilsa fishery and the communities dependent on it are vulnerable to the adverse effects of climate change, making it imperative to adopt mechanisms to cope with its consequences. Using a mixed-method approach, including in-depth interviews, focus group discussions, and a review of secondary resources, this study explores adaptation policies, relevant factors, and aspects of the Hilsa fishing community's response to climate change. The study finds that climate change poses a significant threat to biodiversity, potentially leading to changes in fish migration systems and declining fish stocks. The Hilsa fishers perceive that addressing climate change requires policies that combat poverty, preserve or restore biodiversity, and enhance ecosystem services simultaneously. The study identifies social adaptation strategies such as risk reduction, social relationships, and participation in adaptation planning. Economic adaptation strategies include alternative livelihood development, aquaculture, and access to credit. The study also suggests that effective ecological adaptation actions include developing climate change knowledge and fishers' local ecological knowledge, establishing more effective sanctuaries, and developing networks among protected areas. The study concludes that formal adaptation policies should consider fishers' interests and practices for adaptation, including their knowledge of social, economic, and ecological issues, to address the impacts of climate change on small-scale fishers and their communities.

KEYWORDS

adaptation, alternative livelihood development, climate change, coastal area, ecological knowledge, small-scale fishery, social relationship

1 Introduction

The effects of climate change on overall aquatic environments are broad and comprehensive, inevitably influencing open-water fisheries, fish populations and stocks, species distribution, and fisheries management organizations in numerous ways (Cheung et al., 2013). Climate change has increased trauma in the natural ecosystem and lowered the recovery or resilience of the environment (Adger et al., 2005; Lebel, 2013). It affects human livelihoods inversely and governs susceptibility and adaptive capacity. Both inland and open-water fisheries have suffered severe impacts of tropical cyclones and storm surges brought about by climate change.

Worldwide, 1.3 billion people dwell in tropical coastal regions, and the majority rely on fishing for both food security and employment (Kawarazuka and Béné, 2010; Hicks et al., 2019). The fisheries industry is affected by climate change in several ways. First and foremost, climate change alters the physio-chemical conditions, resulting in higher sea levels, stratification, and changes to dissolved oxygen and ocean acidification as well as higher water temperatures. Climate-related changes in water temperature have an impact on the productivity of aquatic ecosystems and fish production, eventually affecting fishers' livelihoods (Cheung et al., 2009). Hence, they restructure food chains and webs and transform the yields of exploited species of economic importance (Sumaila et al., 2011). Ocean acidification damages the calcareous shells of creatures, ranging from tiny phytoplankton at the foundation of food chains to coral reefs that afford dynamic habitats for fisheries (Hofmann et al., 2010). Thus, ocean acidification associated with warmer water significantly decreases the productivity and habitat of fish stocks. Furthermore, climate changes affect the ocean's biological aspects, including diseases and modifications to species' availability and distribution. Finally, they hamper the socio-economic status, disrupting the fish yield and fishing activities.

Small-scale fisheries (SSFs) engage nearly 90% of all fishers globally and deliver approximately 50% of the marine fish harvested for human consumption (Islam et al., 2014a). However, many issues make SSF vulnerable to threats, for example, overfishing, the extra capacity of boats, distortions in the marketplaces, conflict with other resource manipulators, trade policy, economic instability, biophysical stimuli, and pollution. Besides, governmental negligence enhances the vulnerability of SSFs (Mathew, 2003). Nevertheless, fishers' societies face problems due to the hydrological changes triggered by climate change. It has been proved that climate change directly affects fish growth, reproduction, abundance, migration, and species distribution through temperature, rainfall, and hydro-meteorological factors (Ficke et al., 2007), eventually increasing the vulnerability of SSFs. Therefore, ecosystem degradation due to climate change negatively affects the livelihood of small-scale fishing communities.

Embracing adaptation measures, which are gradually becoming a crucial part of the fishing industry, is necessary for small-scale fishers to lessen the negative consequences of climate change. Adaptation measures will only be successful when fishers' perception of climate change is correct, even though it depends on the geographical situation of a particular area and is governed by local variables and knowledge. Numerous scientific studies on the social dimensions of climate sensitivity, adaptability, and environmental risk in a fishery, mostly from the Asian, African, and Pacific areas, have been performed during the past two decades (Brouwer et al., 2007; Coulthard, 2008; Bunce et al., 2010; Slater et al., 2013). A considerable amount of scientific research on climate change has identified practical adaptation strategies for fishers, but very few studies have considered the social context of the problem, specifically from the perspective of small-scale fishers (Hanich et al., 2018; Le Cornu et al., 2018; Macusi et al., 2020; Galappaththi et al., 2021). Hence, there is an urgent need to investigate the best adaptation strategies for groups, such as small-scale fishers, crucial to maintaining the food supply.

Bangladesh has widespread fishery resources with various indigenous and exotic aquatic flora and fauna. To exemplify, Bangladesh ranks fourth in the production of inland fisheries and is home to about 260 native, 12 exotic, and 24 freshwater prawn species (Ghose, 2014; DoF, 2018). Bangladesh is leading by producing 41.77 lakh MT of fish, with aquaculture alone contributing 56.25% to the total production (DoF, 2018). This vast production contributes directly or indirectly to the livelihoods of roughly 11% of the total population of Bangladesh (Ghose, 2014). Unfortunately, the fisheries sector of Bangladesh is facing many challenges due to climatic variability (Islam et al., 2014a). About 0.5 million coastal fisher folks depend on SSFs, and almost 93% of total marine fish catches are caught in Bangladesh (DoF, 2012). However, various climate-related events, like cyclones, storm surges, coastal flooding, and sea level rise, threaten fishery-dependent coastal people's livelihoods (Islam et al., 2014b).

Hilsa (*Tenualosa ilisha*), a significant species, constitutes 12 percent of over fifty percent of the total marine catches worldwide. Approximately 2 percent of the population in the country engages in Hilsa fishing, either directly or indirectly. Bangladeshi waters alone contribute to 75 percent of the global Hilsa catch. Myanmar accounts for 15 percent, India for 5 percent, and the remaining 5 percent from nations like Thailand and Iran (Habib et al., 2023). However, anthropogenic activities, climate change effects, increased siltation, and rising river basins have disrupted, displaced, or even destroyed Hilsa's migratory routes and spawning grounds. Over the past two decades, the inland water yield of Hilsa has declined by around 20 percent (Islam et al., 2020). Additionally, major natural disasters such as tropical storms, cyclones, and fluctuations in temperature and precipitation, resulting from climate change inflict significant losses upon fishermen. These losses include damage to their homes and boats, loss of nets, and even the uprooting of trees. Due to climate change, hilsa fisheries are experiencing a decrease in abundance and catch rates and an increase in difficulty for hilsa fishermen to survive (Miah, 2015).

Adaptation strategies have become essential to mitigating the negative impacts of climate change on Bangladesh's fisheries. These strategies are crucial for maintaining the food supply and supporting the livelihoods of millions of people, mainly small-scale fishers. Given the current challenges and the urgent need for adaptive strategies, this study aims to explore effective adaptation techniques for small-scale fishers in Bangladesh from social,

economic, and ecological perspectives. For the present study, the Hilsa fishery of Bangladesh is focused. The main research question is: what are small-scale fishers' techniques for social, economic, and ecological adaptation to climate change? By investigating this, the study will provide insights and stimulate discussions on formulating effective adaptation strategies for small-scale fishers in Bangladesh.

2 Theoretical framework

Adaptation to climate change and resilience can be effectively connected to create more climate-resilient development. We drew inspiration for the current study from social–ecological systems (SESs), resilience, and fishery-based climate change adaptations (Figure 1). The framework views resilience as a system's capacity and a process, defining it as the end consequence of coping, adapting, and changing (Galappaththi et al., 2019).

Social–ecological systems (SESs)—SESs are intricate, interconnected systems that offer a holistic view of how humans interact with nature (Berkes and Folke, 1998), a strategy that has frequently been applied in most of the resilience literature (Walker et al., 2004). They are ecological systems connected to and affected by one or more social processes (Anderies et al., 2004). Since people have the potential to significantly improve the interactions and feedback loops between ecological and social subsystems, they are considered as an integral part of any conservation effort in an SES (Quinn and Wood, 2017). Such subsystems include dynamic relationships with people's knowledge (typically regional or traditional), institutions of management, and the laws and customs that govern how people communicate with their surroundings (Nayak et al., 2014). Much research has supported the notion that small-scale fisheries, whether inland or coastal, can be viewed as an essential and integrated social–ecological system that includes both people and the natural environment (Adger, 2000; Berkes, 2009).

Community resilience—In socio-ecological systems, resilience is an emergent feature that serves as an effective lens for observing the processes of change (Holling and Gunderson, 2002). Early in the 1970s, the term "resilience" was used in the literature on systems ecology to describe non-linear ecosystem dynamics that are applicable to natural resource management. However, in the 1990s, the range of issues covered by research utilizing a resilience lens expanded to include problems related to interpreting social dynamics and institutions, notably those pertaining to communities that are dependent on natural resources. Researchers have been investigating the notion of community resilience, the capacity of a community to endure or adapt to rapid changes brought about by hazards, for the past 15 years in an effort to understand how disasters affect communities (Norris et al., 2008; Ostadtaghizadeh et al., 2015). The definition provided by Ostadtaghizadeh et al. (2015) was utilized in this study - "A group of people with diverse characteristics who are linked by social ties, share common perspectives, and engage in joint action in geographical locations or settings". This concept focuses on a community's ability to cooperate and engage in disaster risk mitigation efforts by sharing information, expertise, and initiatives to achieve a resilient community in regionally based populations, such as wards, villages, neighborhoods, towns, and districts (Tariq et al., 2021).

Adaptation—According to the Intergovernmental Panel on Climate Change (IPCC), adaptation is one strategy for addressing the effects of climate change, and it described it as "the process of adjustment to actual or expected climate and its effects." In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities (IPCC, 2014). Adaptation measures aim to improve social and ecological outcomes by minimizing the negative consequences and maximizing the possible benefits of climate change effects (Smit and Wandel, 2006; Eisenack and Stecker, 2012). Typically, adaptation measures can be divided into three categories: "hard" (such

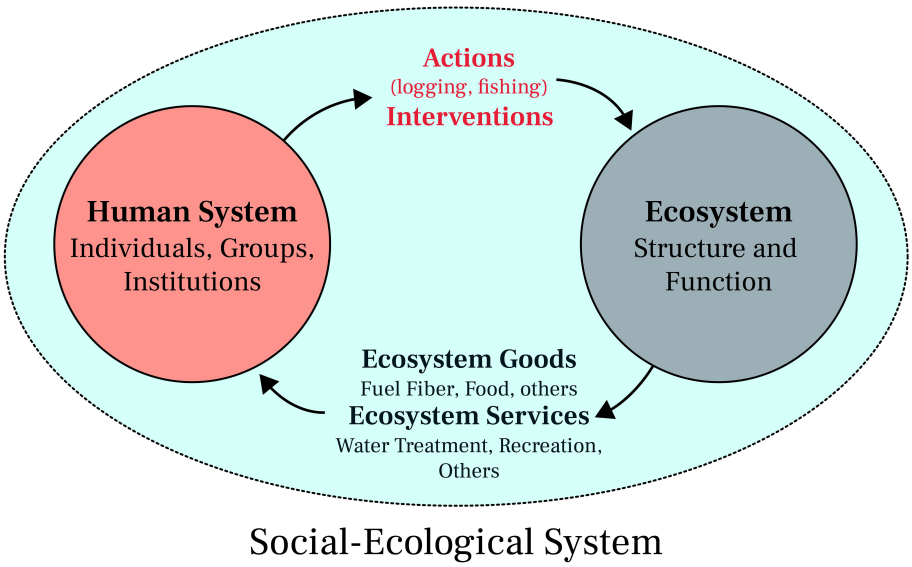

FIGURE 1
Conceptual diagram of a social-ecological system (ref: Resilience Alliance, 2007, p.8).

as engineering or infrastructure interventions), "soft" (such as policy, governance, or institutional changes), and "ecosystem-based" (such as management, conservation, or restoration) techniques (Biagini et al., 2014). Depending on the setting of a community, region, or nation, adaptation can take a variety of shapes and forms because it is not a uniform process, is influenced by many variables, and is frequently undertaken at the regional level (Blythe et al., 2014; Brugger and Crimmins, 2015; UNFCCC, 2019). Because of its significance, the IPCC (2007) positioned local knowledge of adaptation at the core of discussions for developing adaptation measures to safeguard both individuals and communities.

3 Methodology

3.1 Study area

Hilsa is the national fish of Bangladesh, and it has economic, cultural, and ecological value. In this study, fieldwork was conducted in the southern Bangladeshi fishing communities of Shyamnagar, Kalapara and Cox's Bazar Sadar Upazilas, part of Satkhira, Patuakhali and Cox's Bazar districts respectively (Figure 2). In Kalapara, the Andharmanik River is well renowned for serving as a Hilsa nursery and breeding area and is considered as one of Bangladesh's important coastal rivers of the Ganges–Padma system. Furthermore, in Shyamnagar upazila, where the Kholpetua River, Maloncho River, and Chuna River converge, is a better area for Hilsa fish swarming and living. Besides, in Cox's Bazar sadar upazila, Bakkhali, and Maheshkhali Channel is also a better habitat for hilsha fish. Kalapara is home to 2755 fishermen, while Shyamnagar has 2930 fishermen, and Cox's Bazar Sadar Upazila boasts a population of 5895 fishermen (BBS, 2011). Although the last two areas are not included in the Hilsa sanctuaries, there are a large number of Hilsa fishermen in these areas whose lives and livelihoods are closely related to Hilsa fish. As these areas are prone to disasters, people in these areas suffer a lot from disasters, and the effects of climate change are well observed. Therefore, fishermen in the region have engaged themselves in various adaptations to cope with the effects of climate change.

The populations in question are relatively homogeneous, and Hilsa fishing is the most common occupation among the resource users. Their livelihood comes from fishery-related services, such as

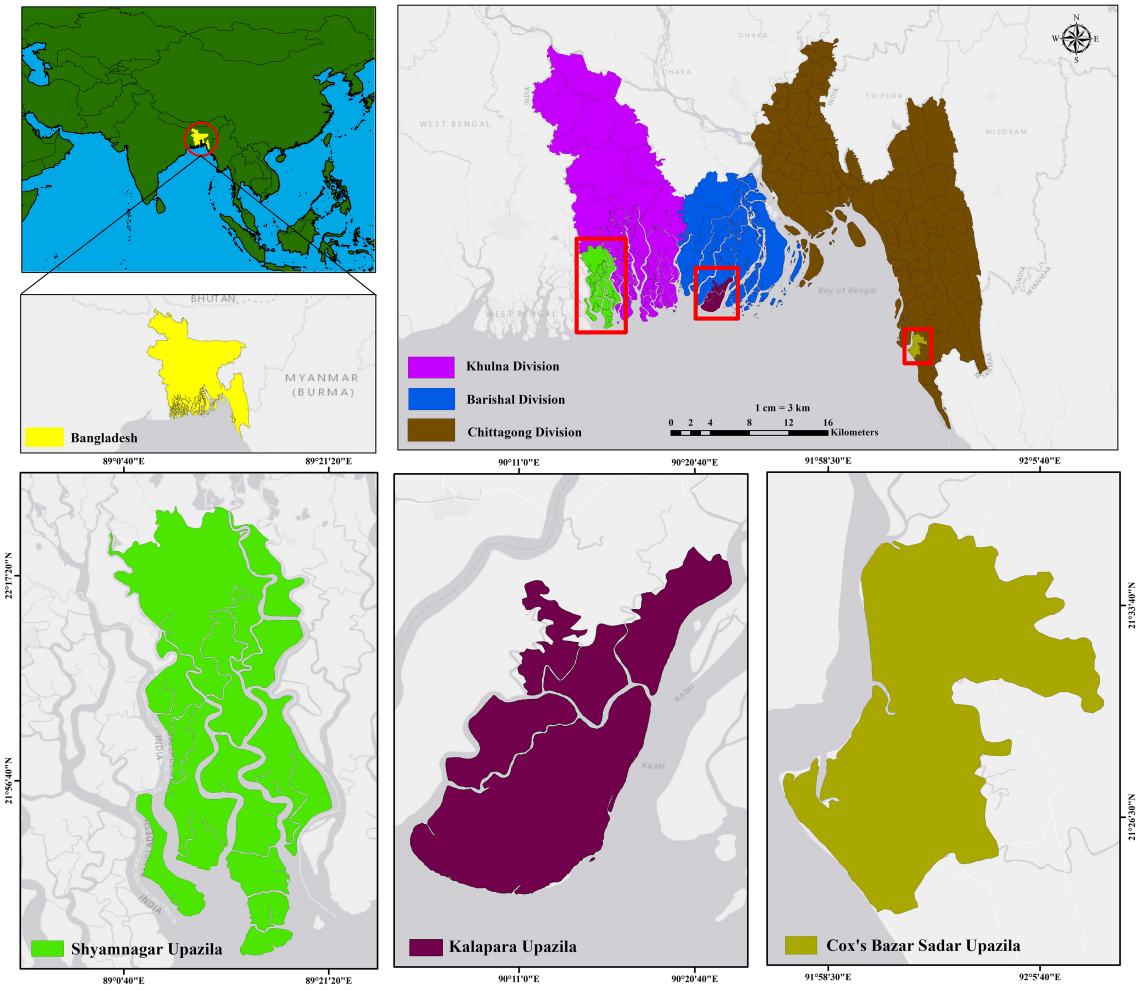

FIGURE 2
Geographical location of study area.

fishing, fish drying, fish selling, net repairing, boat building, and boat maintenance, all dependent on the Hilsa sanctuaries.

3.2 Data collection and analysis

A mixed-method approach was adopted to collect data during the period December 2018 to January 2019. Quantitative data on respondents' livelihood were gathered using structured household questionnaires, while in-depth interviews were undertaken to acquire comprehensive, detailed, and contextually relevant qualitative data on the two fishing communities' adaptability to climatic variability and change as well as their limitations and obstacles (see Supplementary Information). A total of 240 in-depth interviews along with three focus group discussions were conducted to collect the information for this study (Table 1). The sample size of the present study was determined according to the data saturation process (Mason, 2010). The following sample distributions applied to the in-depth interviews:

The interviewees come from different occupational backgrounds among Hilsa fishery stakeholders, namely Hilsa fishers (men and women), fish traders, boat owners, money lenders, local government representatives, and local government administrative personnel. In addition, in conjunction with Hilsa fishery stakeholders, we interviewed academics and environmental specialists. The interviews with different respondents were purely qualitative, specifically aiming to explore the range of opinions and the different representations of the issues at hand. The objective was to maximize the opportunities to understand the different positions and views taken by the members of the communities. Our focus group discussions each involved 10 participants (four Hilsa fishers, both male and female, and one representative of each other stakeholder group). Each focus group discussion lasted 40–50 minutes. We obtained informed consent from the participants to quote their interviews if appropriate and related to the study. The interviews were carried out in local dialects and languages (Bengali). Each interview lasted an average of one hour.

The data was stored, interpreted, and digitized for quantitative dataanalysis. After analysis, the results were presented in tabular format using Microsoft Excel and SPSS software. Simultaneously, in the realm of qualitative data investigations, the content analysis method is employed as a robust and insightful tool for interpreting and categorizing textual materials such as documents, books, oral communication, interviews, and visuals (Vaismoradi et al., 2013). Applying this method allows for extracting valuable information and identifying common themes across various data sources (Duriau et al., 2007). In this study, the inductive content analysis method was particularly effective in unveiling the adaptive skills utilized by fishers in response to climate change stressors, the challenges limiting their resilience, and the interconnectivity of these adaptive skills (Elo and Kyngäs, 2008).

The process (Figure 3) commences with the familiarization phase, in which the data is meticulously read and comprehended, and the research context and objectives are precisely outlined. Subsequently, through inductive reasoning, relevant units of analysis (codes) are identified and assigned to each unit during the initial coding phase. The codes are then rigorously refined and defined during the codebook development phase, culminating in the creation of a comprehensive codebook. This codebook subsequently codes the entire dataset, incorporating necessary modifications and updates to ensure coding consistency.

As the analysis progresses to the category development phase, akin codes are grouped into categories, their patterns, and connections are thoroughly examined, and subcategories are constructed as required. During the data display phase, the coded data is methodically organized and visually depicted, employing either software tools or manual techniques. This sets the stage for a comprehensive analysis of the categories and subcategories, unveiling relationships, themes, and variations while acknowledging the presence of outliers and deviant cases.

The investigation process is inherently iterative and involves regular revisits of previous phases to ensure the refinement and accuracy of the analysis. The interpretation of the findings is predicated on the data analysis, considering the research context, the objectives, and a juxtaposition with the existing literature. To confirm the validity of the findings, a method known as triangulation is used, which corroborates findings from multiple sources and considers alternative interpretations. Lastly, the findings are compiled and articulated in a research report or paper, substantiated with evidence and data examples. The report also includes an in-depth discussion of the implications and contributions of the findings to the field.

For the current research, we also gathered secondary data about the features of the situations and incidents that the primary data did

TABLE 1 Sample distributions of in-depth interviews (N = 240).

Participants/stakeholder groups	Number of participants		
	Shyamnagar (Upazila 1)	Kalapara (Upazila 2)	Cox's Bazar Sadar (Upazila 3)
Hilsa fishers	Man—30 Woman—20	Man—30 Woman—20	Man—30 Woman—20
Fish traders	10	10	10
Money lenders	10	10	10
Local NGO representatives	5	5	5
Local government representatives	2	2	2
Local government administrative personnel	3	3	3

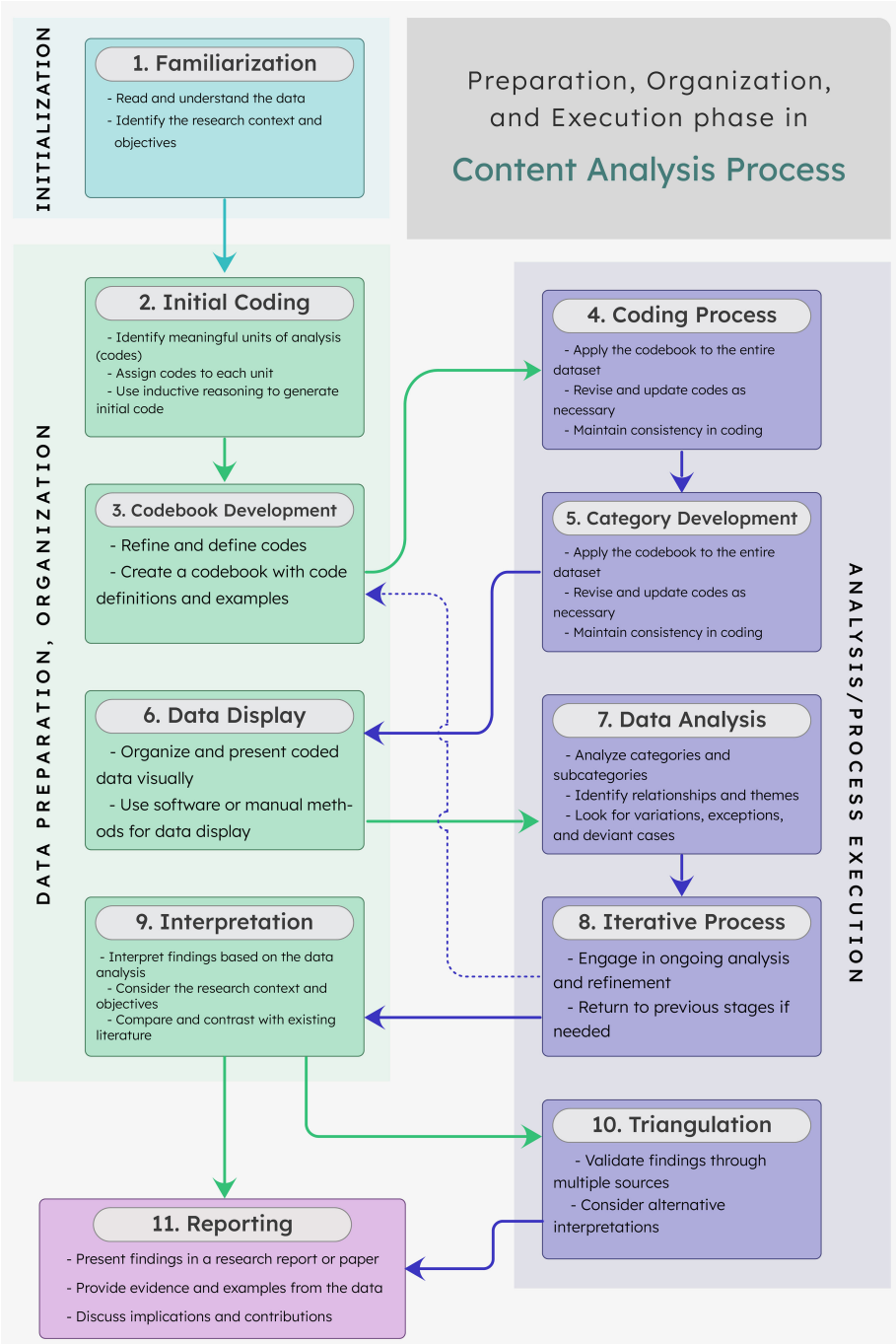

FIGURE 3
Data Preparation, organization, and process execution phases in the content analysis process (modified version of Elo and Kyngäs, 2008).

not fully address. The secondary data sources included study reports published by non-governmental organizations (NGOs) and regional universities collaborating with SSFs in Bangladesh's coastal regions, articles from daily newspapers, and related laws published by the Bangladesh government. Moreover, these data were part of a scientific literature review (see the Supplementary Information) that was relevant to the study objectives. The pertinent information was used after thoroughly reviewing and synthesizing all the collected data.

4 Results

4.1 Hilsa fishers' socio-economic status

The socio-economic status of the interviewed Hilsa fishers is presented in this section (Figure 4). The results reveal that the majority of the participants were older than 35. As a result, their perspectives ought to demonstrate a certain level of maturity and experience. They also show that the majority of the fishermen

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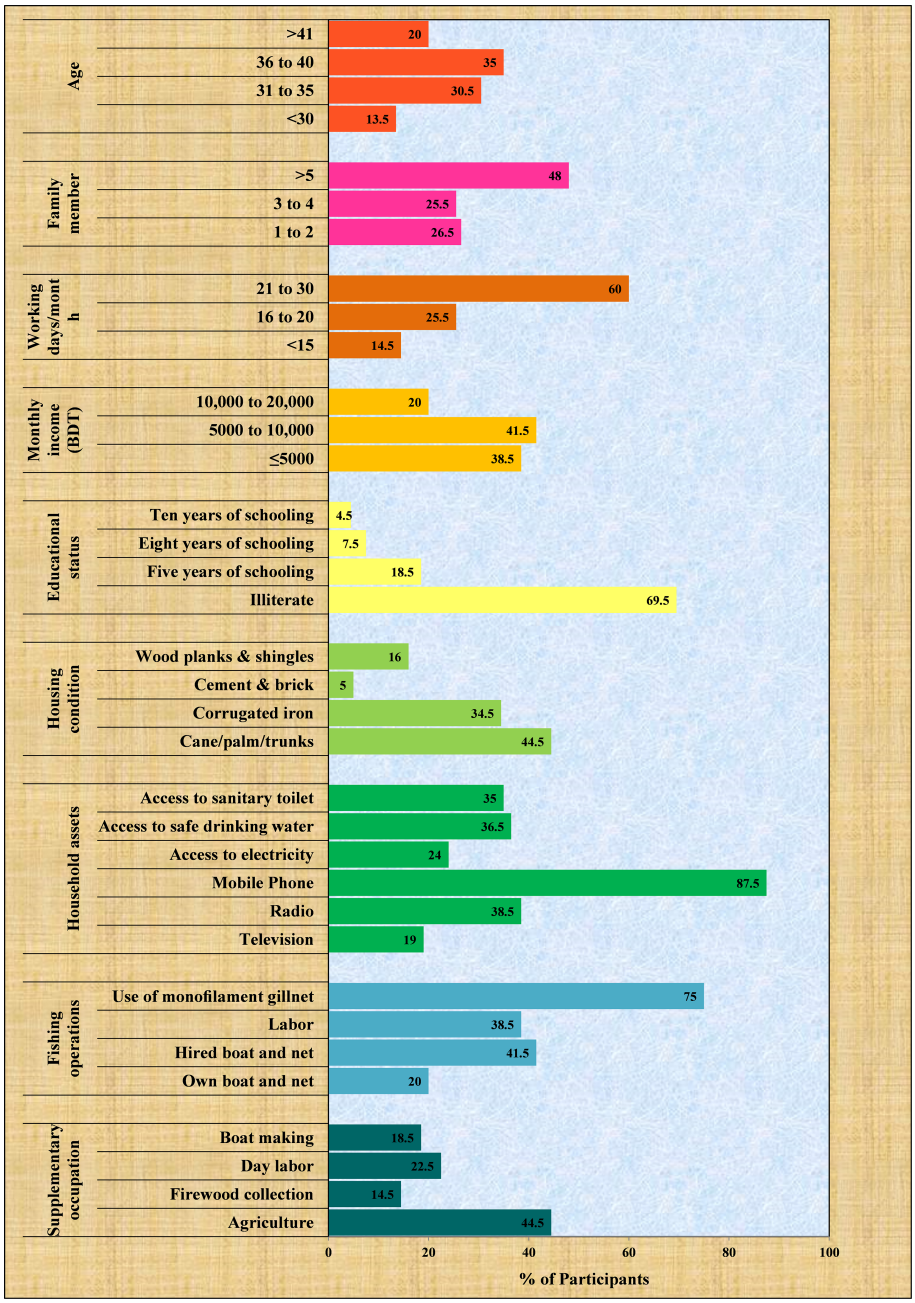

FIGURE 4
Socioeconomic and demographic condition of the respondent fishers (N = 150).

surveyed fell into the category of "very poor" in terms of income: 38.5% earned less than 5000 BDT (1 USD = 100 BDT) per month, and just 20% made more than the national poverty threshold of 10,000 BDT. In addition, almost 50% of fishers had a family consisting of more than five members to feed. Furthermore, they had little access to socio-economic resources. Approximately 44.5% of fishers lived in houses made of thatch. Merely 36.5% of the respondents had access to clean drinking water, while around 35% of them had sanitation facilities. Simultaneously, roughly 24% of fishers in the study area could afford electricity in their houses.

From the present study, it is also observed that only 20% of the fishers interviewed had their own boat and fishing nets and the rest of them either hired (41.5%) the fishing gears from others or worked as a laborer (38.5%) on other fishers' boats. A bulk portion of the participants (60%) confirmed that they had to work for 21–30 days per month, so they actually did not have sufficient leisure time. As a poor economic coping mechanism, almost 75% of fishers used illegal monofilament gillnets. However, more than two-thirds of the fishers were illiterate, while about 4.5% of them had completed their secondary education. Since widespread illiteracy makes it difficult for fishers to improve their status in the workplace, it may be the main cause of their poverty. One of the participants additionally disclosed that the nearest school is more than 2 kilometers away from their village and, due to the very poor condition of the road

connections; it is inaccessible for their children. Thus, child labor is often observed in the study area, though the fishers want to educate their children so that they can improve the socio-economic condition of their families through a decent job.

4.2 Hilsa fishers' perception of climate change

This section is based on the fishers' level of knowledge about the causes of climate change, concerns and consequences, and actual adaptation behaviors. At the beginning of the in-depth interviews with the fishers, we asked them what they understood about the term climate change. An elderly experienced fisherman aged 55 from Upazila 1 (Shyamnagar) of the study area said, "You know, I have been fishing in this area since I was 15; I am not a literate person and have no academic knowledge. If you ask me what climate change is or what you understand about it, I will tell you that, for me, climate change is excessive heat or high temperature during the summertime; it seems the sun is burning, and my skin cannot bear it anymore. You know we catch fish by using a boat and fishing net. There is no roof in our small boat.".

Another fisher from Upazila 2 (Kalapara) in the study area expressed their opinion about climate change as follows: "I am 65 now (approximately). My entire life went on fishing in the Andharmanik River. Suppose you want me to say what climate change is. I can summarize by prioritizing extreme weather occurrences in Bangladesh (extreme winds, waves, and floods), erratic rain patterns, and irregular monsoon patterns. The appearance of the actual time of such calamities is changed in Bangladesh. When there is a need for rain, there is no rain. When there should be the winter season, there is no winter; even sometimes it comes later.". At the same time, we asked about the possible consequences of climate change for fishers' life. An elderly fisher (aged 48) from Upazila 3 (Cox's Bazar) said, "Indeed, climate change has some negative impacts, and we can surely say that this impact could disrupt our daily socioeconomic routines directly or indirectly. If you want me to summarize, what are they? I can talk about reduced fish catches and sizes, damaged boats, and loss of lives, while floods were mainly associated with loss of gear, damaged gear, landing sites, and reduced fishing days.".

When asked about the leading causes of climate change in the coastal area of Bangladesh, one fisher aged 47 from Kalapara stated, "if you ask me about the true causes of climate change, I could surely say deforestation and burning of fossil fuels—both for energy in general and that used in factories and cars are the main causes of climate change.". In addition, during the FGD sessions, it was found that overpopulation, including pollution from fishing boats, is another primary driver of climate change.

We also asked questions during the in-depth interviews and FGD sessions, particularly about the primary target Hilsa shad fishery and the influence of climate change on that fishery. According to the participants, changes in migration patterns and breeding and growth performance make the Hilsa fishery especially sensitive to climate change. When we asked about the climate-related risks, a young fisher aged 25 from Shyamnagar expressed his opinion as follows: "Well, from my viewpoint, we are facing constant climate-related risks; as you know, we live in seafront locations, we are exposed to extreme events, and our occupation entails risky sea fishing. Moreover, we often need to return to the coast due to unsuitable weather conditions related to cyclones and frequent tropical depressions, which can cause financial losses or even casualties. Such events negatively affect our livelihoods and well-being.".

4.3 Hilsa fishers' social adaptation strategies

Undoubtedly, fishermen must consider extreme and unpredictable weather conditions during each of their fishing trips because fishing activities always encompass some risks. As a result, implementing risk reduction measures or eliminating the risks associated with fishing routines can be a social adaptation strategy for fishers to resist the consequences of climate change for their livelihood. For example, fishers stated that early warning systems, timely seasonal weather predictions, and catastrophe recovery programs were some ways in which risk reduction initiatives strive to manage vulnerabilities. We also asked them about the influence of mangroves in the case of risk reduction. Coastal fishing communities' replanting of depleted mangrove swamps has produced increased physical protection from storms (Figure 5A). This has resulted in lower maintenance costs for coastal defenses (dykes) and the protection of lives and property during cyclone seasons. The fishers talked about Cyclone Sidr (November 15, 2007) and Cyclone Aila (May 25, 2009) and how terrible those cyclones' devastating effects on their lives were. Later, they gave examples in which, due to the presence of enough mangroves as coastal defenses, Cyclone Fani (May 4, 2019) inflicted less harm on their lives. Fishers talked about a further benefit of mangrove restoration that enhanced fishery livelihoods by increasing crab, shrimp, and mollusk harvesting.

Strong social interactions are required to increase fishers' adaptability to the effects of climate change. These are essential, especially regarding pre-disaster and post-disaster preparedness. It has been found that strengthening engagement in these social actions has led to deeper social bonds, which can boost support from the community in fishing villages prior to, during, and even after catastrophes. Rebuilding infrastructures, particularly cyclone-resistant houses, by all the villagers and fishermen aided in their mental recovery and long-term resilience (Figure 5B). When we asked about the example of social relationships to the fishers, one elderly fisher from Kalapara stated, "You know what I am saying that social relationships enhance readiness and speed up asset transfer, relocation of members in the communities and rebuilding of infrastructures that have been ruined during the cyclone's effects. Also, the level of trust can be enhanced, and information can be exchanged for mutual benefit through positive social relationships among the local communities and fishing fellows.". Another fisher from Shyamnagar noted that strong communal relationships can also help individuals to recover from the psychological stress caused by climate change. He exemplified, "My friend Asgar, aged 45, lost his house during the recent cyclone.

FIGURE 5
(A) Replantation of depleted mangroves for disaster risk reduction as well as biodiversity enrichment; **(B)** Building cyclone tolerant houses/safe houses for long-term residence; **(C)** Building salinity tolerant fishing boat as an economic adaptation strategy; **(D)** Networking or collaboration for resource exploitations.

He became shocked and worried about his family members of five where to shift or live. In such a situation, the local fishing communities extended their helping hands. They tried to give them shelter and food, helped him to reconstruct the house again.".

Community members will have the chance to contribute ideas and generate opportunities to establish strategies that align with their regional requirements, capabilities, and preferences by participating in climate change planning. During the FGD sessions, the present study's respondents agreed that community engagement would result in a democratically fair decision-making framework with the specific goal of innovation for adapting techniques. They said, "You know such measures are essential and save money and the time and energy required. All members of the fishing communities, including leaders in the villages and at the fish landing center, and crews, including the boat owners, boat captains, and individual fishers, can express their opinions and thoughts by participating in a range of formal events, from annual meetings to round-table discussions. We assume we are honored when you listen to us.".

In the present study, most respondents were illiterate, and only 4.5% (Figure 4) of the respondents had 10 years of schooling. More educated fishers expressed their perception of climate change. Compared with people with less schooling, they were more likely to be adaptive. We observed that younger fishers were more likely to adjust to climate change. Younger fishers were better equipped to adjust to changing conditions. However, based on their experiences, older fishers claimed that it is challenging to acquire new techniques because they have limited knowledge and physical stamina. It is noteworthy that the elderly fishers were interested in learning about climate change and wanted empowerment in climate education via government and non-government organizations in their locality.

4.4 Hilsa fishers' economic adaptation strategies

Fishing is a significant source of income for most coastal fishers, and economic diversification through other sources of income is not feasible. That is why they are undergoing economic hardship because of climate change. Fishers are still attempting to cope with this condition, despite their poor adaptive knowledge about climate change. During the interview with an academic from the Faculty of Fisheries, University of Khulna, he expressed his views about the economic adaptation strategies, highlighting the importance of alternative livelihood development as follows: "In my view, diversifying sources of income and mobilizing household members and relying on assistance from various parties can be an option of economic adaption strategies for the Hilsa fishers due to changing climate issues. Also, in sustaining the economy of fishermen's households, family members (wives and children) can contribute to conducting alternative businesses as a source of additional income; this is important because fishermen's family members have much time and can be directed to productive activities to supplement their income.".

4.4.1 Acquisition and learning of alternative skills

According to prior research, the changing climate will reduce the fish yield and damage fish species' ecosystems. Additional studies have shown that lighter vessels will lead to fewer fishing voyages, as will the changing climate, both effects being considered as having a detrimental impact on the financial situation of fishers (Ottersen et al., 2004). Regarding such concerns, a professor from the Department of Coastal and Marine Fisheries at Sylhet Agricultural University in Bangladesh underlined the necessity of fishers gaining other skills to earn extra income and considered these capabilities as a wonderful adaptive approach. Furthermore, he stated that other factors to consider include an individual fisher's capacity to deal with seasonal limitations, increase flexibility, attain consistency, and respond effectively to crises in fisheries' technical systems. An academic from the Department of Economics, University of Chittagong, Bangladesh, expressed that entrepreneurship can present alternative economic adaptation strategies for fishers engaged in Hilsa fishing. He also mentioned that it provides a variety of economic benefits to fishers in terms of revenue generation and expansion as well as other economic gains.

4.4.2 Credit facilities

Catastrophic events can have an impact on houses, equipment, and amenities, altering the economic situation of small-scale fishers, the majority of whom have poor earnings. Therefore, huge monetary amounts are required for the process of recovery. Expanding access to credit can be a viable approach. During the interviews, an academic from the Noakhali University of Science and Technology, Bangladesh, expressed his views: "Fishers who had access to credit were more likely to apply the adaptation strategies. Access to credit is one of the forms of financial capital that can improve fishing in adapting to climate change. With limited financial capital, fishers may fail to meet the cost of adaptation strategies. I believe credit access is a source of support for fishing activities. Being able to access it enabled fishers to purchase the necessary input easily. Also, having access to credit strengthens fishers' adaptation ability while simultaneously expediting the recovery process.".

4.4.3 Salinity tolerant boat

Salinity deteriorates the condition of boats very fast and the repairing cost for the poor fishers is very high. To solve this issue, recently few fishermen are adopting a new strategy to increase the durability of their fishing boats (Figure 5C). A respondent named Hossein Gazi stated, "If Khoi, Bain, or Sunder wood is used, boats last longer in saltwater. The planks of these threes are joined together with jolui (flat headed nails) after sandpapering and even layering. The boat is built upwards like this, with thick rope or 'kachi' being used to bend over the sides to achieve the boat shape, with a thick dasha (crooked half- crescent) attached with nails. After this shape has been achieved, regular smoothing and further shaping is required for a good finish, with the different segments being tied together with 'kata' or jute rope. Coal-tar is used for final finishing and smoothening. After proper drying, the boat is ready for use.".

4.4.4 Introduction of aquaculture instead of Hilsa fishing

It is well known that Bangladesh is a suitable country for coastal aquaculture due to its ideal biophysical resources and agro-climatic settings, and this sector contributes substantially to the national GDP. Hilsa fishers, during the interviews, expressed this as follows: "If the government can help us by giving training and loans for the establishment of aquaculture firms, we can easily shift from Hilsa catching to aquaculture firming. After that, we can go for traditional freshwater aquaculture, including the Tilapia (*Oreochromis niloticus*).".

4.5 Hilsa fishers' ecological adaptation strategies

4.5.1 Strengthen conservation techniques

While discussing this topic with the local government representative of the environment department, he expressed the importance of strengthening conservation techniques in marine ecosystems, such as the mangrove ecosystem, seagrasses, and coral reefs, and repairing a series of marine reserve areas. He predicted that such acts would support the local fishers in the adaptation process. He added that this could be one of the options to empower and rebuild communities after a disaster occurs. Indeed, government and non-government organizations should come forward to help the fishers to set up reserve areas.

4.5.2 Networking or collaboration

The interactions between fishers and the resources they exploit provide local ecological knowledge in fishing communities. In general, they congregate, plan, and exchange information prior to fishing (Figure 5D). One elderly fisher from Kolapara stated the importance of networking fishers: "You know, from my viewpoint, networking is collaboration among fishers. Our families seek information needed when we have difficulty waiting for the Hilsa-catching season from colleagues, groups, and community leaders.". He added that "learning from how earlier generations coped with climate change and using that knowledge to plan for future disturbances can help younger or novice fishers to adapt to environmental shocks. We also collaborate just before we leave for Hilsa fishing; we meet, plan, and share information in specific places.".

4.5.3 Changing the fishing technology, location, and fishing target

During the FGDs, the participants highlighted that new fishing technologies could be a better option for ecological adaptation. One fisher stated, "You know we are using normal cotton nets to catch Hilsa, and the mesh size is considerable. Hence, juvenile Hilsa could easily pass through the net. Using a modern jal (fishing gillnet made of monofilament synthetic nylon fiber) with a small mesh size can be an option to catch more Hilsa quickly. Also, some fishers are using motorized boats rather than rowboats nowadays. Furthermore we can go for other fish species, including shrimp, if there is not much Hilsa in the areas. Such options can help us adapt to the climate change's adverse situation and minimize our lower Hilsa catch.".

4.5.4 Use of fishers' local ecological knowledge

It was evident during the interviews and FGDs those elderly Hilsa fishers were excellent sources of local ecological knowledge about the fishery. An elderly fisher in Kalapara stated, "I have been fishing for almost 25 years in the Patuakhali areas, and I know what types of food Hilsa eats and where the feeding grounds are, where the breeding grounds are, what types of water colors are favorable for the Hilsa brood-stock to lay eggs in and when the suitable times are for them to lay eggs. Also, I am aware of seasonal fluctuations in fish stocks, the seasonal movement of the fish, and other environmental factors, including temperature and salinity effects on Hilsa migration.". Another fisher from Shyamnagar added: "You know we are illiterate, we gained fishing experience by fishing in the nearby river for a long time. I think local administration and fisheries department officials should discuss Hilsa matters with us and use our local knowledge to set the dates for fishing bans and the geographical boundaries for fish sanctuaries and formulate other fishery policies. Such issues can benefit the government to take the initiative to adapt climate change strategies.".

4.5.5 Protected areas as a Hilsa sanctuary

One of the local fishery officers stated his concerns about the Hilsa sanctuaries as follows: "For the conservation and management of fishery resources, it is usually considered as a protected area where fishing is subject to some limitations by regional and national authorities. Obviously, these sanctuaries have some positive and negative socio-economic effects on the fishers. Since 2005, six Hilsa sanctuaries have been established in Bangladesh as a management intervention in the Meghna, Padma, and Andharmanik Rivers as well as the country's inshore waters to preserve the natural setting and safeguard the habitat for reproduction and juvenile growth. Hilsa production in Bangladesh has increased as a result of the creation of Hilsa sanctuaries, which have aided ecological preservation and reversed the stock's deterioration.". While asking the fishers about the climate change issues during the FGDs, including whether sanctuaries are helpful as an adaptation strategy, fishers supported the establishment of sanctuaries as follows: "We know that fishing is prohibited in the sanctuary, fish can mature, and we can catch large Hilsa fish lately that has huge demand in the local market.". The fishers also discovered that sanctuary confinement might produce a more efficient catch. In addition, because of the sanctuary, other species gather to breed alongside the Hilsa. The number and variety of the harvest then increase as these new fish stocks migrate to the nearby water.

4.5.6 Fishermen's resilience: social, ecological, and economic adaptation and its barrier

The journey towards resilience for fishermen is an adventure of overcoming various challenges, as portrayed in Figure 6. These challenges, which resemble knots that need to be untied, stand between them and their ability to adapt effectively. Surmounting these obstacles opens the door to resilience, ensuring long-term survival in the face of ever-present disasters.

The fishermen's path to resilience might be filled with numerous obstacles, yet each challenge presents an opportunity for growth and adaptation. These challenges, which can seem like tugs pulling them back, are often the catalysts that ignite resilience and spur them toward long-term survival. Social challenges such as a lack of expansive social networks, disjoined communities, language barriers, and cultural differences often deter efficient communication and collaboration. Still, they also foster a sense of unity and shared experiences.

Similarly, ecological challenges such as inadequate conservation enforcement, lack of awareness, disputes over protected areas, and insufficient monitoring pose threats to the preservation of vital habitats and the sustainability of fish management. However, these challenges propel the need for improved conservation practices and policies.

Economic challenges can appear in the form of restricted access to credit facilities, high-interest rates, stringent loan requirements, and a lack of financial literacy and technical skills. These barriers can hinder investment in adaptation measures and boat

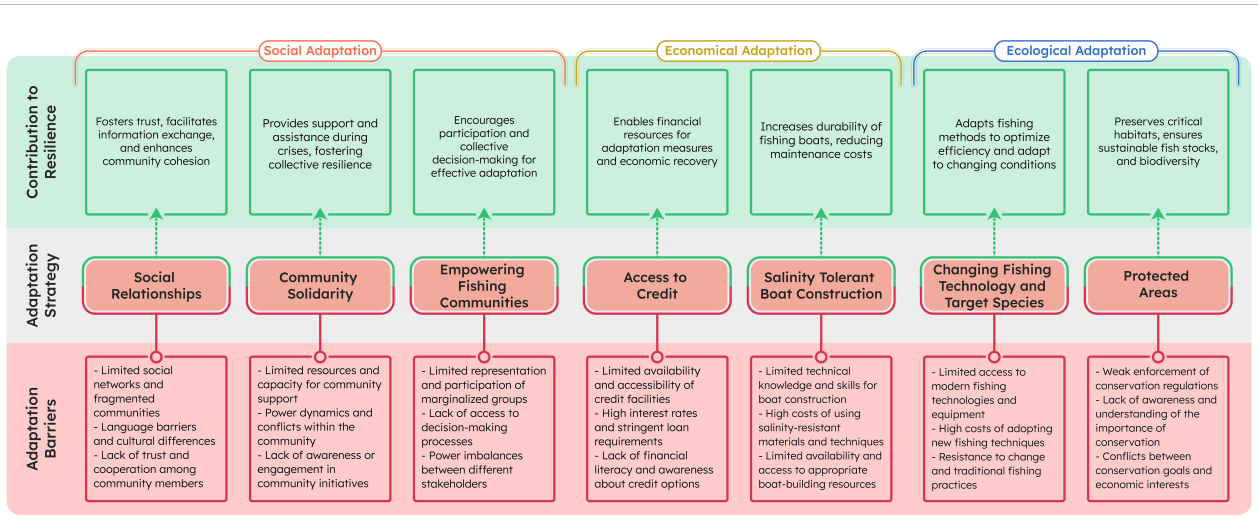

FIGURE 6
The Fishermen's Path to Resilience: An Adventure in Overcoming Challenges.

construction, potentially impeding the sustainability of fishing operations. Despite these challenges, fishermen like Osman from Cox's Bazar exemplify resilience.

Osman shared his experience: "I faced several challenges while attempting to acclimate and build resilience. Economic barriers, such as limited access to credit facilities and high-interest rates, initially deterred my investments in adaptation measures and boat construction. But with determination and the collective efforts to unite fishermen, spread awareness, and foster economic empowerment, I was able to spark a change. This helped pave the way towards a future where our fishing community thrives, bolstered by resilience and sustainability.".

5 Discussion

Through habitat alterations, new species interactions, and population extirpations, climate change is increasing its impact on marine ecosystems globally. The livelihoods and general well-being of the millions of people who depend on small-scale fisheries (SSFs) are being affected by the changes in catch levels, catch composition, and fishing expenses because these people largely rely on marine resources to support their livelihoods. Small-scale fishers are particularly susceptible to climate change due to their physical position and economic situation. Coastal fishing communities on the frontline of climate change must adapt to deal with these effects, and they do so by using several interlinked tactics (Figure 7).

5.1 Social adaptation strategies

The coastal fishing communities of Bangladesh have adopted several social strategies to overcome the worldwide effects of climate change. Social gathering and providing mental support, replanting trees together, undertaking risk reduction initiatives, and participating in religious activities are some of these social strategies. The respondents in this study considered risk reduction, social relationships, and involvement in adaptation planning as social adaptation strategies. First, protected areas are becoming more widely acknowledged as a tool for the protection of biodiversity and as locations to maintain carbon sinks, storage, and

FIGURE 7
Interlinked adaptation techniques of coastal fishers.

a natural infrastructure that safeguards people, species, and ecological processes from the worst effects of climate change (Dinerstein et al., 2019; IPCC, 2019).

The current study demonstrated that the restoration of depleted mangrove swamps has led to enhanced physical protection against catastrophes. This has resulted in lower maintenance costs for coastal defenses (dykes) and the protection of lives and property during cyclone seasons. In addition, fishers talked about another benefit of mangrove restoration: enhanced fishery livelihoods through increased crab, shrimp, and mollusk harvesting (Islam and Haque, 2004). Risk reduction initiatives aim to address vulnerabilities through early warning systems, accurate seasonal weather forecasts, market information systems, micro-insurance, and catastrophe recovery plans. Coastal communities in Vietnam have benefited from Red Cross programs that helped them to re-establish mangrove swamps that have been destroyed by storms, which serves as an excellent example of the usefulness of proactive risk reduction activities in fisheries. Due to this, maintaining coastal fortifications (dykes) is now less expensive, and it protects people and property during typhoon seasons (WDR, 2001).

The external coping method used by small-scale fishers involves participating in a variety of social activities away from home (Das et al., 2020). Small-scale fishers engage in a variety of social activities, such as joining both formal and informal institutional groups in their local area. The local business community for fishers, the local tourism community group, the local group for forest supervision, and non-formal institutions like religious communities are all covered by various formal institutional groupings. In general, fishers are becoming part of the fishing industry business community. There are 10 fishing-related business communities in the Karanggongso region, each with about 10 to 13 fishers as members. Group discussions, registration fees, and social events are all part of the community's activities. Each group is fully administered, including a guest book, production book, member data book, and member inventory book. Additionally, technical and commercial operations are carried out in the community, such as beach cleaning, fishing, farming, and technical training (Susilo et al., 2021). The present investigation mentioned that, to boost fishers' resilience during the post-disaster period, strong social ties are required. A greater level of engagement in these social activities has led to deeper social ties, which can boost community support. Additionally, social connections improve preparedness and hasten the transfer of assets, the migration of community members, and the reconstruction of infrastructures damaged by the cyclone's effects. Some fishers offered assistance to others who had lost everything and were undergoing trauma after the catastrophe. Moreover, this research reveals that the local religious community is a place where people might find psychological help for coping with post-disaster stress. Ahamed (2013) focused on religious activities before a cyclone as part of people's worship to appease their God, raising future and alternative awareness and encouraging active community participation in management planning. Participating in climate change planning will allow citizens to contribute ideas and generate opportunities to implement plans that are tailored to their own needs, interests, and abilities. It has been observed in countries such as Bangladesh, Bhutan, Cambodia, Maldives, and the United Kingdom that community members can participate in climate change adaptation planning through involvement in relevant authorities (Few et al., 2006; Holstein, 2010). The present study also showed that everyone in the fishing communities, including village and fish landing center leaders, crews, boat owners, captains, and individual fishers, can express their opinions and thoughts by taking part in a variety of formal events, such as round-table discussions and annual meetings (Shaffril et al., 2017). Therefore, social gatherings and community events hasten the development of emergency preparedness plans and procedures. Fishers are involved in various religious groups in addition to formal ones. Participants in this religious community gain benefits from being a part of it, including a passion for worship, friendship, and a sense of tranquility, according to the respondents who were questioned for this study.

Moreover, younger fishers had a higher probability of adapting to climate change because they were more able to adjust to new circumstances. However, based on their experiences, older fishers claimed that it is challenging to acquire new techniques because they have less education and physical stamina (present study). According to the research by Lin (1991), education and technology acceptance levels are positively correlated with climate adaptation. Higher education is linked to easier access to information about technology (Maddison, 2007; Sarker et al., 2013). Studies have also shown that education, which is typically positively connected with access to climate information, raises the likelihood of adjusting (Maddison, 2007; Deressa et al., 2009). The more knowledgeable the fishers are, the more information they have about climate change; this is crucial in assisting them to be proactive with their plans as opposed to being reactive (Limuwa et al., 2018).

Some barriers limit or disrupt these fishers' social adaptation. The ability of fishers to adapt and deal with the adverse effects of climate change will be constrained by limits, barriers, and restraints on adaptation (Galappaththi et al., 2021). The limitations and obstacles to climate change adaptation among Bangladeshi fishing communities were noted by Islam et al. (2014a). The physical aspects of the climate and sea, such as the frequency and duration of tropical cyclones and concealed sandbars, which prevent fishers from returning to coastal villages safely, are among the limitations. Low incomes, difficulty obtaining credit, unfavorable credit practices, inaccurate weather forecasts, underestimation of the likelihood of cyclones, coercion of fishers by boat owners and captains, lack of education, skill, and alternative sources of income, poorly enforced maritime and fishing laws, and lack of access to fish markets are some of the obstacles to coping with climate change. Additionally, societal obstacles, including communication and information-sharing barriers as well as cultural restrictions on cooperation and sharing, are important. The efficiency of adaptation responses is influenced by certain social norms, religious convictions, and cultural values that restrict social reciprocity and cohesiveness (Galappaththi et al., 2022). The present study also found a lack of education, technologically inferior boats, and inaccurate weather forecasts as barriers to Hilsa fishers' adaptation.

5.2 Economic adaptation strategies

In the case of fishing in the Bay during a highly abundant period, Hossain et al. (2018) stated that many fishers avoid hiring other fishers or their neighbors to save money. When fishers use their fishing earnings for household expenses, an increase in fishing days can help to improve the income ratio; that is, more time invested in fishing provides more profit and extra income pre-disasters (Nhemachena and Hassan, 2007; Sereenonchai and Arunrat, 2019).

When compared with other studies, the authors have demonstrated how fishers have successfully responded to the consequences of climate change by extending their skill sets and changing their means of survival. For instance, the Coastal Vedda community in Sri Lanka has implemented three community-level adaptive methods. They are flexible structures that support group activity and cooperation, culture-based fisheries (CBFs), and diversification of sources of income (Galappaththi et al., 2020). The adoption of different skills to supplement the fishers' income is regarded as a commendable adaptive effort. Furthermore, alternative livelihoods and new opportunities are two primary strategies among all the adaptive strategies that SSFs generally undertake. These two adaptive elements include engaging in alternative forms of income, moving temporarily to another location, participating in fish drying and processing rather than fishing, forcing women and young members of the family to labor outside, and engaging in more farmland than fishing activities (Alam et al., 2021). According to Salik et al. (2015), small-scale fishers with low, fragmented, and irregular earnings have poorer levels of climate change adaptation. Thus, income insufficiency reduces their coping and adaptation capability, which makes their livelihoods more vulnerable. Additionally, entrepreneurship is one of the potential avenues for creating social value, such as enhancing neighborhood quality of life and maintaining non-residential infrastructure, which reduces migration (Alam and Mallick, 2022). The current study's findings also indicate that diversifying income sources, mobilizing household members, relying on aid from other parties, such as GoB/NGOs, starting entrepreneurship, implementing aquaculture, and gaining access to credit are all beneficial. The economic adaptation of the Bajo Mola community is fairly broad, and bank support, easy access to marketing events, innovation, technology, and investment in aquaculture and fish production have dramatically increased (Marlina et al., 2021). The present study found that Hilsa fishers want government support and easy loans to implement aquaculture in their region. Additionally, their wives and toddlers can assist in the operation of alternative businesses as a source of additional finance to support the economics of fishers. Women in some regions try to support their family income through homestead gardening, poultry farming, livestock rearing, crab fattening, and fish farming in cages (Njaya et al., 2011).

However, several negative aspects prevent fishers from adapting successfully. Low incomes, illiteracy, and unfavorable credit policies all work together to restrict and prevent the utilization of adaptation mechanisms to deal with harsh environmental circumstances and events. Extreme events can put a family's finances in danger because of the existing low income, unfavorable credit policies, a lack of technical skills that limits the options for a livelihood, the failure to enforce maritime and fishing laws, which allows illegal industrial fishers to engage in poaching, a lack of fish abundance due to pollution and poaching, the dominance of commercial fishing travelers, and other issues that can sometimes make matters worse when attempting to survive effectively and economically. Small fishing communities need more money to purchase fishing gear and experience obstacles when obtaining loans from different financial organizations. Besides, to survive during extreme climate events, the fishers took informal loans from moneylenders with a high interest rate, which is sometimes double or triple the standard banking loan rate (Alam and Mallick, 2022). According to the results of the current study, fishers who had access to easy loans were more likely to use adaptive tactics. One of the financial resources that can help fisheries to adapt better to climate change is the simple terms that loans provide. Fishers might be unable to afford the cost of adaptation measures due to their limited financial resources during and after a disaster. Hence, during this difficult time, they badly need financial support to strengthen their adaptive strategies.

5.3 Ecological adaptation strategies

Utilizing natural resources and ecosystem services is part of an ecosystem-based adaptation strategy. A good example is the preservation of mangroves, which act as natural flood defenses along coastlines (Reid et al., 2019). Some of the ecological adaption options highlighted by the current study include using fishers' local ecological expertise or traditional knowledge, adjusting fishing technology, location, and target, enhancing conservation measures to protect reserve areas, networking, and teamwork.

The fishing community makes substantial use of traditional knowledge and practices to predict and deal with climate change and calamities. Information about the local ecology, fish habitats, and the hydrological cycle is primarily gleaned from traditional knowledge. It aids fishermen in their fishing activities, helps them to understand the local ecology, disaster trends, and patterns, and assists them in designing an appropriate response strategy. By examining wave motions, wind and cloud movement, tide levels, and animal behavior, fishermen can also forecast the weather and natural calamities (Hasan, 2016). The new investigation came to identical conclusions to those of Hasan (2016). Fishers are familiar with the foods that Hilsa consume, their eating and breeding habitats, the best types of water colors for Hilsa brood-stock to lay their eggs in, and the best times for them to do so. They are also aware of the seasonal changes in fish populations, the movement of fish, and other environmental factors, such as the impact of temperature and salinity on Hilsa migration. Likewise, Zhang et al. (2012) demonstrated that local fishermen were strongly aware of the unpredictable climate or the changing environment.

Additionally, the current study indicated that ecological adaptation strategies are utilized to strengthen conservation practices. To restore various marine reserve areas, conservation strategies for marine ecosystems, like mangroves, seagrass, and coral reefs, need to be

strengthened—as the respondents argued. The local fishers are helped by such protectors as they need to adapt. Following a calamity, they also strengthen and help to rebuild the local communities. Recent research has revealed that, for the preservation of marine ecosystems, including the mangrove environment, seagrass beds, and coral reefs, as well as the restoration of various marine reserve areas, strengthening conservation strategies is crucial. The local fishers' adaptation process is greatly aided by such approaches.

Moreover, climate change and its impact on the abundance and available target species have been linked to modifications in the distribution and productivity of marine ecosystems. In any fishing grounds, the stocks of some species are falling while the stocks of others are rising. Fishing times and locations have changed significantly due to global warming, and these ecosystems are particularly vulnerable to climate change (Carozza et al., 2019). Long-term changes in fish distribution and abundance in southeast Australia led to the discovery of an abundance of new species (Last et al., 2011). Additionally, Townhill et al. (2019) asserted that, due to climatic changes, desirable fish species can become accessible at new fishing sites. The issue has undoubtedly had an effect on fishing activities. Modifying the fishing time and location is one of the solutions that they proposed. Most of Lake Malawi's fishers have adapted to climate changes like extreme weather and low catch rates by lengthening their fishing trips, employing highly effective illegal fishing nets, increasing their farmland, running small businesses, and engaging in casual work in both agriculture and fishing. The fishers' proclivity to adapt to these changes rose as the household heads' age climbed, their education level increased, they were married, and they earned an increased annual income (Limuwa, 2019). The present study revealed that, currently, fishers catch Hilsa with normal cotton nets with a substantial mesh size. As a result, juvenile Hilsa may simply pass through the net. Additionally, some fishers now favor motorized boats over rowboats since they can quickly cover great distances in search of other fish species, such as shrimp, if there are not many Hilsa in the area. These options might help the Hilsa to cope with the negative consequences of climate change while limiting our ability to catch them at lower levels. A growing corpus of research supports the notion that small-scale inland and coastal fishing can be seen as an important and integrated social–ecological system that includes both people and nature (Mozumder et al., 2019). The current study concluded that the creation of Hilsa sanctuaries had aided ecological conservation and stopped the population decline of Hilsa. A more effective catch may result from sanctuary confinement. Additionally, due to the sanctuary, other species come to breed and find shelter alongside the Hilsa. The number and variety of fish caught increased when these new fish stocks subsequently expanded to the nearby water.

Finally, according to Keys et al. (2014), the capacity for adaptation can be strengthened in three major ways. These include increasing the awareness and understanding of climate change and inclusion of educational material in schools about adaptation, community network building, and villagers' participation in identifying sources of specific risks that merge with the networking or collaboration issues found by the present study. The first way in which local ecological knowledge (LEK) is created in fishing communities is through interactions between fishers and the resources that they use. Second, younger or less experienced fishers may find it easier to adjust to environmental shocks by learning from how previous generations of fishers dealt with climate change and utilizing that information to plan for future disturbances. Third, adaptive knowledge is acquired via experience usually passed down from generation to generation through networking and collaboration. In a related investigation, Sereenonchai and Arunrat (2019) demonstrated that rural Thai fishing communities have traditionally used indigenous knowledge systems (IKSs) to combat the consequences of a continuously shifting climate. Integrating indigenous knowledge systems and individual perception allows for adaptations in response to local change because the inhabitants have been there for a long time and are accustomed to the surroundings (Ishaya and Abaje, 2008). A fisher in Chumphon Province asserted that they pass on to future generations their indigenous knowledge system and personal perspective as useful and reliable tools to assist them in dealing with the effects of climate change (Zhang et al., 2012).

Mantyka-Pringle et al. (2017) observed that knowledge system deterioration—such as weakened conventional knowledge systems, a lack of knowledge co-production efforts, a lack of education, training, research, and limited access to updates—can inhibit participation in adaptive ecological responses. According to the present investigation, a lack of attempts to promote knowledge co-production can hinder the transmission of traditional knowledge to young fishers, ultimately resulting in subpar ecological adaption in the future.

6 Conclusion

This study focused on the strategies for social, economic, and ecological adaptation to climate change of coastal hilsa fishers in Bangladesh. The hilsa fishers believed that addressing climate change requires actions that simultaneously combat poverty, preserve or restore biodiversity, and enhance ecosystem services. The respondents considered risk reduction, social relationships, education, and involvement in adaptation planning as social adaptation strategies. In addition, alternative livelihood initiatives, law enforcement, and adherence to the laws and ordinances governing fisheries, aquaculture, and access to credit were suggested as economic adaptation strategies. Finally, fishers and other stakeholders stated that practical ecological adaptation actions are fishers' climate change knowledge and local ecological knowledge, networking, or collaboration among fishers, and developing more extensive and more effective protected areas. The most important marine and coastal fishery in Bangladesh is hilsa. Considering this fishery's economic, social, and cultural values, we recommend considering the following steps so that hilsa fishers can adopt social, economic, and ecological strategies against climate change.

1. The establishment of local weather stations, radio stations, and television channels as well as the emergence of information and communication technology (ICT) to

provide accurate weather forecasts: Providing regular and continuous climate information, such as wind speed, wave level, temperature, and rain intensity, and providing access to it for distant fishers via a dedicated radio channel/by setting up regional weather stations. Additionally, supplying technological equipment and tools such as GPS, Eco-sounder, Fishfinder, mobile phones, and 4G network coverage from the Department of Fisheries (DoF) to enable fishers to be more efficient in their fishing trips so that they can catch more and avoid potential disasters or accidents in the deep sea by acquiring early weather news/information.

2. The establishment of permanent and interlinked fishers' welfare groups, collective organization, and distribution of several regional adaptation tactics of fishers of several regions: Establishing interlinked fishers' welfare groups (*Matsya Samiti*) to increase fishers' capacity to share and promote climate change adaptation strategies among the different fishing communities, which will introduce more social, economic, and traditional adaptation strategies to different fishing communities of the country.
3. The research and policy scope should be broadened: More emphasis on regional-based research to determine the exact impact of climate change and viable remedies for it and to make more efforts to increase the generic adaptive capacity. Finally, interlinkages between different sectors in research and policy (e.g., integrated watershed management or integrated coastal zone management) should be implemented.
4. More investment in improving the adaptive capacity and research: Fishers' vulnerability to common and unidentified threats can be reduced through investments in increasing their adaptive capacity and research on the adoption of further new strategies. In addition, poverty alleviation decreases vulnerability.
5. Eliminate legal and institutional obstacles: Despite these obstacles, fisher still desire the modification of their fishing practices in response to climate change. This suggests that the respondents' main activity is fishing. Therefore, removing legal and institutional obstacles may aid in sustaining fishing activities in response to climate change. Examples include improving markets' accessibility to fishers and fishing regulations in their favor.
6. Diversifying income sources through jobs and projects and providing training: Several government programs and non-governmental organizations (NGOs) may introduce new opportunities, such as vocational and entrepreneurial-related jobs, arrangements for training, and demonstrations. These will all help fishers to cope with the impacts of climate change. Continuous learning through knowledge co-production (learning new knowledge and updating existing knowledge) can be effective.
7. Participation of first nations' communities in adaptation planning and adaptive co-management: This action would provide a chance to develop a variety of effective adaptation strategies that take into account local voices and needs, particularly given the close connection between indigenous well-being and ecological health (Donatuto et al., 2014). It will be advantageous for the government to take the initiative to adapt climate change strategies when local administration and fisheries department officials analyze hilsa issues and can use local knowledge to define the dates for fishing prohibitions and the geographical boundaries for fish sanctuaries and to formulate other fishery laws.
8. Monetary facilities: Need-based policies, including easy access to credit, insurance, and microcredit facilities, should be mainly introduced post-disaster so that fishers refrain from using money lenders and avoid massive and long-period debt cycles.
9. Floating farms as an effective alternative: Floating farms can play a vital role in providing a future food supply. Small-scale fishers in Bangladesh could revive floating farms to cope with extreme monsoon seasons and more extended periods of flooding caused by climate change. The issues encountered by millions of underprivileged households, particularly landless households, can be impressively solved by Bangladesh's floating farms. In areas where flooding and waterlogging predominate in the yearly weather cycle, these ingenious, environmentally friendly farming techniques help to produce a supply of food and crops for the fishers and offer livelihood diversification. It is an ecological adaptation strategy that all SSFs can employ in our country in their vulnerable situation.
10. Keeping fishermen in good physical condition: Health is essential for fishers. Without a healthy and robust body, fishers will not be able to catch fish, so conducting health monitoring and prevention will be an excellent strategy to survive climate change. In addition, this approach will help fishers to continue to carry out their activities without barriers caused by health problems.

Our research had several limitations. Firstly, the sample size is limited, which could have affected the study's validity; however, given the study's qualitative nature, the data quality compensates to some extent for the limited sample size. Secondly, this study focused mainly on the household and community scales. Considering the intra-household variability may provide new insights into the social, ecological, and economic adaptation of the hilsa fishing communities. In addition, a broader range of studies, including more coastal districts and all six hilsa sanctuaries in Bangladesh, may help to generalize the present study's findings. Further research is needed to subject the present study's findings to a more robust quantitative methodology by employing a robust quantitative methodology, including t-tests, to validate further and expand our findings.

In summation, it is hoped that this research will stimulate a discussion on how fishers' choices and practices for adaptation, including their knowledge of social, economic, and ecological issues, might be incorporated into formal adaptation programs.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the participants was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

Conceptualization, MHM. Data curation, MM, DD, MH, MAM and A-AN. Formal analysis, MHM, DD, MH, MM and A-AN. Investigation, MHM. Methodology, MHM, PS, MI. Project administration, MHM, and PS. Resources, MHM, and PS. Supervision, PS. Visualization, MH, DD, MI, MAM and A-AN. Writing—original draft, MHM, DD, MH, MAM and A-AN. Writing—review and editing, MHM, MI, and PS. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

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