

Towards Sustainability: A Literature Review of Small-Scale Fishery Management Practices in Bangladesh

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Degree Thesis for Bachelor of Natural Resources

Degree Program in Sustainable Coastal Management

Raseborg, 2024

DEGREE THESIS

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Degree Programme and place of study: Bachelor of Natural Resources

Specialisation: Sustainable Coastal Management

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Title: Towards Sustainability: A Literature Review of Small-Scale Fishery Management Practices in Bangladesh

Date: 21.05.2024 Number of pages: 52 Appendices: 1

Abstract

The systematic literature review conducted in this study focuses on small-scale fishery management techniques in Bangladesh. The review encompasses a comprehensive analysis of various studies published between 2000 and 2024, shedding light on the challenges, opportunities, and sustainability issues within Bangladesh's small-scale fisheries. The research delves into the economic, environmental, and social dimensions of small-scale fishing in Bangladesh, emphasizing the sector's significant contribution to the country's economy, food security, and employment. Notably, the study highlights the importance of sustainable management practices, such as community-based management (CBM) and co-management, in enhancing fish stock health, biodiversity, and resilience. Furthermore, the integration of traditional ecological knowledge (TEK) with scientific knowledge emerges as a crucial strategy for promoting sustainable and resilient practices in small-scale fisheries. The study concludes with a set of recommendations aimed at enhancing the sustainability, resilience, and equity of small-scale fisheries in Bangladesh, emphasizing the need for a holistic approach that addresses ecological, economic, and social dimensions. By following these recommendations, future research endeavors can contribute to the development of effective and sustainable management strategies, ensuring the long-term viability and prosperity of Bangladesh's small-scale fisheries sector.

Language: English

Key Words: small-scale fisheries, Bangladesh, sustainability, community-based management, fisheries governance, climate change resilience, economic viability

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1 Introduction

1.1 Background of the study

Small-scale fisheries (SSFs) are crucial for global food security and livelihoods, as well as having a significant social and cultural impact in various regions [1]. This value is displayed in various contexts, such as local government and the tradition of incorporating catches in formal dinners and ceremonies. Traditional small-scale fisheries often self-regulate to protect local resources through measures such as regulating fishing access, implementing closed seasons, and banning certain fishing gear [2]. The rules are maintained by the community and sociocultural norms rather than external workers. Fishing is deeply rooted in many communities' management practices and holds cultural significance. It is also essential to the identity of many fishing communities. In addition to economic advantages, fishing often holds substantial benefits for individuals as it is a way of life for many [3].

"Small-scale fishery" (SSF) is commonly practiced with small, traditional fishing boats, low-tech gear, and arduous fishing. The main characters in this platonic scenario are a small group of fishermen. Even individual fishing practices are assumed to be environmentally and socially harmonious and sustainable or commercially justifiable and competitive. The first-world capitalist industrial fisheries, this SSF hegemonic image is often spatialized in tropical third-world waters [4].

Fishing science and policy have historically prioritized industrial interests over small-scale fishing. Scientific publications global small-scale sector policy instruments, and global SSF size and impact initiatives have grown in recent decades. Given the rising interest in SSF, it's crucial to assess how the definition affects efforts to enumerate and scale up sector knowledge, what dimensions matter, and what gets counted. Other studies have examined how national fisheries programs define SSF, but they have yet to carefully and empirically examine how science has defined it and how it has changed [5].

Various techniques can be used to describe small-scale fisheries. Some fishermen who operate without boats or on vessels less than 15 meters long fall under a single classification. These individuals may need the ability to fish in deep waters and may use less energy-demanding equipment. Moreover, depending on the species' abundance, these fishermen can often target multiple species. Small-scale fisheries are a resilient

industry that has adjusted to the social and ecological conditions in which they operate, challenging the common misconception that they are obsolete. Women play a significant role in the industry, especially in post-harvest positions such as processing seafood. It is believed that 90% of fishermen are employed in small-scale fisheries [6].

The fishing sector in Bangladesh, upon which the economy and food security heavily rely, is particularly crucial for marginalized fishermen's families. However, most fishing families come from marginalized communities, as fishing is often considered a low-status occupation. Small-scale fisheries have indeed contributed to increasing the food supply, creating employment, nutritional development, and international trade. Yet, overfishing and environmental hazards have posed significant challenges, limiting the availability of open-water fish and thereby impacting fishing communities' livelihoods. Many fishermen, in an effort to mitigate these challenges, employ non-toxic and specialized gear, which unfortunately lowers their income. The sustainable management of small-scale fisheries, therefore, requires efficient governance to address these complex socioeconomic circumstances [3].

1.2 Problem statement

In Bangladesh, small-scale fisheries play a vital role in the economy, food security, and people's livelihoods, making their management essential for attaining sustainability. However, the development of successful policies and plans is hampered by the lack of a thorough grasp of current management practices. A comprehensive assessment of the literature is necessary to close this knowledge gap by compiling and evaluating the body of information on Bangladesh's small-scale fishery management techniques. The purpose of this assessment is to create the foundation for informed decision-making and the creation of sustainable management techniques in the nation's small-scale fisheries industry by identifying important obstacles, achievements, and areas in need of improvement.

1.3 Objectives of the study

- i. To assess the current status of small-scale fishing in Bangladesh by examining its economic, environmental, and social aspects.

- ii. To analyze sustainable fishery management methods in small-scale fisheries in Bangladesh by identifying, categorizing, and evaluating current or suggested approaches.
- iii. To pinpoint deficiencies and potential areas for improving sustainability.

1.4 Scope of the study

A systematic literature study explores Bangladeshi small-scale fishing management practices. The research will examine regulatory frameworks, community-based initiatives, technological interventions, and the socioeconomic implications of managerial techniques. The research synthesizes a wide range of literature to provide policymakers, practitioners, and researchers working to sustain Bangladeshi small-scale fisheries with valuable insights. The assessment will suggest sustainable fishing management studies and interventions.

1.5 Theoretical framework

The relationship between ecological legacies and human socioeconomic systems evolves, impacting scales from the local to the global [7]. Consequently, recent scholarly discussions have emphasized the importance of focusing on interconnected social-ecological systems (SESs) for sustainability science [8]. It has been nearly 50 years since the SES concept was first introduced [9]. However, only in the last 20 years has it evolved into a structured approach for studying the complex interactions between human and natural systems [10]. This concept has since seen widespread application across environmental sciences, social sciences, and economics [11]. An SES represents an ecological system deeply interconnected with one or more social networks [12], emphasizing the critical role of human involvement in conservation efforts through positive feedback loops and interactions between ecological and social subsystems [12]. These subsystems are closely linked with people's knowledge, often rooted in local or traditional practices, alongside management institutions and the regulations guiding human-environment interactions [13]. SESs are also recognized as nested, multilevel systems that provide society with vital services like food, fibre, and energy [14], with ecological resources shaping socioeconomic systems on various scales [15]. The global concern over the depletion of natural resources across different ecosystems, including fisheries, forests, and water sources, is escalating [16].

The practical applications of the SES concept are best understood through the lens of small-scale fisheries (SSFs)[17], which are integral and complex SESs integrating human and natural elements [1]. In many developing nations, SSFs play a crucial role as vital SESs, offering essential ecosystem services and livelihood opportunities to some of the world's poorest and most vulnerable communities [18]. The understanding of these systems is challenging due to the different terminologies and concepts employed by scientific disciplines [19]. However, different research methodologies have been developed and utilized to explicitly consider the interactions between social and ecological systems [20]. Additionally, frameworks have been created to standardize research language for SESs, with a view to guiding more sustainable development of these systems [17]. Three primary analytical frameworks are commonly employed in SES studies: the original framework by Carl Folke and Fikret Berkes, focusing on institutional and ecological resilience; the robustness framework, which examines SES robustness to ensure resilience against known disturbances; and multitier frameworks, which help in organizing and understanding the impact of variables within broader socioeconomic, political, and ecological contexts [21].

The SES framework is not just a theoretical construct but a practical tool for understanding and addressing real-world issues. It offers an analytical lens for a better understanding of the complex interactions within SESs that can shape conservation efforts [22]. Analyzing modern SESs necessitates models and methodologies that acknowledge the intricate interconnectedness of societal and environmental systems, challenging traditional governance approaches [23]. Addressing issues within an SES can involve social, economic, ecological, and regulatory solutions through governance and management [24]. This approach demands a collective response from all stakeholders within the SES to address declines and resolve issues or lessen impacts [25]. This perspective is also applicable to the small-scale fisheries of Bangladesh, where SES theory, with its focus on the interplay between human societies and natural ecosystems, provides a framework for understanding resilience and examining environmental and social dynamics of SSFs and their adaptation to ecological changes while contributing to food security and livelihoods.

2 Methodology

A systematic literature review (SLR) is a key part of academic research because it lists all the studies that have already been conducted on a subject. SLRs surpass traditional story critiques due to their clarity and structure. Instead of listing research, SLRs include all relevant works on a topic. This improves picture comprehensiveness and decreases selection bias. Systematic literature reviews (SLRs) follow procedures to identify, select, and evaluate material impartially [26]. They use systematic and well-defined criteria to choose and evaluate publications, making it more likely that the review process will be repeated. Other professionals can obtain the same results using the same methods [27], which underlines the importance of accuracy and global knowledge. Researchers use systematic literature reviews (SLRs) to find consensus in many studies. They also reveal research gaps and scholarly disagreements. The evaluation recommends empirical decision-making and identifies areas for further research [28]. SLRs can influence behaviour and policy after analyzing the data. This research helps policymakers and practitioners to understand evidence, efficacy and study findings in different circumstances [29]. One day, SLRs will be a place to begin major studies, meta-analyses, and other kinds of studies. SLRs can help people come up with new research questions and studies by highlighting information gaps and showing where mistakes were made in previous studies [30].

I followed a systematic and comprehensive process to locate, select, evaluate, and compile pertinent academic papers, reports, and documents in conducting this systematic literature review on small-scale fishery management techniques in Bangladesh. The structure of the process ensured that the subject was examined broadly, with an emphasis on flexible and sustainable management techniques. Below is a more detailed explanation of the methods that were followed to conduct this review:

Google Scholar was used to find relevant material. To include a variety of research, keywords and search terms including "small-scale fisheries," "Bangladesh," "sustainability," "fishery management," "adaptive management," "co-management," and "social-ecological systems" were employed. To focus on modern perspectives, the search was limited to English-language articles published from 2000 to 2024 (see the Appendix). Google Scholar indexes various scholarly articles, papers, theses, books, abstracts, and other academic resources from multiple sources, including academic publishers, professional societies,

universities, and other reputable organizations. Google Scholar is not the only resource available for scholarly research, but its comprehensive coverage, user-friendly interface, citation-tracking capabilities, and free access make it a valuable tool for researchers across disciplines.

Inclusion and exclusion: The scope of this research necessitates a focused examination of literature that directly contributes to understanding small-scale fishery management within Bangladesh. To ensure the relevance and specificity of selected studies, the following inclusion criteria have been established:

1. **Specificity to small-scale fishery management practices in Bangladesh:** Studies must explicitly address management practices within the context of Bangladesh's small-scale fisheries. This includes traditional, innovative, and regulatory management approaches that are being applied or proposed within this specific geographical and socioeconomic context.
2. **Challenges and opportunities for sustainability:** The research seeks to identify and analyze studies that discuss these fisheries' challenges, potential opportunities for enhancing their sustainability, and the various factors influencing their resilience and long-term viability.
3. **Adaptive, co-management, or community-based management strategies:** Studies examining adaptive management strategies, including co-management and community-based approaches, are a key focus. These strategies are critical in understanding how local communities, alongside governmental and nongovernmental organizations, collaborate in the sustainable management of fishery resources.
4. **Impact of environmental changes and global challenges:** Given the dynamic nature of environmental systems and global socioeconomic trends, studies that explore the impact of environmental changes (e.g., climate change) and global challenges (such as the COVID-19 pandemic) on the viability and sustainability of small-scale fisheries are particularly relevant. This includes examinations of how these fisheries adapt to such changes and challenges.

To maintain the focus and quality of the literature review, studies that do not meet the following criteria will be excluded:

1. Studies not specific to Bangladesh: Research that does not specifically focus on Bangladesh's small-scale fisheries will be excluded, as the context-specific socioeconomic, environmental, and regulatory landscapes are crucial to this study's objectives.
2. Lack of focus on small-scale fisheries: Studies that do not specifically address small-scale fisheries but rather focus on large-scale, industrial fishing operations or no fisheries aquatic management will be excluded to maintain the specificity of the research focus.
3. Absence of empirical data or analysis related to management practices: Theoretical studies, opinion pieces, and reviews that do not provide empirical data, case studies, or detailed analysis of management practices within the context of Bangladesh's small-scale fisheries will be excluded. This criterion ensures that the research is grounded in practical, evidence-based insights.

By adhering to these inclusion and exclusion criteria, this thesis aims to compile and analyze a body of literature that offers comprehensive insights into the management, challenges, and sustainability of small-scale fisheries in Bangladesh, thereby contributing valuable knowledge to the field of fisheries management and sustainability science.

Data extraction and analysis: For each chosen study, information about the authors, the year the study was published, its goals, methods, primary results, and suggestions were gathered. This method made it easier to find trends, insights, and gaps in the literature by comparing and analyzing different studies in a structured way. All the information gathered was put together to tell the whole story of how small-scale fisheries in Bangladesh struggle to stay sustainable, how well different management styles work, and how flexible solutions help fisheries be more likely to survive. The story also discusses how small-scale fishing can fit into more significant economic and social processes. This proves how important it is to discover sustainability in all its forms. The chosen studies were evaluated on how well they followed the study objectives, how relevant their conclusions were to the goals, and how they would affect small-scale fishing management. This ensured valid and dependable results. The systematic review examined all Bangladeshi small-scale fishery management studies, focusing on long-term and adaptable management. Its results and conclusions are intended to contribute to sustainable fisheries management discussions and impact policy and practice in Bangladesh and similar countries.

3 Results

3.1 Short description of the Bangladesh fishery

The fisheries sector in Bangladesh (Table 1) plays a crucial role in the country's economy, contributing significantly to food security, employment, and economic growth. Bangladesh has a diverse range of fisheries resources, including inland and marine fisheries. Inland fisheries cover a vast area and consist of inland capture and inland culture subsectors, while marine capture fisheries cover a substantial marine area [31]. Fish is a primary source of protein in the Bangladeshi diet, with a high per capita fish consumption rate. The fisheries sector contributes significantly to both the national and agricultural GDP, with consistent growth over the years. Bangladesh ranks high globally in fish production, being self-sufficient and recognized as a major fish producer. The sector supports millions of livelihoods both directly and indirectly, with a significant number of women depending on fisheries for their livelihoods [32]. The fisheries sector also plays a crucial role in export earnings, with aquaculture being a prominent sector showing growth. However, the sector faces challenges such as wetland degradation, overexploitation, and habitat degradation, necessitating sustainable management practices for long-term viability. Legal arrangements and policies are in place to regulate and protect fisheries resources, ensuring quality control and sustainable exploitation [33]. Overall, the fisheries sector in Bangladesh is a vital component of the economy, contributing to food security, employment, and export earnings, with a focus on sustainable growth and development.

Table 1. Fishery sectors of Bangladesh: overview

Fishery Sector	Characteristics	Key Challenges	Suggested Management Strategies
Inland Open Water	<ul style="list-style-type: none"> - Includes rivers, beels (floodplains), and estuaries. - Characterized by traditional and small-scale fishing methods. 	<ul style="list-style-type: none"> - Overfishing and habitat destruction. - Pollution and water quality degradation. - Loss of access 	<ul style="list-style-type: none"> - Community-based fisheries management (CBFM). - Habitat restoration. - Implementation

	<ul style="list-style-type: none"> - Rich in biodiversity. 	rights for traditional fishers.	of sustainable fishing practices.
Inland Closed Water	<ul style="list-style-type: none"> - Comprises ponds, ditches, and seasonally flooded lands. - Primarily used for aquaculture and culture-based fisheries. - Growing sector with increased aquaculture activities. 	<ul style="list-style-type: none"> - Intensive aquaculture leading to ecological imbalance. - Use of chemicals and antibiotics. - Conflicts over water use and land rights. 	<ul style="list-style-type: none"> - Promotion of eco-friendly aquaculture practices. - Training and capacity building for farmers. - Integrated resource management.
Marine Fisheries	<ul style="list-style-type: none"> - Coastal and deep-sea fisheries. - Includes artisanal, small-scale, and commercial operations. - Important for export earnings. 	<ul style="list-style-type: none"> - Overexploitation of marine resources. - Illegal, unreported, and unregulated (IUU) fishing. - Climate change impacts and vulnerability of coastal communities. 	<ul style="list-style-type: none"> - Strengthening monitoring, control, and surveillance (MCS) systems. - Co-management and participatory governance. - Sustainable livelihood initiatives for coastal communities.
Mangrove Fisheries	<ul style="list-style-type: none"> - Primarily located in the Sundarbans. - Supports unique biodiversity and endemic species. - Relies on both capture fisheries and aquaculture. 	<ul style="list-style-type: none"> - Deforestation and habitat alteration. - Increased salinity due to climate change. - Conflicts between conservation efforts and local livelihood needs. 	<ul style="list-style-type: none"> - Ecosystem-based management approaches. - Alternative livelihood programs. - Enhanced protection and conservation policies.
Hilsa Fishery	<ul style="list-style-type: none"> - A key species contributing significantly to national fisheries production. - Seasonal migrations are crucial for its life cycle. 	<ul style="list-style-type: none"> - Overfishing during breeding seasons. - Habitat degradation. - Socioeconomic dependence of communities on hilsa fisheries. 	<ul style="list-style-type: none"> - Seasonal fishing bans and protected areas. - Community awareness and participation in conservation. - Socioeconomic

			support during fishing bans.
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3.2 The small-scale fishery of Bangladesh

The review of the literature utilized a total of 46 articles published between 2000 and 2024 (see the Appendix). The studies covered various aspects of small-scale fisheries in Bangladesh, including management practices, sustainability issues, socioeconomic impacts, and adaptive strategies in the face of environmental and policy changes. The results from these articles offer a comprehensive insight into the challenges and opportunities within Bangladesh's small-scale fisheries and are stated as such.

3.2.1 Current status of small-scale fishing in Bangladesh: economic, environmental, and social perspectives

This section will present findings related to the current state of small-scale fisheries in Bangladesh, focusing on their economic contribution, environmental impacts, and social dimensions. It will include data on production levels, income, employment, biodiversity, ecosystem health, community structure, and the role of fisheries in the socioeconomic development of local communities.

Bangladesh is a major fish producer, with a total output of 4.62 million metric tons (MT) in the fiscal year 2020–2021. Most of the country's fish and shrimp, i.e., 57.10%, come from aquaculture, while 28.16% and 14.74% come from inland capture and marine capture, respectively. Bangladesh ranks fifth in aquaculture production and third in inland open-water capture production globally, standing first in its production worldwide [33]. The sector contributed about 3.57% to the national GDP and about 1.24% of the foreign exchange earnings of the country. From 2020 to 2021, Bangladesh earned BDT4088.96 crore, or 1.24% of total export revenues, from exporting 76.59 metric tons of fish, shrimp, and other fishery products. The per capita annual fish consumption in Bangladesh is about 23 kg/year, against a recommended minimum requirement of 21.90 kg/year, indicating that Bangladesh is now self-contained in terms of fish production. Major carp make the highest contribution to total fisheries production, whereas chia (*Monopteros albus*), pomfret, and sharks cover a small portion of the total fisheries yield. Among the eight

divisions of Bangladesh, the Chittagong division contributed the highest fish production, and the Rangpur division contributed the lowest in the 2020-2021 financial year [33].

The fisheries sector supports the livelihoods of more than 18 million people in the country both directly and indirectly, with about 1.4 million women being dependent on the fisheries sector for their livelihoods through fishing, farming, fish handling, and processing [34]. The economic importance of small-scale fisheries in Bangladesh is highlighted by their contribution to the country's export earnings. Fishery resources have emerged as one of the most critical contributors to Bangladesh's export earnings, with the highest contribution being in agricultural exports [35]. The sector is the second-largest export industry and the most critical contributor to export earnings in Bangladesh, as fishery products are exported to around 60 countries worldwide, with the European Union (EU), the USA, and Japan being the main export countries for Bangladeshi fish and fishery products [30]. However, small-scale fisheries in Bangladesh also face significant challenges from an environmental perspective. Overexploitation, the use of destructive gear, siltation, the closure of natural fish passes, the use of pesticides and agrochemicals, discharges of industrial wastes, and the loss of natural breeding grounds through habitat degradation are major constraints facing the inland capture, culture, and marine sectors [36]. These environmental challenges threaten the sustainability of small-scale fisheries in Bangladesh, highlighting the need for effective management strategies to ensure the long-term viability of the sector [37]. Small-scale fisheries in Bangladesh are a vital sector that contributes significantly to the country's economy, employment, and food security [38]. However, the sector also faces significant challenges from environmental and social perspectives, highlighting the need for effective management strategies and adaptation measures to ensure the long-term viability of the sector [39].

Small-scale fishing in Bangladesh is a crucial sector that plays a significant role in the country's economy, food security, and the livelihoods of millions of people [40]. However, it faces several challenges from economic, environmental, and social perspectives [41]. From an economic point of view, small-scale fishing in Bangladesh is a low-status occupation traditionally dominated by socially neglected classes. Most fishing families are illiterate, with only 1% having secondary or higher education. The daily wage of fishers depends on their fishing instruments, the fishing season, fishing technique, and fishing efforts [42]. The contribution of small-scale fisheries to expanding the food supply, job

creation, raising nutritional status, and gaining foreign trade has been significant in the last few decades [43]. However, overexploitation and environmental hazards have resulted in a decline in the supply of fish from open-water resources, thereby negatively impacting the livelihood of fishing communities. A lack of knowledge about modern fishing gear and technologies keeps fishers in the low-income generation process [44]. From an environmental perspective, small-scale fishing in Bangladesh faces challenges such as habitat degradation, climate change, a lack of financial sustainability, inadequate equipment and infrastructure, and a lack of access to markets. Many fisheries suffer from an excess of fishing, which endangers their long-term existence, particularly in small-scale fisheries settings where controlling access is challenging [45]. The multiscale management of small-scale fisheries remains problematic, and many small-scale fisheries still need to be better managed. From a social perspective, small-scale fishing in Bangladesh is a significant source of employment, with approximately 0.5 million fishers and 2.5 million people employed in the fisheries sector [46]. However, the sector is vulnerable to climate change, with fishing communities being one of the most climate-vulnerable groups in Bangladesh [46]. The inability of fishing communities to adapt to global environmental problems, such as climate change, is exacerbated by the inherent seasonality of their income and the extreme lack of viable alternatives in this sector. Changes in seawater temperature, salinity, pH, precipitation, and coastal disasters impact social and ecological phenomena, such as fish yield, livelihood, and management. Disasters, including cyclones, floods, and droughts, have become more frequent and more severe in Bangladesh, wreaking havoc on the country's agriculture, economy, and other sectors. Small-scale fishing in Bangladesh faces significant challenges from economic, environmental, and social perspectives [47]. To address these challenges, proper management practices, support for local economies, and the implementation of insurance services and no- or low-interest loans for fishing communities are recommended.

Additionally, expanding access to credit for small-scale fishers can be a viable approach to help them recover from catastrophic events and adapt to climate change. A comprehensive understanding of the social, economic, and ecological adaptation strategies for small-scale fishers in Bangladesh's coastal areas is essential to develop effective adaptation techniques for climate change. The small-scale fisheries of Bangladesh play a pivotal role in the country's socioeconomic fabric, contributing significantly to the national income, food

security, and employment [48]. Despite their importance, these fisheries face complex challenges that are economic, environmental, and social in nature.

Economic perspective: Small-scale fisheries in Bangladesh are a critical source of livelihood for millions. However, the economic viability of these fisheries is under threat due to overexploitation of resources, inadequate access to markets, and the impact of climate change on fish stocks [48]. The seasonal dadon loan system, while providing immediate financial relief, traps many fishers in cycles of debt, limiting their capacity to invest in sustainable practices. Small-scale fisheries in Bangladesh are a critical source of livelihood for millions, contributing significantly to the national economy, employment, and food supply. However, the economic viability of these fisheries is under threat due to overexploitation of resources, inadequate access to markets, and the impact of climate change on fish stocks. [49]

The open-access nature of fishing grounds in Bangladesh has allowed fishers to engage in professional, seasonal, and subsistence-level fishing. However, the challenge lies in increasing the contribution of small-scale fisheries to poverty reduction and food security for fishing communities [50]. To implement a sustainable fisheries management system, the interacting social, economic, and ecological aspects must be considered. Therefore, any effective management strategies must jointly control the overexploitation of resources, protect the river ecosystem, and conserve fisheries' biodiversity. A combination of socioecological, ecological-economic, and socioeconomic approaches to fisheries assessment and governance must be included in management strategies [51].

Inadequate access to markets and the impact of climate change on fish stocks further exacerbate the economic challenges faced by small-scale fishers. Climate change has resulted in changes in fish migration patterns, affecting the availability and distribution of fish species, and thereby impacting the livelihoods of fishers [1]. Additionally, the lack of financial sustainability, inadequate equipment and infrastructure, and limited access to markets are significant challenges faced by many small-scale fisheries [5]. The implementation of proper management practices and the support of local economies are expected to ease the pressure on small-scale fisheries, resulting in increased food security and improved quality of life for local communities. However, the multiscale management of small-scale fisheries remains problematic, and many fisheries need to be better

managed [51]. Therefore, understanding the factors enabling and constraining the responsible management of small-scale fisheries is crucial for ensuring their sustainability and the well-being of the communities that are dependent on them.

Environmental perspective: The environmental sustainability of small-scale fisheries in Bangladesh is compromised by habitat degradation, pollution, and the adverse effects of climate change, such as increased salinity and more frequent extreme weather events [5]. These environmental challenges not only diminish fish stocks but also threaten the biodiversity upon which these fisheries depend, necessitating a shift towards more sustainable fishing methods and conservation efforts [52].

Habitat degradation is a significant issue in Bangladesh, where overexploitation and environmental hazards have resulted in a decline in the supply of fish from open-water resources, impacting both the economy and food security of the country [53]. Pollution from industrial and agricultural activities further exacerbates the problem, with harmful substances entering aquatic ecosystems and affecting fish populations [54].

The impact of climate change on small-scale fisheries in Bangladesh is particularly severe, with rising temperatures, changing rainfall patterns, and increased salinity affecting fish migration patterns and the availability of fish species [51]. Additionally, more frequent extreme weather events, such as cyclones and storm surges, cause significant damage to fishing infrastructure and disrupt fishing activities, further threatening the livelihoods of fishers [55].

To address these challenges, there is a need for a shift towards more sustainable fishing methods and conservation efforts. This includes the promotion of responsible fishing practices, the protection of critical habitats, and the implementation of effective management strategies that consider the social, economic, and ecological aspects of fishing practices [56].

Local ecological knowledge can also play a crucial role in improving the management of small-scale fisheries. It can provide valuable insights into the behaviour and distribution of fish species and the impact of environmental changes on these populations [57]. By integrating this knowledge with scientific research and modern management practices, it is possible to promote more sustainable fishing methods and conservation efforts that

benefit both the environment and the communities that are dependent on these fisheries [58].

Climate change adaptation strategies are also essential for ensuring the resilience of small-scale fisheries in the face of environmental challenges. This includes the development of early-warning systems for extreme weather events, the implementation of measures to reduce the impact of climate change on fish populations, and the promotion of alternative livelihood options for fishers [59]. In summary, the environmental challenges facing small-scale fisheries in Bangladesh are complex and multifaceted, requiring a comprehensive and integrated approach to management and conservation. By promoting sustainable fishing methods, protecting critical habitats, and implementing effective adaptation strategies, it is possible to ensure the long-term viability of these fisheries and the well-being of the communities that are dependent on them.

Social perspective: Socially, small-scale fishers in Bangladesh face issues of marginalization, with limited participation in decision-making processes and inadequate government support. Gender inequalities persist, with women in post-harvest activities remaining economically and politically marginalized [60]. Community-based management and co-management strategies have been suggested as ways to enhance the social well-being of fishers, ensuring more equitable access to resources and participation in fisheries management. The lack of grassroots associations and organizations that affiliate fishers and protect their interests contributes to the challenges faced by small-scale fishers in Bangladesh [61]. Fishers often struggle to access loans, subsidies, and schemes intended to support their livelihoods, highlighting the structural issues that hinder their socioeconomic development [60]. Additionally, the leasing system controlled by the Ministry of Land, which restricts free access to open-water bodies, poses a significant obstacle to the holistic growth of the sector [61].

Women in post-harvest activities, such as processing and marketing, face economic and political marginalization, with limited opportunities for empowerment and participation in decision-making processes [62]. Addressing gender inequalities in the fisheries sector is crucial for promoting social equity and ensuring the full participation of women in all aspects of fisheries management and value chains [63]. Community-based management and co-management strategies offer promising solutions to enhance the social well-being

of fishers in Bangladesh. By involving local communities in decision-making processes, promoting equitable access to resources, and fostering collaboration among stakeholders, these approaches can empower fishers and strengthen their resilience to social and economic challenges [64]. Addressing social issues such as marginalization, gender inequalities, and limited participation in decision-making processes is essential for promoting the well-being of small-scale fishers in Bangladesh. Community-based management strategies and efforts to empower women in the fisheries sector are crucial steps towards creating a more inclusive and sustainable fishing industry that benefits all members of the fishing community [65].

To address these multifaceted challenges, a holistic approach is required. This includes improving access to formal credit systems, promoting alternative livelihoods, enhancing fishers' participation in governance, and implementing sustainable fisheries management practices. Additionally, fostering resilience in fishing communities against environmental and economic shocks is crucial for the sustainable development of small-scale fisheries in Bangladesh. While small-scale fisheries in Bangladesh face significant challenges, there are opportunities for sustainable development. A concerted effort from the government, NGOs, fishers, and other stakeholders is required to ensure the viability and sustainability of these fisheries, which are so vital to the nation's economy, environment, and social fabric.

3.2.2 Sustainable management practices & co-management practices

The sustainable management of small-scale fisheries in Bangladesh is a critical aspect that requires a comprehensive analysis of various management practices to ensure the long-term viability of these fisheries. Several studies and reports shed light on the challenges and opportunities associated with sustainable fishery management in Bangladesh.

A recent study explored social, economic, and ecological adaptation strategies for small-scale hilsa fishers in Bangladesh's coastal areas in response to the impacts of climate change. This study emphasizes the importance of understanding the social context of climate change adaptation for small-scale fishers and highlights the need for effective adaptation techniques [60]. The FAO report discusses the multidimensional challenges faced by Bangladesh's small-scale fisheries, emphasizing the lack of grassroots associations, limited access to support schemes, and the minimal participation of fishing communities in

the decision-making process [59]. This highlights the social barriers that hinder sustainable fishery management in the country. An analysis of fisheries policies in Bangladesh underscores the need for consistency and transformation in policy frameworks to address issues such as overexploitation, conflicts among sectors, the lack of community-centred management approaches, and inadequate enforcement of regulations [66]. This highlights the importance of policy alignment with sustainable management practices. The experiences shared in the paper on fisheries co-management in Bangladesh include the operational approaches used to create institutions for increasing the participation of local fishers in decision-making and resource use rules [67]. This emphasizes the role of partnerships between governmental organizations, NGOs, and fishing communities in promoting sustainable fishery management. A study on the social-ecological challenges of small-scale hilsa fishery in Bangladesh highlights the growing challenges such as habitat degradation, climate change, financial sustainability issues, inadequate infrastructure, and excess fishing pressure. This study emphasizes the importance of proper management practices and local economic support for enhancing food security and improving the quality of life for fishing communities. The analysis of sustainable fishery management practices in Bangladesh's small-scale fisheries requires a holistic approach that considers social, economic, and ecological factors. By evaluating the effectiveness, efficiency, and adaptability of various management practices, it is possible to identify innovative and traditional approaches that contribute to the sustainability of these fisheries, thereby ensuring the well-being of fishing communities and the conservation of marine resources [68].

Sustainable management practices in Bangladesh's small-scale fisheries are crucial for ensuring the long-term viability of fish stocks, the health of aquatic ecosystems, and the livelihoods of millions of people dependent on this sector. This analysis delves into the variety of management practices employed or proposed, evaluating their effectiveness, efficiency, and adaptability to changing environmental and socioeconomic conditions. It also highlights both innovative and traditional approaches contributing to sustainability [69].

Community-based management (CBM): Community-based management practices have shown promising results in enhancing fish stock health and biodiversity. By involving local communities in decision-making processes, CBM fosters a sense of ownership and

responsibility towards resource conservation. CBM practices are cost-effective, as they utilize local knowledge and resources, reducing the need for extensive governmental intervention. These practices are highly adaptable to local conditions and can be modified based on community feedback and environmental changes [70].

Co-management: Co-management strategies involving partnerships between fishers, government agencies, NGOs, and research institutions, have been effective in addressing overfishing and habitat destruction. These partnerships facilitate the sharing of knowledge, resources, and responsibilities. The collaborative approach of co-management distributes the management costs and leverages the strengths of each stakeholder group, thereby enhancing overall efficiency. Co-management frameworks are flexible, allowing for adjustments in management strategies based on scientific evidence and stakeholder input [71].

Seasonal and area closures: Seasonal closures during breeding seasons and the designation of marine protected areas (MPAs) have contributed to the recovery of fish populations and habitats. While implementing closures requires an initial investment in enforcement and monitoring, the long-term benefits of restored fisheries can outweigh these costs. Closures can be adjusted based on ecological and social needs, although their success depends on effective enforcement and community support.

Gear restrictions: Restrictions on harmful fishing gear, such as fine-mesh nets and bottom trawlers, have reduced bycatch and habitat damage, contributing to the sustainability of fisheries. Gear restrictions are relatively easy to implement and monitor, making them an efficient management tool. Gear regulations can be updated in response to technological advancements and changing ecological conditions [72].

Traditional ecological knowledge (TEK): Incorporating TEK into fishery management recognizes the value of indigenous practices and knowledge systems in conserving biodiversity and sustaining fisheries. TEK-based approaches are cost-effective, as they rely on existing knowledge and practices that have evolved over generations. TEK is inherently adaptive, as it is based on continuous observation and interaction with the natural environment [73].

Aquaculture development: Promoting sustainable aquaculture practices helps relieve pressure on wild fish stocks while providing alternative livelihood options for fishers. Modern aquaculture techniques can be highly productive and profitable. However, ensuring sustainability requires careful planning and management to avoid environmental impacts. Aquaculture systems can be designed to adapt to changing environmental conditions and market demands [74].

Sustainable fishery management practices in Bangladesh's small-scale fisheries exhibit a diverse range of approaches, each with its strengths and challenges. A multifaceted strategy that combines community-based management, co-management, seasonal closures, gear restrictions, traditional ecological knowledge, and sustainable aquaculture appears to be the most promising path towards achieving fishery sustainability. The success of these practices hinges on their ability to balance ecological health, economic viability, and social equity, requiring ongoing evaluation, stakeholder engagement, and adaptability to changing conditions.

3.3 Identifying gaps and opportunities for enhancing sustainability in small-scale fisheries

This section will outline the deficiencies in current management practices and potential areas for improvement to achieve greater sustainability in small-scale fisheries. It will discuss gaps in policy, practice, and research and propose strategic areas for intervention, including capacity building, policy reform, technology adoption, and community engagement strategies.

While Islam and Chuenpagdee (2022) propose a classification approach for assessing vulnerability in small-scale fisheries (SSFs), there's a need for comprehensive vulnerability assessments incorporating climate change impacts, economic pressures, and social vulnerabilities, with a specific focus on gender and youth inclusion [75]. Hossain et al. (2004) discuss the potential of community-based fisheries management (CBFM) as a future management option. However, there's a significant gap in implementing effective CBFM practices that are inclusive, equitable, and adaptive to changing environmental and socioeconomic conditions [76]. Islam et al. (2017) highlight issues with the implementation of fisheries laws and regulations, pointing to the need to enhance the legal framework and ensure its enforcement to prevent overfishing and protect marine biodiversity [77]. The

dependence on informal loan systems, as discussed by Mozumder et al. underscores the gap in accessing formal financial services and markets, which could empower fishers to invest in sustainable practices and reduce vulnerability to exploitative lending [78]. Alam et al. and Ullah et al. emphasize the role of fishers' local ecological knowledge (LEK) in managing fisheries sustainably. There is a gap in integrating LEK with scientific research and fisheries management policies to improve stock assessment, monitoring, and adaptation strategies [79].

Opportunities for enhancing sustainability: Enhancing the governance structure to promote more inclusive participation of fishers in decision-making processes can lead to more sustainable fisheries management. This includes strengthening fisher associations and ensuring their active involvement in co-management practices. Addressing economic vulnerabilities requires the promotion of alternative livelihoods and income diversification strategies for fishers, as suggested by Deb and Haque (2016). This could reduce the pressure on fisheries resources and improve community resilience [80]. Encouraging sustainable aquaculture practices as an alternative or complementary activity to capture fisheries can help meet the growing demand for fish while alleviating pressure on wild fish stocks. Developing infrastructure and policies to improve access to markets and formal financial services for small-scale fishers can reduce their reliance on informal lending and improve their economic stability. Adopting technological solutions for better fisheries management, such as digital tools for data collection, monitoring, and traceability, can enhance the sustainability of fisheries resources. Implementing adaptation strategies to cope with the impacts of climate change, as discussed by Mozumder et al. (2023), is crucial. This includes habitat restoration, biodiversity conservation, and developing climate-resilient fisheries practices. Enhancing the sustainability of small-scale fisheries in Bangladesh requires a holistic approach that addresses ecological, economic, and social dimensions [17]. This includes strengthening governance frameworks, promoting community-based management, enhancing access to financial services and markets, leveraging local ecological knowledge, and implementing climate change adaptation measures. Collaborative efforts among government, NGOs, fisher communities, and researchers are essential to realize these opportunities and fill the identified gaps.

4 Discussions

4.1 Economic, environmental, and social interconnections

The SSFs of Bangladesh represent a cornerstone of the nation's economy, providing substantial contributions to food security, livelihoods, and export earnings. The significance of SSFs extends beyond mere economic metrics, deeply entwined with the social fabric and environmental health of the region [37]. Over 18 million individuals rely directly or indirectly on the fisheries for their livelihood, underscoring the sector's socioeconomic importance. However, the sustainability of SSFs is under considerable threat from various angles, including the overexploitation of resources, access limitations, habitat degradation, and the overarching specter of climate change.

Economically, the viability of SSFs is critical for the national economy but is jeopardized by unsustainable fishing practices fueled by immediate economic pressures and a lack of access to alternative livelihoods or financial support mechanisms. The decline in the sector's growth rate over the last decade signals an urgent need for interventions such as improved access to formal credit, insurance, and broader markets to enable fishers to adopt and invest in sustainable practices [47].

From an environmental perspective, the sustainability of SSFs is compromised by overfishing and habitat degradation, further exacerbated by climate change. The decline in open-water fish resources due to these factors calls for immediate conservation and restoration efforts. Moreover, the impact of climate change on the availability and distribution of fish necessitates adaptive management strategies that can respond dynamically to environmental shifts [81].

Socially, SSFs serve as a lifeline for millions, especially in rural areas. Yet, challenges like marginalization, limited participation in decision-making processes, and gender inequalities persist. Women, in particular, who play a crucial role in post-harvest activities, remain economically and politically marginalized. Addressing these social issues through community-based management and co-management strategies that promote inclusive governance, capacity building, and gender equity is imperative [82].

An integrated approach to management that recognizes and addresses the interconnectedness of these economic, environmental, and social dimensions is essential for the sustainable development of SSFs in Bangladesh [83]. Strategies that ensure economic support, promote environmental conservation, and enhance social equity are crucial to tackling the multifaceted challenges facing SSFs [66]. The collaboration between government agencies, NGOs, fisher communities, and researchers will be key to developing sustainable solutions that benefit both the fisheries and the communities reliant on them, thereby contributing to the national economy and ensuring the preservation of vital ecosystems for future generations.

4.2 Challenges facing small-scale fisheries

SSFs in Bangladesh are confronted with numerous challenges that threaten their sustainability and the well-being of the communities that depend on them. These challenges are complex and multifaceted, spanning ecological, economic, and social domains, and their interplay amplifies the impact on the fisheries sector [47].

Ecologically, overexploitation driven by the open-access nature of fisheries resources is a significant concern. The drive to meet immediate economic needs often results in unsustainable fishing practices, leading to the depletion of fish stocks. This not only threatens the ecological balance but also undermines the economic foundation of fishing communities, perpetuating cycles of poverty and environmental degradation [84].

Habitat degradation is another critical challenge, exacerbated by factors such as aquaculture expansion, industrial pollution, and the indiscriminate use of fishing gear. These activities compromise the health of aquatic ecosystems, impacting fish breeding and feeding grounds, and thus reducing the availability of fish. Moreover, the resilience of these ecosystems to environmental changes, including those induced by climate change, is significantly diminished [85].

Climate change represents a huge threat to the sustainability of SSFs. Its impacts are wide-ranging, altering fish distribution and abundance, affecting marine and freshwater ecosystems, and leading to changes in fish migration patterns. The increased vulnerability of coastal communities to extreme weather events further compounds the challenges

posed by climate change, highlighting the need for adaptive and resilient fisheries management strategies [85].

Social challenges are also prevalent in the SSF sector. Issues of marginalization and limited access to decision-making processes are significant barriers facing fishing communities [86]. These challenges are often more pronounced in economically disadvantaged regions, where communities lack access to essential services such as education, healthcare, and financial services. Gender inequalities further exacerbate the situation, with women in the fisheries sector facing additional barriers to participation in management and access to resources

Addressing the myriad challenges facing SSFs in Bangladesh requires an integrated and holistic approach to fisheries management. This approach should encompass efforts to regulate fishing practices, protect and restore habitats, and build the adaptive capacity of fishing communities to cope with climate change. Ensuring inclusive and equitable decision-making processes that prioritize the needs and voices of marginalized groups is crucial for developing policies that are both effective and fair. Collaborative and adaptive management strategies, underpinned by strong partnerships among stakeholders, are essential for securing the future of SSFs in Bangladesh and ensuring the sustainability of natural resources and the livelihoods of dependent communities [87].

4.3 Evaluation of current management practices

The management of SSFs in Bangladesh involves a range of practices aimed at promoting sustainability, including community-based management, co-management, seasonal closures, and gear restrictions. These initiatives represent important steps toward sustainable fisheries management but face several challenges in terms of their implementation, impacting their overall effectiveness.

Community-based management (CBM) has emerged as a promising approach, offering the potential to enhance local stewardship of fisheries resources and foster a sense of ownership and responsibility among community members. By integrating traditional ecological knowledge with contemporary management practices, CBM can lead to fisheries management that is both culturally sensitive and ecologically appropriate. However, the effectiveness of CBM is often limited by challenges such as restricted access to resources,

inadequate legal and policy frameworks supporting community rights, and difficulties in enforcing community-established rules. Additionally, the scalability of successful CBM initiatives remains a concern, with many projects struggling to expand their impact beyond initial locales [1].

Co-management arrangements, involving collaboration among fishers, government agencies, and sometimes NGOs, have been instrumental in bridging the gap between local needs and national management objectives. These arrangements facilitate more responsive and adaptive management practices, leveraging the strengths of diverse stakeholders. Despite these advantages, co-management in Bangladesh faces significant challenges, including power imbalances between stakeholders, insufficient representation of marginalized groups, and inconsistent support from governmental bodies. The lack of long-term commitment from all parties involved further undermines the sustainability of co-management efforts [17].

Seasonal closures and gear restrictions represent another set of management practices aimed at conserving fish stocks and promoting sustainable fishing. By implementing seasonal closures during breeding seasons and restricting the use of destructive fishing gear, these measures can contribute significantly to the recovery of fish populations [88]. However, the effectiveness of these practices is often compromised by inadequate enforcement, insufficient monitoring, and a lack of awareness and understanding among fishers regarding the importance of compliance. Enhancing enforcement mechanisms through community participation, increasing awareness campaigns, and providing alternative livelihood options during closures are essential steps in improving compliance and effectiveness.

Overall, while current management practices offer a foundation for sustainable fisheries management in Bangladesh, their effectiveness is limited by enforcement challenges, insufficient community involvement, and structural inadequacies in the management frameworks. Addressing these issues requires a multifaceted approach that includes strengthening legal and policy support, investing in capacity building for stakeholders, enhancing research and monitoring efforts, and providing socioeconomic support to communities affected by management practices. By improving the current management practices, Bangladesh can make significant strides toward the sustainable development of

its small-scale fisheries, ensuring the long-term viability of this vital sector and the well-being of the communities that depend on it.

4.4 Role of policy and governance

The sustainable management of SSFs in Bangladesh, as in other parts of the world, is profoundly influenced by the frameworks of policy and governance in place [89]. These frameworks play a crucial role in shaping the day-to-day operations of fisheries and determining their long-term viability and resilience. The development of robust, adaptive policy frameworks and effective governance mechanisms is essential for addressing the challenges facing SSFs and promoting their sustainability [90].

Robust policy frameworks provide the structural backbone for sustainable fisheries management, outlining clear guidelines and regulations that govern fishing practices, gear usage, seasonal closures, and access rights [91]. These policies need to be grounded in scientific research and traditional ecological knowledge to ensure their relevance and effectiveness in conserving fish stocks and habitats while supporting the livelihoods of fishing communities. The robustness of these policies is critical for withstanding the socioeconomic and environmental pressures facing SSFs, ensuring that management strategies can maintain their integrity and effectiveness over time [92].

Adaptive policy frameworks are equally important, given the dynamic nature of marine ecosystems and the various socioeconomic and environmental changes impacting SSFs. The ability of policies to evolve in response to changing circumstances is crucial for maintaining the relevance and effectiveness of fisheries management strategies. Adaptive policies that incorporate climate change projections and provide mechanisms for adjusting management approaches in response to ecological changes can help ensure the sustainability of fishery resources in the long term [93].

Governance plays a pivotal role in the implementation of fisheries policies, acting as the link between policy frameworks and on-the-ground practices. Effective governance ensures that policies are not merely theoretical constructs but are actively enforced and adhered to within fishing communities. However, the effectiveness of governance can vary significantly, depending on its structure, inclusivity, and responsiveness to local needs and realities [17].

One of the major challenges in the governance of SSFs is the disconnect between national policymaking and local realities [94]. Policies designed at the national or regional level often fail to account for the specific socioeconomic conditions, ecological characteristics, and cultural practices of fishing communities. This gap can lead to the implementation of management strategies that are inappropriate or ineffective for the local context, neither conserving fisheries resources nor adequately supporting the livelihoods of fishers [95].

Furthermore, governance mechanisms frequently encounter issues of inclusivity and participation. Sustainable fisheries management requires the involvement of all relevant stakeholders, including fishers, local communities, scientists, NGOs, and government agencies. However, marginalized groups, particularly small-scale fishers, and women often face barriers to participating in decision-making processes. This exclusion not only undermines the fairness and equity of fisheries management but also limits the effectiveness of policies by neglecting the knowledge, needs, and perspectives of those most directly impacted by them [96].

To address the short coming in governance, a shift toward more inclusive and participatory governance models is necessary [97]. Such models would ensure that the voices and concerns of small-scale fishers and other marginalized groups are heard and considered in the policymaking and implementation processes [98]. Community-based management and co-management approaches, where decision-making responsibilities are shared between government bodies and fishing communities, offer promising avenues for fostering more participatory governance. These models can enhance the legitimacy and acceptance of fisheries management strategies, leading to improved compliance and more sustainable outcomes [99].

Inclusive governance also involves integrating traditional ecological knowledge (TEK) with scientific research in the policymaking process. This integration can provide a more comprehensive understanding of marine ecosystems and the socioeconomic dynamics of fishing communities, leading to fisheries management strategies that are both scientifically sound and culturally relevant [100]. By valuing and incorporating the insights and practices embedded in TEK, policies can be more effectively tailored to the specific needs and conditions of local communities, thus enhancing the sustainability and resilience of SSFs [101].

The sustainable management of SSFs in Bangladesh and elsewhere depends significantly on the development of robust, adaptive policy frameworks and the effectiveness of governance mechanisms [102]. By establishing policies that are both strong and flexible, and by adopting more inclusive and participatory governance models, it is possible to achieve a balance between conserving fisheries resources, supporting the livelihoods of fishing communities, and ensuring the long-term sustainability of these vital systems. Achieving this balance requires collaborative efforts among government agencies, NGOs, fisher communities, and researchers, working together to develop and implement sustainable management solutions that address the complex challenges facing SSFs [103].

4.5 Adaptation and resilience to climate change

The impacts of climate change on SSFs in Bangladesh are profound and wide-ranging, affecting the ecological dynamics of marine and freshwater ecosystems, the availability and distribution of fish stocks, and the livelihoods of communities that depend on these resources [4]. The urgency of developing effective adaptation strategies to mitigate these impacts and safeguard the sustainability of SSFs is underscored by the findings of this study. Building resilience within SSFs emerges as a critical approach to addressing the challenges posed by climate change and ensuring the sector's ability to absorb shocks, adapt to changing conditions, and transform in ways that maintain its core functions and sustainability.

Climate change introduces a multitude of environmental stressors to marine and freshwater ecosystems, including rising sea temperatures, ocean acidification, altered precipitation patterns, and increased frequency and intensity of extreme weather events. These changes have both direct and indirect effects on fish populations and their habitats, impacting fish distribution, abundance, and the timing of breeding and migration patterns. For SSFs in Bangladesh already facing challenges such as overfishing and habitat degradation, the exacerbation of these issues by climate change further threatens the sector's sustainability and the well-being of dependent communities [104].

The socioeconomic implications of climate change for fishing communities are substantial. Changes in fish availability, driven by shifts in distribution and abundance, can lead to reduced catches, directly affecting food security and income for millions of people. Additionally, extreme weather events pose significant risks to fishing gear, boats, and

infrastructure, straining the economic stability of fishers and exacerbating their vulnerability to environmental and socioeconomic shocks [105].

Building resilience in SSFs involves a holistic approach that addresses the ecological, economic, and social dimensions of sustainability. Enhancing ecological resilience entails protecting and restoring critical habitats, such as mangroves, coral reefs, and seagrass beds, which serve as vital breeding and nursery grounds for fish [106]. Establishing marine protected areas (MPAs) and promoting biodiversity within these ecosystems can help buffer them against the impacts of climate change, supporting the regeneration of fish stocks and maintaining the health and integrity of aquatic environments.

Economic resilience is equally important for SSFs, requiring the diversification of income sources for fishing communities to reduce their vulnerability to climate-induced fluctuations in fish viability. Supporting alternative livelihoods, such as aquaculture, agriculture, or ecotourism, can provide stable income opportunities and reduce dependence on fishing. Access to microfinance and insurance schemes can also offer financial safety nets for fishers facing climate-related losses, helping to cushion the economic impacts of environmental changes and extreme weather events [107].

Enhancing social resilience is crucial for empowering communities to collectively respond to the challenges of climate change. Fostering participatory governance models that include fishers in decision-making processes can strengthen community cohesion and the capacity for adaptive management. Improving access to information, resources, and education and training programs is essential for building the knowledge and skills needed to adapt to changing environmental conditions. Empowering women and marginalized groups within fishing communities is particularly important for ensuring that adaptation efforts are inclusive and equitable, addressing the needs and perspectives of all community members [108].

Effective adaptation to climate change requires integrated strategies that combine elements of ecological, economic, and social resilience. For example, co-management arrangements that involve fishers, scientists, and policymakers can facilitate the implementation of adaptive management practices that are tailored to local conditions and needs. Utilizing traditional ecological knowledge (TEK) alongside scientific research can

provide valuable insights into sustainable fishing practices, early-warning indicators of ecosystem changes, and innovative adaptation strategies [109].

Adapting to climate change in the context of SSFs in Bangladesh demands a comprehensive and integrated approach that builds resilience across ecological, economic, and social dimensions. By implementing holistic adaptation strategies, it is possible to mitigate the impacts of climate change, support the sustainability of fisheries, and protect the livelihoods of vulnerable fishing communities. Achieving this goal will require concerted efforts from government agencies, nongovernmental organizations, the scientific community, and fishers themselves, working collaboratively towards a resilient and sustainable future for small-scale fisheries [110].

4.6 Integration of traditional ecological knowledge (TEK)

The integration of traditional ecological knowledge (TEK) with scientific knowledge plays a significant role in enhancing the management of SSFs in Bangladesh, offering a pathway to more sustainable and resilient practices. This integration is especially critical in Bangladesh, where SSFs are not merely economic activities but also deeply embedded in the cultural, social, and environmental fabric of the country. The nuanced understanding and insights provided by TEK can significantly inform fisheries management, making it more responsive to the local ecological and social contexts [111].

TEK in Bangladesh encompasses a wealth of knowledge accumulated over centuries by communities that have lived in close harmony with their aquatic environments [112]. This body of knowledge includes insights into seasonal and lunar cycles for fishing, traditional fishing methods that minimize bycatch, and an understanding of habitat markers for fish breeding sites. By blending TEK with contemporary scientific methods, fisheries management can benefit from the deep connection and understanding local communities have with their ecosystems, leading to management strategies that are both effective and deeply respected by those who rely on them.

The contributions of TEK to sustainable practices in Bangladesh are manifold. TEK has informed communities about the importance of respecting certain lunar and seasonal cycles for fishing, which align with the breeding periods of various fish species. This traditional knowledge can be integrated into scientific fisheries management to establish

closed seasons, ensuring that fish populations can regenerate, thereby contributing to the long-term sustainability of the fishery [113].

Traditional fishing methods in Bangladesh, often characterized using selective gear and techniques, target specific species and sizes, minimizing the impact on juvenile fish populations and nontarget species [114]. These practices, informed by TEK, can guide the development of regulations on fishing gear and methods, promoting sustainable fishing that reduces overfishing and bycatch while enhancing biodiversity.

TEK also encompasses knowledge about the significance of maintaining healthy aquatic habitats, such as mangroves, flood plains, and rivers, which are crucial for fish breeding and growth. Integrating this traditional understanding with scientific efforts towards habitat restoration and conservation can significantly enhance the resilience of fish stocks and their ecosystems, thus supporting the sustainability of SSFs [115].

Furthermore, communities in Bangladesh, drawing on their traditional knowledge, have observed environmental changes and adapted their fishing practices accordingly. This adaptive capacity is particularly valuable in the context of climate change, providing insights into early warning signs of environmental stress and potential adaptive strategies that could be formalized within scientific management plans. Recognizing and integrating this adaptive knowledge into formal management frameworks can enhance the sector's resilience to changing environmental conditions and ensure the sustainability of SSFs [92].

For TEK to be effectively integrated into the management of SSFs in Bangladesh, several steps can be taken. Systematic efforts to document and validate TEK through participatory research involving local fishers and communities are essential to ensure that this knowledge is accurately captured and respected within scientific frameworks. Revising national fisheries policies to explicitly recognize the value of TEK and incorporating its principles into legal frameworks and management strategies can further elevate the role of community knowledge in decision-making processes. Additionally, training programs for fisheries managers and policymakers on the importance of TEK and methodologies for its integration can foster greater appreciation and utilization of this knowledge, leading to more effective and culturally relevant management strategies [116].

Strengthening mechanisms for community engagement in fisheries management is also crucial to ensure that TEK holders are actively involved in the management process. This

can be facilitated through the establishment of local fisheries management committees that include older fishers and knowledge holders, promoting a collaborative approach to fisheries management that values and leverages the deep ecological insights inherent in TEK [117].

Integrating TEK with scientific knowledge in the management of SSFs in Bangladesh offers a holistic approach that respects cultural heritage, promotes ecological sustainability, and enhances the resilience of fisheries and fishing communities. By valuing and leveraging the rich body of traditional knowledge held by local communities, Bangladesh can develop fisheries management practices that are not only scientifically sound but also socially equitable and culturally relevant. This integration is key to addressing the complex challenges facing SSFs, ensuring the long-term viability of this vital sector, and supporting the livelihoods and well-being of the communities that depend on it [103].

4.7 Recommendations for enhancing sustainability

To enhance the sustainability of SSFs in Bangladesh, a comprehensive approach that addresses the ecological, economic, and social dimensions of the sector is imperative. The analysis presented in this thesis has highlighted the interconnected challenges facing SSFs, including overexploitation of resources, habitat degradation, the impacts of climate change, and social issues such as marginalization and limited access to decision-making processes. Based on this analysis, the following recommendations are proposed to foster a more sustainable, resilient, and equitable SSF sector in Bangladesh.

Enhancing access to financial services: The development and expansion of microfinance programs tailored to the needs of small-scale fishers are crucial for enabling sustainable fishing practices. Offering low-interest loans for sustainable fishing gear, safety equipment, and habitat restoration projects can empower fishers to invest in the sustainability of their livelihoods. Additionally, introducing insurance schemes to protect against losses due to environmental disasters, such as cyclones and floods, can provide a financial safety net for fishers, mitigating the economic impacts of these events [118].

Promoting alternative livelihoods: Encouraging the development of sustainable aquaculture as an alternative livelihood for small-scale fishers can reduce the dependence on overexploited fish stocks and provide stable income opportunities. Providing training

and support for environmentally sustainable and socially equitable aquaculture practices, such as integrated multitrophic aquaculture (IMTA), can enhance the sector's sustainability. Furthermore, leveraging Bangladesh's rich biodiversity and cultural heritage to develop community-based ecotourism projects can offer alternative sources of income for fishing communities while promoting conservation awareness and environmental stewardship [119].

Strengthening community participation in management: Establishing and strengthening co-management structures that include fishers, community leaders, NGOs, and government representatives is essential for fostering active participation in decision-making processes. Ensuring that management measures are both scientifically sound and culturally appropriate requires the involvement of all stakeholders in the management process. Investing in capacity-building programs for community leaders and fishers, focusing on sustainable fisheries management, leadership skills, and conflict resolution, can empower communities to engage effectively in co-management and call for their rights and resources [120].

Improving access to markets and infrastructure: Developing initiatives to improve fishers' access to local and international markets is crucial for enhancing the economic viability of SSFs [1]. Establishing fishing cooperatives that can negotiate better prices, quality standards, and access to market information can increase fishers' profitability and reduce their vulnerability to market fluctuations. Additionally, supporting the development of value-added products can increase income opportunities and promote the sustainable use of fishery resources. Improving fishing-related infrastructure, including landing sites, storage facilities, and transportation, can reduce post-harvest losses, improve product quality, and increase the overall efficiency of the fisheries sector [121].

Enhancing resilience to climate change: Implementing and supporting community-based adaptation strategies to address the impacts of climate change on SSFs is vital for ensuring the sector's long-term sustainability. Restoring mangroves and other critical habitats, introducing climate-resilient fish species in aquaculture, and developing early-warning systems for extreme weather events are key measures for building the sector's resilience to climate change. Establishing platforms for the exchange of traditional ecological knowledge (TEK) and scientific knowledge on climate change adaptation among fishers,

researchers, and policymakers can facilitate the co-creation of innovative adaptation strategies that are grounded in local realities and experiences [117].

By implementing these recommendations, Bangladesh can move towards a more sustainable and resilient small-scale fishery sector that supports the livelihoods of millions of people, conserves biodiversity, and contributes to national food security. Achieving this vision requires collaborative efforts from the government, NGOs, the private sector, and fishing communities, guided by an ethos of sustainability, equity, and resilience. Working together, stakeholders can develop and implement effective management solutions that address the complex challenges facing SSFs, ensuring the long-term viability of this vital sector and the well-being of the communities that depend on it.

5 Conclusion

The SSFs in Bangladesh are indispensable to the nation's economy, contributing significantly to food security and supporting the livelihoods of over 18 million people. Despite their crucial role, SSFs encounter numerous challenges, including the overexploitation of resources, habitat degradation, the adverse effects of climate change, and socioeconomic issues such as marginalization and limited access to decision-making processes. This thesis has underscored the intertwined nature of economic, environmental, and social factors within SSFs, advocating a holistic management approach that addresses these dimensions collectively. While initiatives like community-based management, co-management, seasonal closures, and gear restrictions show potential, their success is often hampered by challenges with enforcement, community engagement, and structural inadequacies within the management frameworks.

This study has several limitations that may impact the interpretation and application of its findings. Firstly, the reliance on existing literature and documented practices may not fully capture the breadth of traditional and emerging management strategies across all Bangladeshi regions. Secondly, the dependence on published literature might lead to an incomplete picture due to potential gaps in data regarding undocumented or newly developed management approaches. Lastly, given the ecological, social, and economic diversity within Bangladesh, the findings and recommendations presented may not be universally applicable across all SSF contexts.

To build upon the groundwork laid by this thesis and address its limitations, the following areas for future research are recommended to further the sustainable management of SSFs in Bangladesh:

1) Conduct detailed case studies across diverse communities or regions within Bangladesh to gain deeper insights into the unique challenges and the efficacy of different management practices within specific SSF contexts. 2) Undertake targeted research into the specific effects of climate change on SSFs, including alterations in fish stock availability, changes in fishing practices, and the socioeconomic repercussions on community livelihoods. This research should aim to develop nuanced adaptation strategies. 3) Examine the dynamics of gender and social equity within SSF management, focusing on identifying barriers to inclusive participation in decision-making processes and exploring opportunities for empowering marginalized groups within fishing communities. 4) Perform comprehensive economic analyses of SSFs to evaluate the feasibility of alternative livelihoods, the impact of financial services and incentives on sustainability, and the broader economic benefits of adopting sustainable management practices. 5) Investigate the potential role of technological innovations in enhancing SSF sustainability, such as advancements in fishing gear, monitoring and enforcement mechanisms, and data collection technologies for informed management decision-making. 6) Assess the effectiveness of existing policy and governance frameworks in supporting sustainable SSF management. This should include exploring opportunities for policy reforms that promote inclusivity, adaptability, and responsiveness to the needs of local communities. By pursuing these directions, future research can contribute to a more comprehensive understanding of the complexities involved in managing SSFs in Bangladesh. This will enable the development of more effective, equitable, and sustainable management strategies, thereby ensuring the long-term viability and prosperity of this essential sector.

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7 Appendices

Appendices: Summary of Reviewed Literature

Sl No	Year of Publication	Title	References
1.	2000	Property Rights, Livelihoods, and Poverty around Some Fishing Grounds in Rural Bangladesh	Toufique, K. A. (2000, May). Property rights, livelihoods, and poverty around some fishing grounds in rural Bangladesh. In <i>Eighth Conference of the International Association for the Study of Common Property, Bloomington, IN, USA, May</i> .
2.	2001	Current constraints and future possibilities for Bangladesh fisheries	Alam, M. F., & Thomson, K. J. (2001). Current constraints and future possibilities for Bangladesh fisheries. <i>Food policy</i> , 26(3), 297-313.
3.	2002	Small-scale fish culture in Northwest Bangladesh: a	Barman, B. K., Little, D. C., & Edwards, P. (2002). Small-scale fish culture in

		participatory appraisal focusing on the role of tilapia	Northwest Bangladesh: a participatory appraisal focusing on the role of tilapia. In <i>Rural aquaculture</i> (pp. 227-244). Wallingford UK: CABI Publishing.
4.	2002	Performance of Fisheries Sector Planning in Bangladesh	Rahman, S., & Ahmed, K. K. (2002). Performance of fisheries sector planning in Bangladesh. <i>Outlook on AGRICULTURE</i> , 31(4), 243-251.
5.	2004	Community Based Fisheries Management as the future fisheries management option for small-scale fisheries of Bangladesh	Hossain, M. M., Islam, M. A., Ridgway, S., & Matsuishi, T. (2004). Community based fisheries management as the future fisheries management option for small-scale fisheries of Bangladesh.
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