

**Role of Information Systems in supporting Small-scale Fisheries in Island and Coastal
Communities towards Sustainability – The Case of the Sundarbans**

**by
Pallabi Chakraborty**

**A thesis
presented to the University of Waterloo
in fulfilment of the
thesis requirement for the degree of
Master of Environmental Studies
in
Social and Ecological Sustainability**

Waterloo, Ontario, Canada, 2025

© Pallabi Chakraborty 2025

Author's Declaration

This thesis consists of material all of which I authored or co-authored: see Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners. I understand that my thesis may be made electronically available to the public.

Statement of contributions

Chapters 1, 2, 3, 4, and 6 of this thesis were solely authored by Pallabi Chakraborty under the supervision of Professor Simron J. Singh and advisory support from Professor Jennifer J. Silver. These chapters were developed exclusively for the purpose of this thesis and are not intended for publication. Constructive input was provided by Professor Priyadarshi Patnaik, Mr. Diganta Panda, and Professor Prateep Kumar Nayak during various stages of the research and writing process.

Chapter 5 consists of a co-authored manuscript titled “Designing Information Systems for Equity and Sustainability: Enhancing Resource Access, Capacity Development, and Governance in Mangrove-Dependent Small-Scale Fisheries.” This article was prepared for submission to a peer-reviewed journal, and the specific contributions of each co-author are outlined below:

Brief overview of contribution

- Pallabi Chakraborty – Conceptualization, methodology, data collection, data analyses, writing (original draft).
- Dr. Simron Jit Singh – School of Environment, Enterprise and Development, Faculty of Environment, University of Waterloo: Supervision, conceptualization, methodology, writing (review and editing)
- Dr. Priyadarshi Patnaik – Department of Humanities & Social Sciences, Indian Institute of Technology-Kharagpur, West Bengal, India: Conceptualization, methodology, writing (review and editing)
- Mr. Diganta Panda – Ph.D. Candidate, Department of Humanities & Social Sciences, Indian Institute of Technology-Kharagpur, West Bengal, India: Conceptualization, methodology, writing (review and editing)
- Dr. Jennifer J. Silver – Department of Geography, Environment & Geomatics, University of Guelph: External Committee Member, conceptualization, methodology, writing (review and editing)

- Dr. Prateep Kumar Nayak – School of Environment, Enterprise and Development, Faculty of Environment, University of Waterloo: Conceptualization, methodology, writing (review and editing)

Citation: Chakraborty, P., Singh, S. J., Patnaik, P., Panda, D., Silver, J.J. and Nayak, P.K. (Forthcoming). Designing Information Systems for Equity and Sustainability: Enhancing Resource Access, Capacity Development, and Governance in Mangrove-Dependent Small-Scale Fisheries. Manuscript submitted to Maritime Studies.

Abstract

In the context of the Anthropocene and escalating environmental pressures like sea-level rise, small-scale fisheries, like those dependent on mangrove ecosystems, are facing growing vulnerabilities. These fisheries are critical to food security, employment, and coastal resilience but are increasingly threatened by environmental degradation, governance deficits, and social inequalities. The transition from vulnerability to viability in small-scale fisheries requires integrated approaches that address social, ecological, and governance challenges while empowering local communities. Access to diverse capital assets (natural, financial, educational, social) and inclusive participatory governance are vital. Information systems, especially digital tools co-designed with stakeholders, can bridge data gaps, support collaborative management, and enhance resilience if they are context-sensitive and participatory. The research investigates how an information System can empower small-scale fisheries communities by improving data access, promoting inclusive governance, and addressing systemic inequalities. In doing so, it asks: What is the role of an information system in supporting the transition from vulnerability to viability in island and coastal small-scale fisheries? And how can insights into the society-technology interface better inform the design and implementation of inclusive digital systems that truly empower stakeholders?

The research adopted a mixed-methods case study approach to evaluate the test version of the Vulnerability to Viability-Information System for small-scale fisheries in two Sundarbans villages, marked by ecological vulnerability and socio-economic marginalization. Quantitative data from structured surveys and interviews captured usage patterns and perceptions of the test version of information system, while qualitative data from in-depth interviews and participant observations provided insights into the cultural and institutional factors shaping technology adoption. Snowball sampling ensured access to diverse participants, and data collection involved video demonstrations, real-time feedback, and use of digital tools. Rigorous methodological steps, including piloting, triangulation, reflexivity, and ethical safeguards, were employed. Fieldwork reflected local complexities, and data were analyzed integrating both inductive and deductive techniques.

The findings highlight the multifaceted role of information systems in supporting the transition from vulnerability to viability in small-scale fisheries in the Sundarbans. While digital tools,

such as mobile applications, offer potential to improve access to real-time data, their effectiveness is limited by structural barriers including low literacy, poor infrastructure, language mismatches, and social inequalities. The pilot information system tested during the study faced usability issues due to lack of contextual adaptation and vernacular integration. These challenges reveal that inclusivity, through features like voice-based interfaces, offline functionality, and local language content, is not optional, but foundational to effective design and adoption.

Beyond usability, the research emphasizes the importance of embedding such technologies within a co-productive society-technology interface. Fishers expressed interest in platforms that integrate traditional ecological knowledge with scientific data, enabling them to navigate environmental risks and regulatory demands more effectively. This hybrid knowledge approach not only improves local decision-making under climate uncertainty but also preserves cultural practices and fosters epistemic justice. Moreover, the system's effectiveness is deeply tied to its capacity to support equitable governance. Local institutions are crucial intermediaries, but are often weakened by elite control and inconsistent state support. Digital tools must, therefore, strengthen transparency and empower marginalized voices in resource access and governance.

The study further foregrounds gender as a critical dimension in technology design. Women in the sector, already constrained by socio-cultural norms, are frequently excluded from digital innovations unless systems are explicitly tailored to their needs. Gender-sensitive features and leadership support are necessary to ensure that technology enhances, rather than reinforces, existing inequalities. Overall, the findings position information systems not as standalone solutions but as participatory, justice-oriented infrastructures that must be co-designed with stakeholders. When integrated into broader governance and knowledge systems, these tools can strengthen resilience, build collective agency, and enable inclusive, sustainable resource management.

Key words: Small-scale fisheries, mangrove ecosystem, participatory governance, digital tools, traditional ecological knowledge, context-specific design, digital literacy, inclusive development, sustainable resource management, localized information systems

Acknowledgements

Growing up in the small city of Shillong in the northeastern state of Meghalaya, India, I began a journey that would gradually expand my worldview and shape my aspirations. The close-knit community and serene landscapes of Shillong provided the foundation for my early academic and personal growth. My experiences during undergraduate and postgraduate studies there nurtured my curiosity and interest in environmental and social issues, ultimately leading me to pursue further education in Canada after years of anticipation and perseverance.

My time at the University of Waterloo has been both enriching and humbling. The transition to a new country came with its share of challenges, but it also brought invaluable opportunities for learning, reflection, and growth. Here, I encountered diverse perspectives and academic rigour, which have deepened my understanding of global environmental and social sustainability.

Hence, I acknowledge that the University of Waterloo is situated on the traditional territory of the Neutral, Anishinaabeg, and Haudenosaunee peoples. This land is part of the Haldimand Tract, which was promised to the Six Nations that includes six miles on each side of the Grand River. I recognize the enduring presence and deep traditional knowledge of the Indigenous peoples with whom this land is shared. I express my respect and gratitude for the opportunity to study, research, and reflect on these lands as part of my academic journey. This acknowledgement is offered as part of my ongoing commitment to learning from Indigenous perspectives and contributing, in however small a way, to reconciliation and respectful coexistence.

This journey would not have been possible without the unwavering support of many people. I am deeply grateful to my husband, Valerian Sequeira, for being my strongest supporter and guide. His encouragement and quiet strength helped me stay committed to my work, even when long field visits took me far from home.

I also express heartfelt gratitude to my father, Mr. Gopal Chakraborty, whose resilience and love for animals continue to inspire me, even though he was often unsure about my academic and professional paths. My late mother, Mrs. Shyamalee Chakraborty, remains a guiding presence in my life; her quiet strength, love, and belief in me have carried me through the most difficult moments. I dedicate this work to her.

My sincere thanks go to my long-time friend, Dr. Reetuparna Ghosh, whose companionship and support have remained constant since our university days in Shillong. I am also grateful to my extended family, good friends, teachers and former co-workers, whose good wishes have sustained me throughout this endeavour.

I am thankful to the World Conservation Network (WCN – USA) for providing a scholarship, and to Dr. Purnima Devi Barman, a passionate conservationist, for nominating me for this support. I am especially grateful to Dr. Sonali Ghosh (IFS), Field Director, Kaziranga National Park, for introducing me to Professor Simron J. Singh at the University of Waterloo. Her support has been invaluable both professionally and personally.

Professor Singh has been instrumental in guiding me through this program and encouraging me to re-enter academia after years of professional experience in India. I deeply appreciate his mentorship, understanding, and belief in my research.

I am deeply grateful to Ms. Supriya Pande (Master of Climate Change, Geography and Environmental Management), whose support during the initial phase of my journey, from applying for my student permit to settling into life in Canada, was invaluable. Her guidance and warmth made me feel at home upon my arrival.

This research is part of the Social Sciences and Humanities Research Council (SSHRC)-funded Vulnerability to Viability Global Partnership, and I am honoured to contribute to this important initiative. I also wish to thank Professor Priyadarshi Patnaik (IIT-Kharagpur), a valued member of the V2V - Information System Working Group, for his support throughout the research process. My sincere appreciation goes to Mr. Diganta Panda (Ph.D. candidate, IIT-Kharagpur) for his contributions to the development of the V2V-IS and assistance during field planning.

I am especially thankful to Professor Jennifer J. Silver (University of Guelph) for her extensive advisory support which included thoughtful and critical inputs on the social, political, and ecological dimensions of small-scale fisheries. Professor Prateep K. Nayak (SEED) also offered valuable feedback on my work, and I extend my sincere thanks to him. I also express my gratitude to Professor Sisir Pradhan (SEED) for shedding much-needed light on the various aspects of quantitative and qualitative methodologies required to conduct research in socio-ecological systems.

Special thanks to Ms. Karen Pieters, Manager at the Human Research Ethics Board, University of Waterloo, for her careful guidance through the ethics approval process. I also thank Dr. Elham Mohammadi (SEED) for her kind support at multiple stages of my work. Furthermore, I am grateful to Dr. Jenia Mukherjee (IIT-Kharagpur) for her encouragement and insights during fieldwork.

My deepest appreciation goes to the community members and stakeholders in the Sundarbans who generously participated in the fieldwork. I am especially thankful to Mr. Prasanta Mukherjee of the Society for Integrated Life (SOIL), Mrs. Nilima Munda, and Mr. Ranjit Munda in Samshernagar village for their hospitality and vital cooperation. In Kumirmari village, I thank Mr. Tapas Mondol, Mr. Ashok Mondol, Mr. Debjoyoti Mondol, Mr. Samaresh Mondol, Ms. Sudha Rani Mondol, and Ms. Ujjala Barman of the Sundarban Parjatan Parisheba Samaboy Samity Limited (SPPSSL) for their support in facilitating logistics and sharing critical insights into small-scale fisheries.

Finally, I am grateful to the School of Environment, Resources and Sustainability (SERS), University of Waterloo, for welcoming me into its master's program, especially Professor Derek Armitage (Director, SERS), Ms. Amanda Campbell (former Graduate Coordinator, SERS) and Ms. Stephanie Mohl (present Graduate Coordinator, SERS). The coursework and guidance and teaching offered by Professor Robert Gibson, Professor Andrea Collins, Professor Helena Shilomboleni, and Professor Jenna Dixon (School of Public Health and Health Systems) have been intellectually rewarding and thought-provoking. I also thank Professor James Nugent for his kindness during my Teaching Assistantship with him, during which I learnt a lot. I have benefited greatly from the companionship and support of my classmates, and all the members of the V2V project at SEED, and I offer them my warmest thanks and best wishes.

To all who have been part of this journey, in both small and significant ways, I offer my sincere appreciation.

Dedication

To my mother, whose love, courage, and quiet strength continue to guide me. This work is a tribute to her unwavering belief in me, even when the path was uncertain. Her presence lives on in all I do.

And to my husband, whose unwavering support and belief in my dreams have sustained me every step of the way.

Table of Contents

Author's Declaration	ii
Statement of contributions	iii
Abstract	v
Acknowledgement	vii
Dedication	x
List of Figures	xiii
List of Tables	xiv
List of Abbreviations	xv
List of Boxes	xvii
Chapter 1 – Introduction	1
1.1 Background	1
1.2 Small-scale Fisheries	2
1.3 Vulnerability to Viability	3
1.4 Addressing Data Gaps in SSF Management	6
1.5 Problem Statement	7
1.6 Thesis Structure	8
Chapter 2 - Literature Review	10
2.1 Information Systems and Information and Communication Technology for SES	10
2.2 Knowledge Co-production	12
2.3 Society – Technology Interface	15
2.4 Data Commons	18
2.5 Inference	20
Chapter 3 – Methodology	22
3.1 Research Design	22
3.2 Study Area	25
3.3 Methods	32
3.4 Data Analysis	33
3.5 Limitations of the Study	34
Chapter 4 - Interactions with Knowledge, Technology, and Governance in Sundarbans	35
4.1. Knowledge Needs and Sources	35
4.1.1 Culturally & Linguistically Relevant Knowledge	35
4.1.2 Market & Trade Insights	37
4.1.3 Institutional Support	38
4.2 Gender dynamics	39
4.3 Administrative Agency	40

4.3.1. Local Governance Helps Mediate Conflicts with Authorities, but unevenly	40
4.3.2. Widespread Distrust in Government Aid Distribution	40
4.3.3. Exploitation by Defense and Forest Authorities	40
4.4. Ongoing Changes	42
4.4.1 Political and Environmental Changes Push Fishers Toward Alternative Income Sources	41
4.4.2 Short-Term Opportunities and Development vs. Long-Term Disruptions	41
Chapter 5 - Designing Information Systems for Equity and Sustainability: Enhancing Resource Access, Capacity Development, and Governance in Mangrove-Dependent Small-Scale Fisheries	45
5.1 Introduction	46
5.1.1 Background	46
5.1.2 Review of Existing Knowledge	47
5.2 Methodology	50
5.2.1. Study Area	50
5.2.2 Methods	51
5.3 Results	53
5.3.1 Participant Profile and Information Access	53
5.3.2. Evaluation of the test application	57
5.3.3. Expectation from an ideal V2V-IS	60
5.4. Discussion	64
5.4.1 Demographic, governance and technological interpretation	64
5.4.2. Challenges and opportunities in the integration of digital tools	67
5.5 Conclusion	73
Chapter 6 - Discussion and Conclusion	76
6.1 Bridging knowledge gaps through a contextual approach	76
6.2 Bridging the gender gap through technology	78
6.3 Governance dynamics	79
6.4 Precarious Adaptations	81
6.5 Conclusion	82
References	84
Appendix A: Recommendations towards inclusive and sustainable digital intervention	105
Appendix B: Interview and Survey Questions	107
Appendix C: Photographs from the field	111

List of Figures

Fig. (i) Steps followed in the V2V-IS development	28
Fig. (ii) Schema of V2V-IS	28
Fig. 1 Map of Study Area: Samshernagar (Sn) and Kumirmari (Km) villages of the Sundarbans Biosphere Reserve	24
Fig. 2 Snapshot of the test version of the V2V-IS that was demonstrated to the research participants before the questionnaire and interview	29
Fig. 3 Diagrammatic representation of methods (data collection and analyses)	53
Fig. 4 Sunburst diagram depicting use of different tools in the study area to access information ..	57
Fig. 5 Stacked columns depicting Likert scale perception on V2V-IS	57
Fig. 6 Trend depicting access to information through technology according to gender	58
Fig. 7 Perception of V2V-IS test app among male and female participants	59
Fig. 8 Illustration of the proposed V2V-IS focusing on accessibility, capacity building, support, equity and resilience	72

List of Tables

Table 1 Participant demographics and status of fishing permits in Samshernagar and Kumirmari villages	54
Table 2 Detailed profile of participants	55
Table 3 Perception of V2V-IS test app according to use of technology to access information....	56

List of Abbreviations

aAQUA - Almost All Questions Answered

BLC - Boat License Certificate

BSF – Border Security Force

FAO - Food and Agriculture Organization of the United Nations

FiRST - Fisheries Resource Information System and Tools

FIS – Fisheries Information System

GIS - Geographic Information System

HTML - HyperText Markup Language

PHP - Hypertext Preprocessor

IIT – Indian Institute of Technology

ICT – Information and Communication Technology

IoT – Internet of Things

IS - Information System

ISSF - Information System on Small-scale Fisheries

JFMC – Joint Forest Management Committee

mAgri – Mobile enabled agricultural services

MySQL - Database Management System

NGO – Non-governmental Organization

OBIS - Ocean Biogeographic Information System

PA – Protected Area

PeskAAS - Automated Analytics System for Small Scale Fisheries

SC – Scheduled Caste (officially designated groups of people in India)

SDMT - Structured Decision-Making Tools

SES – Socio-ecological System

SMS – Short Messaging Service

SOS - Universal distress signal used in emergencies to signal for help

SSF - Small-scale fisheries

SSHRC – Social Sciences and Humanities Research Council, Government of Canada

ST – Scheduled Tribe (officially designated groups of people in India)

V2V - Vulnerability to viability

List of Boxes

Box 1 Voices from the Sundarbans: Knowledge, Technology & Governance	42
Box 2 Quotes from participants on expectations from an ideal V2V-IS	62

Chapter 1

Introduction

1.1 Background

In the Anthropocene era, an age defined by the profound impact of human activity on the Earth's climate and ecosystems, resilience has become an urgent necessity. Among the many environmental challenges, we face today, sea-level rise stands out as a particularly critical threat to low-lying and vulnerable coastal regions. This growing risk underscores the need for integrated and sustained efforts to build communities and marine ecosystems that can adapt and thrive amidst rapid environmental changes (Gibson et al., 2015). However, the consequences of such environmental disruptions extend far beyond physical landscapes. They reverberate through socio-ecological systems (SES), the intertwined relationships between ecosystems and the human communities that depend on them for livelihoods, culture, and wellbeing.

To navigate these complex realities, it is essential to understand and strengthen social-ecological systems (SES), defined as ecosystems closely connected to and influenced by one or more social systems (Anderies et al., 2004), and delivering vital services like food, fiber, and energy (Binder et al., 2013). Understanding SES is thus key to crafting resilient, inclusive, and adaptive strategies for sustainable development in coastal and marine contexts (Villasante et al., 2022). As such, SES like small-scale fisheries (SSF) are in a state of continuous transformation, striving to balance local livelihood needs with broader environmental pressures, such as climate change, biodiversity loss, and policy shifts.

Huxham et al. (2017) reported that mangrove-dependent SSF are particularly vulnerable to these transformations, as they rely on the unique ecosystem services provided by mangrove forests for breeding, shelter, and feeding of key fish species. The degradation of mangrove habitats due to factors like deforestation, rising sea levels, and coastal development exacerbates the challenges these communities face, threatening both their livelihoods and the sustainability of the resources they depend on. Consequently, preserving and restoring mangrove ecosystems is crucial to supporting the resilience of these fisheries in the face of environmental and socio-economic changes.

1.2. Small-scale Fisheries

Small-scale fisheries (SSF) are typically composed of a stable fleet of small, low-weight vessels. In contrast to the industrial fishing sector, SSF operate with minimal capital investment and use a wide variety of fishing gear, encompassing a wide range of practices from traditional, low-technology, low-capital methods to increasingly sophisticated and modernized techniques. The nature of artisanal fishing practices can differ greatly, shaped not only by biological and environmental factors but also by the distinct social, economic, and historical contexts of the fishing communities. They are vital contributors to national economies, local livelihoods, food security, and nutrition, particularly in developing regions (Berkes & Nayak, 2018; Chuenpagdee et al., 2005). Globally, SSF are estimated to provide employment for over 90% of people engaged in capture fisheries, with women playing crucial roles in pre- and post-harvest activities (FAO, 2015). These communities depend heavily on marine, coastal, and inland water ecosystems, creating socio-ecological systems that are dynamic, adaptive, and deeply embedded in local cultural and economic fabrics.

The very dynamism that characterizes SSF, however, is also a reflection of constant pressures and vulnerabilities. SSF are increasingly confronted by a complex array of challenges, including environmental degradation, overfishing, habitat loss, and pollution, all exacerbated by climate change impacts such as ocean acidification, extreme weather events, and sea-level rise (Chuenpagdee, 2011). At the same time, social inequalities, shaped by gender, caste, ethnicity, and economic marginalization, intersect with governance deficiencies, such as unclear tenure rights, inadequate regulatory support, and exclusion from decision-making processes, which deepen the vulnerability of SSF communities (Nayak & Berkes, 2019). These pressures not only threaten the ecological sustainability of fisheries but also undermine the social resilience and adaptive capacities of fishing communities.

Furthermore, global market forces and increasing competition over marine resources have introduced additional volatility into local systems, often favouring large-scale industrial actors at the expense of small-scale operations. Therefore, while fish trade has the potential to contribute to poverty reduction, the benefits are not uniformly distributed, and small-scale fishers may not always reap the advantages of global market integration. This underscores the complexity of global market interactions and the need for nuanced policies that consider the unique challenges

faced by SSF in the context of international trade (Béné et al., 2016). As a result, ensuring the viability and resilience of SSF requires a multidimensional approach that addresses environmental, social, and governance challenges in an integrated and participatory manner.

1.3 Vulnerability to Viability

Here, vulnerability refers to the susceptibility of SSF to various external forces, such as environmental change, regulatory pressures, and socio-economic constraints, coupled with limited coping mechanisms. In contrast, viability denotes the capacity of SSF systems to navigate these pressures, adapt to changing conditions, and foster resilience across economic, social, political, and ecological domains (Dias et al., 2023). The vulnerability of SSF communities is multidimensional and closely linked to issues of poverty, marginalization, and environmental stressors, requiring a comprehensive and integrated response. Enhancing resilience and adaptive capacity is central to reducing vulnerability and achieving viability. Frameworks such as sustainable livelihoods and wellbeing provide useful lenses for understanding this transition, allowing analysis of material, relational, and subjective dimensions of fisher wellbeing. For instance, addressing the poverty-climate change nexus calls for coordinated action that centers poverty alleviation to enhance adaptive capacities and reduce exposure to risks (Freduah et al., 2018).

Access to capital assets, encompassing natural resources, education, health services, financial means, and social networks, is fundamental to enhancing the resilience of small-scale fishing communities. Secure access to natural resources such as fishing grounds and clean water bodies ensures the basic material foundation for their livelihoods, while education equips fishers and their families with the knowledge and skills needed to adapt to changing environmental, regulatory, and market conditions. Health services play a critical role by safeguarding the physical wellbeing necessary for participation in labour-intensive fishing activities, especially in regions vulnerable to climate and occupational hazards.

Financial capital, including savings, credit facilities, and insurance mechanisms, provides a buffer against economic shocks such as sudden price drops, natural disasters, or equipment losses. Equally important are social networks, connections within communities, cooperatives, or fisher organizations, that foster information sharing, collective bargaining, and mutual aid during times of crisis. Together, these forms of capital strengthen a community's capacity to withstand

external shocks, recover from setbacks, and pursue long-term livelihood strategies, thereby playing a pivotal role in reducing vulnerability and promoting the viability of small-scale fisheries (Freduah et al., 2018).

Moreover, according to Nakamura et al. (2021) governance structures play a crucial role in shaping the outcomes for SSF, particularly through the lens of legal and policy frameworks. They argue that governments heavily influence SSF communities by creating regulations, subsidy systems, and conservation measures that affect how resources are accessed and managed. These regulatory frameworks are not neutral; they are embedded with power relations that influence the way communities interact with external interventions. The intersection of these power dynamics, shaped by gender, caste, and land tenure, often determines the distribution of resources and decision-making authority within SSF communities.

Gender-sensitive assessments and capacity-building initiatives are thus vital to address the inequalities that emerge from these intersecting forms of social stratification. By incorporating gender and political ecology frameworks into policy and governance processes, it becomes possible to identify and mitigate the unequal power structures that hinder the equitable distribution of benefits and participation in decision-making. This highlights the need for governance approaches that promote inclusive access to capital assets, such as natural resources, education, and financial resources, and ensure that marginalized groups, particularly women, can actively engage in and benefit from the sustainable management of small-scale fisheries. In this context, fostering resilience in SSF communities requires addressing both the structural inequalities within governance systems and the enhancement of their adaptive capacities to external challenges.

In moving towards viability, SSF communities require fostering an integrated and inclusive approach to governance that supports both the sustainable use of resources and the empowerment of local communities. The concept of interactive governance (Kooiman et al., 2005) emphasizes the importance of collaboration among various stakeholders, including fishers, NGOs, state agencies, and researchers, at multiple levels to address the complex, cross-cutting challenges faced by SSF communities. Such challenges include the impacts of climate change, resource mobility, and the depletion of fish stocks. Effective governance is not only about setting policies

but also about creating platforms where all stakeholders can actively participate in decision-making processes.

A critical element of this governance approach is the need for accurate, timely, and localized data, not only for external management bodies, but crucially for small-scale fishers themselves. Such data empowers fishers to make informed decisions about harvesting strategies, seasonal planning, and risk management in the face of changing environmental and socio-economic conditions. When made accessible and relevant, data becomes a tool for both community-based stewardship and more responsive governance.

Without reliable information, fisheries management, at all levels, risks becoming reactive and fragmented, unable to adapt to shifting ecological and social realities. It is highlighted that localized data, gathered in collaboration with communities, helps ensure that resource management is context-specific, responsive, and adaptive. Such data is also crucial for designing policies that are grounded in the realities of local fishers and their environments, enabling more effective and equitable governance structures. Thus, data not only informs governance but also empowers fishers by providing them with the tools they need to participate meaningfully in the management of their resources, strengthening the resilience and long-term viability of SSF communities.

However, many SSF often face significant challenges due to data gaps, which are exacerbated by informal market structures, remote geographical locations, and limited digital infrastructure (Dias et al., 2023). The lack of reliable and comprehensive data makes it difficult for fishers, policymakers, and other stakeholders to effectively monitor fishing activities, enforce regulations, and assess the sustainability of fishery resources. To address these gaps, digital tools such as websites, mobile applications, and SMS-based services offer valuable solutions. These technologies can enhance the tracking of fishing activities, improve communication among fishers and regulatory bodies, and promote knowledge-sharing on sustainable practices and market trends (Chuenpagdee et al., 2019).

Additionally, digital tools can facilitate transparency by ensuring regulatory compliance and improving market access, which is often limited by the informal nature of many SSF markets. However, as noted by Anand et al. (2024), the success of these digital solutions depends on their inclusive design, which must consider factors such as digital literacy, language barriers, and the

socio-cultural context of SSF communities. Without addressing these barriers, digital tools may fail to meet the needs of marginalized groups within these communities or even exacerbate existing inequalities.

To ensure that digital technologies contribute effectively to the sustainability and resilience of SSF systems, it is essential to invest in appropriate infrastructure, community-led monitoring systems, and participatory data governance. These efforts will help bridge the digital divide, allowing SSF communities to harness the potential of digital tools without undermining their traditional knowledge and practices, thus reinforcing the viability of SSF systems in the long term.

1.4 Addressing Data Gaps in SSF Management

Access to diverse natural, human, physical, social, and financial assets is fundamental for addressing the complex challenges of SSF and ensuring sustainability (Bebbington, 1999; Weeratunge et al., 2014). Yet, historically embedded power structures often constrain access and agency. In response, critical and decolonial approaches to capacity development challenge dominant paradigms and promote community control over resources (Bockstael, 2017). While these efforts open new pathways for inclusive development, dismantling entrenched inequalities remains essential.

Governments and institutions significantly shape SSF through policy and regulation, making it vital to engage with gendered power relations, social inequities, and global governance influences (Elmhirst, 2011; Nayak & Armitage, 2018; Collins et al., 2019). Addressing multifaceted challenges like climate change and socio-economic vulnerability requires transdisciplinary capacity building, regional knowledge co-production, and multi-level collaborative governance (Khan et al., 2018; Jentoft & Chuenpagdee, 2015; van Maurik Matuk et al., 2023).

One key strategy is strengthening information systems (IS) that integrate qualitative and quantitative data, ranging from catch statistics and environmental conditions to market and governance insights (Ramirez-Rodriguez, 2011; Agapito et al., 2019). The FAO (2015) highlights SSF's underrepresentation in formal data systems, calling for improved infrastructure. Information System platforms, especially when embedded in participatory governance and

structured decision-making tools (SDMTs), can enhance transparency, compliance, and inclusion (Chuenpagdee et al., 2019; Gammage & Jarre, 2020). However, if not designed with attention to literacy, access, and local languages, they risk reinforcing exclusions, particularly for women, youth, and Indigenous fishers.

Sustainable SSF governance depends on collaboration across communities, governments, NGOs, IT professionals, and researchers. IS technologies support real-time tracking, knowledge exchange, and adaptive management, linking traditional and scientific knowledge for more resilient outcomes (Jentoft & Chuenpagdee, 2015; Dias et al., 2023). At larger scales, they enable responses to globalization, climate change, and trade through comprehensive, transparent, and interoperable data systems (Feoli & Nauen, 2001).

Critically, IS must be developed through inclusive, participatory processes. Stakeholder involvement ensures relevance, fosters ownership, and enhances legitimacy (Boiral & Heras-Saizarbitoria, 2017; Seddiky et al., 2020). Embedding community knowledge and concerns in system design strengthens trust and usability (Ghose, 2001), while structured dialogue and conflict resolution mechanisms support shared governance and just outcomes (Ramirez, 1999; Lewins, 2001).

1.5 Problem Statement

Despite the growing recognition of the importance of IS in supporting sustainable management of SSF, these communities continue to face challenges in accessing and utilizing diverse resources due to entrenched power dynamics, gendered social inequalities, and exclusion from formal data systems (Dias et al., 2023). Existing governance frameworks often fail to effectively incorporate the needs and knowledge of marginalized stakeholders, hindering participatory decision-making and resource management. While critical and decolonized approaches to capacity development have emerged, there remains a significant gap in the integration of these perspectives into IS design and implementation. This research seeks to explore how participatory IS can be developed and utilized to empower local SSF communities, foster inclusive governance, and address environmental, social, and economic challenges. This research was therefore conducted to investigate the role of IS in bridging gaps in data infrastructure, promoting equitable access to resources, and supporting collaborative management practices. It aimed to support the development, piloting, and testing of the mobile/web-based application of

an IS within a mangrove-dependent SSF context and demonstrate the effectiveness of this database in enhancing the understanding of the dynamics of SSF in their transition from vulnerability to viability by answering the following questions and fulfilling certain objectives.

Research Questions

1. What is the role of Information System in supporting vulnerability to viability in island and coastal SSF?
2. How can an understanding of the society-technology interface better inform the design and implementation of an effective Information System that empowers stakeholders?

Objectives

- To examine how social, cultural, and institutional factors shape small-scale fishers' interactions with knowledge, technology, and governance in the Sundarbans.
- To identify social, institutional and systemic challenges hindering the effective implementation and use of advance technology in SSF.
- To examine stakeholder (SSF communities, NGOs, government actors and academics) perceptions and expectations on using new technology.
- To establish a mechanism for feedback between the development, design, and implementation of the Information System.

1.6 Thesis Structure

This is an article-based thesis divided into six chapters.

Chapter 2 covers a review of historical and current literature which discuss the integration of information systems and information and communication technologies in small-scale fisheries, highlighting their potential to improve livelihoods, resource management, and decision-making. It emphasizes the importance of participatory approaches, context-specific design, and addressing social, infrastructural, and policy-related challenges for successful implementation.

Chapter 3 describes a qualitative research methodology used in this research using case study approach and snowball sampling, through semi-structured interviews and surveys, to understand the socio-economic realities and lived experiences of crab collectors in the study area, with

attention to gender, caste, and ecological vulnerability. It emphasizes ethical research practices, researcher positionality, and the integration of local knowledge systems.

Chapter 4 presents an in-depth thematic analysis of the study's core findings in relation to the research objectives. It explores how social, cultural, and institutional dynamics shape small-scale fishers' access to and interaction with knowledge, technology, and governance in the Sundarbans. The chapter examines the significance of traditional ecological knowledge, shifting livelihood patterns, market and regulatory challenges, gendered access to resources and decision-making, and the implications of ongoing political and environmental changes. These insights underscore the urgent need for locally adapted, inclusive systems that can support fishers in navigating uncertainties and sustaining their livelihoods within a rapidly transforming socio-ecological landscape. Crucially, this contextual understanding provides the foundation for Chapter 5, demonstrating that the information system must be designed in ways that respond to these lived realities.

Chapter 5 contains a manuscript intended for publication, presented in its original form. It provides a focused account of the research, covering the background, literature gaps, study area, methodology, and key findings. This chapter examines stakeholder perceptions of new technologies in SSF, focusing on how design, accessibility, knowledge integration, capacity building, governance, economic empowerment, and data autonomy shape the development of inclusive, context-sensitive information systems. Building directly on the challenges and opportunities identified in Chapter 4, the findings support a feedback mechanism connecting system design, development, and implementation, and advocate a rights-based, people-centered approach that uses technology to empower traditional communities while grounding it in their lived socio-ecological realities.

Chapter 6 discusses the findings of the research, emphasizing the importance of an inclusive, community-driven approach to the design of digital systems for small-scale fisheries. It highlights the integration of traditional knowledge with technology, the need to overcome barriers like the digital divide, and the importance of addressing gendered power imbalances. The chapter concludes with reflections on the role of information systems in the Sundarbans and outlines directions for future research in this field.

Chapter 2

Literature Review

Introduction

While this review highlights the global and regional advancements with Information Systems and Information and Communication Technology in supporting SSF and agriculture, it also reveals recurring challenges linked to governance, inclusivity, and knowledge management. Efforts to design digital systems that support SSF increasingly draw from diverse theoretical frameworks, including knowledge co-production, socio-technical studies, and information commons. While these literatures offer powerful insights into how knowledge, technology, and governance intersect, persistent challenges remain. Scholars have noted that entrenched power dynamics continue to marginalize local and Indigenous knowledge systems, and that ideals such as inclusivity, justice, and transparency often falter in practice. Risks like data colonialism, institutional capture, and the high costs of sustaining digital commons remain under-addressed in governance models. In exploring how these systems can truly empower rather than exclude SSF communities, this study critically engages with these three bodies of literature to better understand how knowledge flows, technological choices, and governance structures shape resilience and equity. The sections that follow review each of these frameworks and their relevance to more just and context-sensitive digital systems for SSF.

2.1 Information Systems and Information and Communication Technology for SES

Information Systems (IS) and Information and Communication Technology (ICT) play pivotal roles in transforming knowledge into accessible and practical forms, especially in SSF and other SES. An IS involves the journey of knowledge from creation to delivery, ensuring information is useful and accessible (Bose, 1986). ICT, as defined by Heeks (1999), encompasses electronic means of capturing, processing, storing, and communicating information, from computers and the internet to traditional media like radio and television. The integration of IS and ICT in SSF enhances efficiency, sustainability, and equity by improving access to critical information, facilitating communication among stakeholders, and supporting participatory decision-making.

Several global initiatives demonstrate the varied application of IS and ICT. Grassle (2000) introduced the Ocean Biogeographic Information System (OBIS) as a platform for marine

biological data. Similarly, Mišura et al. (2004) and Chavence et al. (2007) developed fisheries information systems (FIS) in Croatia and West Africa, respectively, highlighting improvements in data management but revealing challenges around access, cooperation, and technical barriers. GIS-based applications have also been significant: Hall and Close (2007) mapped fishing practices in the Caribbean, while Horta and Defeo (2012) and Leopold et al. (2014) used Geographic Information System (GIS) to study fishing effort and catch patterns in Uruguay and New Caledonia.

Mobile technologies have enhanced agricultural and fisheries information dissemination. Donner (2009) and Ogbeide et al. (2015) reviewed short message services (SMS) in Africa, while Mallalieu (2015) emphasized ICTs for SSF in African, Caribbean and Pacific countries. However, adoption challenges persist due to digital divides, as documented by Bhandari et al. (2014) and Magesa (2015). In ICT4D, Heeks (2012) reviewed the shift from personal computers to mobile devices but noted the need for empirical studies.

Recent advancements include community-driven platforms like Oviedo and Bursztyn (2017) who demonstrated participatory monitoring in Brazil, and Petrik and Raemaekers (2018) discussed Abalobi app adoption in Africa. While Wiyono et al. (2018) and Jeffers et al. (2019) showed that basic mobile phone-based innovations like Nelpin and smartphone-based monitoring engage fishers but revealed infrastructure and training gaps. Integrated systems like ISSF (Chuenpagdee et al., 2019) and PeskAAS (Tilley et al., 2020) consolidate data across regions, supporting SSF governance yet face challenges like inconsistent data quality and digital exclusion.

Meanwhile, ICT-enhanced weather, market, and catch data services (Walker, 2021; Agusa et al., 2021) and participatory mapping (Grati et al., 2022) emphasize the need for user-centric and inclusive digital platforms. Bolognini et al. (2023) demonstrated that participatory app co-design enhances market access, although scaling and sustainability challenges remain. Across regions, studies (Neitzel et al., 2017; Aura et al., 2019; Haambiya et al., 2021) highlight the empowerment potential of ICT but caution that infrastructure, socio-economic constraints, and sustainability issues must be addressed.

In India and the broader South Asian region, ICT integration in fisheries and agriculture mirrors global trends but with distinct challenges. Sabu et al. (2014) linked technology adoption among

Indian fishermen to economic development, yet highlighted limited generalizability due to regional specificity. Parmar et al. (2019) found that ICT users in Rajasthan accessed more market and production information, although digital access remained uneven. Tilley et al. (2021) pointed to the digital divide in India's SSF, stressing that while ICT could combat illegal fishing and enhance governance, it must integrate traditional knowledge systems to avoid marginalizing certain groups. India's experience is also informed by agricultural ICT systems, such as e-Choupal and Bhoomi (Tiwari, 2008), highlighting that beyond technology deployment, systemic changes in governance, connectivity, and training are vital.

Jeffers et al. (2019) demonstrated that smartphone-based monitoring can empower communities, yet infrastructure limitations persist. Moreover, Hsu et al. (2019) in Taiwan and Nugroho et al. (2021) in Indonesia reiterated that digital literacy and financial constraints significantly impact ICT adoption. Rahman et al. (2020) observed that Bangladeshi farmers often relied on personal experience and informal networks rather than modern ICT tools, indicating infrastructural and cultural barriers. Research on ICT applications in South and Southeast Asia, including the Fisheries Resource Information System and Tools (FiRST) (Garces et al., 2006) and catch monitoring initiatives in Indonesia (Sari et al., 2021), emphasized the need for capacity-building, legal clarity, and data-sharing mechanisms.

2.2 Knowledge Co-production

Knowledge co-production is identified to be essential for addressing the various challenges faced by SSF since it enables adaptive, inclusive, and context-sensitive governance, respects the value of diverse knowledge systems, and ultimately supports more resilient and sustainable fisheries (Jentoft and Chuenpagdee, 2015; van Maurik Matuk et al., 2023). Therefore, the definition of co-production of knowledge used in this work is, 'iterative and collaborative processes involving diverse types of expertise, knowledge, and actors to produce context-specific knowledge and pathways towards a sustainable future', by Norström et al. (2020). The authors explained that the quality of knowledge co-production relies on context, pluralism, goal orientation, and interactivity. Implementation varies based on specific challenges, actors, social and political contexts, and project scale. It is essential to monitor and evaluate co-production practices effectively, aligning with the complex relationships between science, policy, and practice. Evaluation metrics include inclusiveness, trust-building, goal achievement, and interaction

quality. These assessments should be context-specific, involving participatory frameworks, qualitative and quantitative indicators, and continuous learning. Monitoring and evaluation should facilitate ongoing improvement, considering short- and long-term impacts, and adapting to changing circumstances.

Expanding on this Cooke et al. (2021) explore knowledge co-production as an essential strategy for effective fisheries management, conservation, and governance. They emphasize that successful co-production depends on understanding the specific context, engaging multiple knowledge systems, and aligning goals, where the key elements include ensuring inclusivity, building trust, fostering meaningful interactions, and developing clear, shared objectives. The authors highlight the importance of continuous monitoring and evaluation, which should be adaptive and context-specific, considering the social and political dynamics that affect fisheries management. The paper also underscores the need for iterative learning and adjustment in response to evolving challenges, offering a framework to assess co-production practices' effectiveness in addressing complex ecological and societal issues.

Local knowledge, as highlighted in Ban et al. (2018) and Lima et al. (2017), provides valuable, real-time insights into fishery systems, capturing the nuanced, immediate changes in local environments. This knowledge is crucial for understanding spatial and temporal variations in fishery resources, often not reflected in broader scientific data. However, integrating scientific data and methodologies with local knowledge enhances the broader context for interpreting these changes, allowing for more effective management. By combining these knowledge systems, the research emphasizes the importance of data sharing across different systems, creating a more holistic understanding of fisheries management and improving decision-making. This approach also highlights the value of incorporating Indigenous perspectives to address ecological challenges and ensure sustainable outcomes. In this context, combining historical perspectives with model-based methods allows for a deeper understanding of how marine ecosystems and fisheries are changing, especially in response to climate change.

By integrating scientific and local knowledge, as discussed by Gianelli et al. (2021), the approach supports adaptive management practices that are more responsive to evolving environmental conditions. This collaboration is essential because it helps bridge the gap between historical data, which can reflect past trends, and real-time observations, enabling more effective

decision-making in the face of shifts that go beyond historical norms in SSF. Yet, at the same time, it is important to observe how people and governments work together to provide public services, like water management in Ecuador (Goodwin, 2019). The paper discusses how partnerships between local communities and governments have shifted over time, from a sense of collective ownership towards occasional resistance to state control. This shift highlights the complex interplay between technical expertise and political factors in co-production efforts. While technical knowledge is essential for effective service delivery, the political dimensions, including issues of power, autonomy, and governance, are equally critical. The author emphasizes the need for further research to explore these complexities, particularly to understand how co-production can balance local autonomy with state involvement in managing public goods and services, fostering better outcomes while addressing potential conflicts.

Muhl et al. (2023) build on this discussion by emphasizing the importance of information sharing, data sovereignty, and recognizing diverse knowledge systems in collaborative governance. They argue that co-production should not be reduced to merely technical or instrumental challenges, such as optimizing resource management or improving efficiency. Instead, the processes involved in co-production must be understood as deeply entwined with issues of knowledge, power, and governance. In coastal and marine governance, this means acknowledging the different forms of knowledge and ensuring that these diverse perspectives are valued equally. The authors underscore that the relationships between knowledge production and political dynamics can either empower or marginalize certain groups, influencing the outcomes of co-production efforts. As such, they advocate for ongoing reflection, critical engagement, and research to ensure that co-production leads to just, equitable, and ecologically sustainable governance, particularly in complex and contested spaces like coastal ecosystems. This continued examination is necessary to balance the interests of various stakeholders and to ensure that governance models are both inclusive and effective in addressing environmental challenges.

Expanding on this, Honeybun-Arnolda et al. (2024) introduce the concept of "ecologies of co-production," emphasizing the need to understand co-production as a dynamic, multi-layered process influenced by a range of ecological, social, and political factors. They highlight that co-production cannot be understood in isolation but should be viewed within broader ecological and historical contexts that shape the relationships between stakeholders. This view aligns with Muhl

et al.'s emphasis on the need to consider power dynamics and governance structures when co-producing knowledge, acknowledging that ecological change and human action are deeply interconnected in the Anthropocene.

Käyhkö et al. (2025), on the other hand, examine the institutionalization of knowledge co-production in sustainability research, focusing on how co-production practices are becoming more formalized and integrated into institutional frameworks. This formalization process, however, raises concerns about how certain knowledge systems may be institutionalized at the expense of others, potentially marginalizing local or Indigenous knowledge in favour of more dominant scientific or governmental perspectives. The notion of co-production being not just a technical or instrumental process but one that involves careful consideration of the relationships between knowledge, power, and governance is reinforced. And this calls for continued critical engagement with the institutional and ecological dimensions of co-production, advocating for governance models that are not only equitable and inclusive but also adaptable to the changing realities of environmental challenges. Hence, ongoing research and reflection are essential to ensuring that co-production practices remain just, ecologically sustainable, and capable of addressing the complex, multi-dimensional challenges of the Anthropocene.

2.3 Society – Technology Interface

Pinch and Bijker's seminal paper (1984) lays the foundation for understanding the social construction of both scientific facts and technological artifacts. Their work emphasizes that technology is not merely the outcome of scientific advancement but is deeply embedded within social processes, cultural values, and societal beliefs. By illustrating the mutual influence between society and technology, they argue for an integrated approach that considers social factors as integral to technological development. This perspective challenges the traditional view that technology is an autonomous force, instead suggesting that technological artifacts are co-constructed by societal needs, interests, and conflicts. The authors advocate for an interdisciplinary approach, bridging the gap between the sociology of science and the sociology of technology, to more holistically understand the society-technology interface.

Building on the ideas of societal influence on technology, Latour (1992) delves into the concept of anthropomorphism in technological systems, where human actions and responsibilities are delegated to nonhuman entities, such as machines. Latour's analysis centers on the interactions

between human and nonhuman actants, exploring how competences are distributed among them. This approach highlights the complexities of ensuring that machines and technological systems perform tasks as intended, acknowledging the significant role nonhuman actors play in shaping social dynamics. Latour argues that to fully understand societal processes, sociological analysis must extend beyond human actors to include nonhuman entities. His work underscores the importance of recognizing the impact of technology on human actions and social structures, advocating for a nuanced and inclusive approach to studying technological systems.

Feenberg (1999) approaches the relationship between technology and society from a democratic perspective, critiquing views that regard technology as an autonomous force driven by efficiency and rationality. He argues that technology is deeply intertwined with social and historical contexts, and its development should be understood within these frameworks. Feenberg emphasizes the importance of recognizing the roles various actors play in shaping technological systems and the meanings attributed to technology in everyday life. His work explores the political implications of technology, advocating for the democratization of technological control to enable more inclusive and socially conscious decision-making processes. Feenberg concludes by suggesting that reevaluating technology within a democratic framework could lead to more equitable and socially responsible technological development.

Dorward et al. (2003) bring a practical perspective to the discussion by examining the interconnected roles of markets, institutions, and technology in livelihood development and poverty reduction. They describe markets as mechanisms for resource allocation, which often fail to serve the needs of the poor due to systemic inefficiencies. Institutions are portrayed as the “rules of the game” that shape behaviors, with weak institutions in rural economies leading to high transaction costs and limited market access. Technology is identified as a critical driver of development, influencing both institutional arrangements and livelihood activities. The authors advocate for a holistic approach that integrates markets, institutions, and technology to effectively enhance economic growth, support sustainable livelihoods, and reduce poverty. Their work emphasizes the importance of understanding the broader social and economic context in which technology operates and the need for coordinated efforts to address the challenges of development.

Later, Luna-Reyes et al. (2005) advance the discussion by proposing that information systems development should be seen as an emergent socio-technical change rather than a linear technical process. Using a practice-oriented approach, they argue that information systems evolve through continuous interactions between people (society) and technologies. Hence, technology and society are seen as dynamically co-evolving, making the development of agricultural information systems inherently unpredictable and context dependent.

Following this, Mackrell, Kerr, and Von Hellens (2009) offer a concrete, empirical case study from the Australian cotton industry that further emphasizes the socio-technical nature of decision support systems. They show that even when technically sound agricultural systems are introduced, social factors such as farmers' values, trust in technology, and community norms heavily influence adoption and usage. Their qualitative findings provide a real-world extension of both Dorward et al.'s concern with broader structures and Luna-Reyes et al.'s emergent perspective by demonstrating how farmers' perceptions, peer influence, and institutional interactions shape technology use in complex, lived ways.

Moving forward, Hariyanto and Anwar (2019) take a more formal socio-technical systems approach to the development of agricultural information systems. They argue that any design process must simultaneously consider technical requirements and social contexts from the beginning. Their work emphasizes structured methodologies that involve farmers and stakeholders early and throughout the design and implementation phases. This represents a shift from merely studying socio-technical interactions to actively embedding socio-technical thinking into system design practices, thereby operationalizing the earlier theoretical insights.

Most recently, Durán et al. (2023) conducted a systematic review of literature on socio-technical transitions in sustainable agriculture across Latin America and the Caribbean and argued that successful agricultural transformation requires coordinated changes across technologies, societal practices, and institutional frameworks. Their review supports the idea that piecemeal technological fixes without systemic social change are ineffective. Similarly, Manning (2024) focuses specifically on the barriers farmers face when adopting new technologies, highlighting how uncertainty, lack of trust, knowledge gaps, and systemic inertia limit innovation. Manning's work emphasizes that innovation is as much about navigating complex social systems as it is about inventing new tools.

2.4 Data Commons

The idea of information as a commons began to take serious scholarly shape with the work of Ostrom in *Governing the Commons* (1990). Although Ostrom originally focused on natural resource commons, such as fisheries, forests, and irrigation systems, her foundational ideas on collective action, self-governance, and community-based management laid the intellectual groundwork for thinking about other types of commons, including informational resources. Ostrom challenged the dominant narrative of the "tragedy of the commons," showing that communities could successfully manage shared resources without centralized control or privatization if certain institutional principles (like clear boundaries, participatory decision-making, and conflict-resolution mechanisms) were present. Her framework for sustainable commons governance became a crucial reference point when scholars later turned their attention to the governance of shared information resources.

Building on Ostrom's work, Hess and Ostrom (2003) explicitly extended the commons framework to the realm of information. They argued that information can and should be seen as a type of commons, subject to many of the same governance challenges as physical resources. Information, while non-rivalrous (one person's use does not diminish another's), can still face access restrictions, degradation, and enclosure (e.g., through copyrights or patents). Hess and Ostrom emphasized that access, preservation, and openness are crucial for maintaining the vitality of an information commons. Their work initiated serious academic discussions about how digital knowledge, research data, and cultural artifacts could be managed collectively and sustainably, much like fisheries or forests.

These foundational works paved the way for more practical explorations of how to govern information commons, leading to the contributions of Fisher and Fortmann (2010). In their paper, they focus specifically on data commons, shared repositories of scientific data, and investigate various governance models (centralized, decentralized, community-based). They highlight critical challenges such as ownership rights, access policies, data quality assurance, and privacy protection. Importantly, Fisher and Fortmann apply Ostrom's design principles, such as clearly defined boundaries, monitoring mechanisms, and fair conflict resolution processes, to the management of data commons, demonstrating how lessons from natural resource commons can inform and enhance the collective stewardship of information. Their work marks a significant

step from theoretical discussions toward actionable strategies for building information commons that support collaboration, innovation, and scientific progress.

Further, Gurstein's paper (2011) "Open Data - Empowering the Empowered or Effective Data Use for Everyone?" critically examines the open data movement, questioning whether it genuinely benefits everyone or primarily empowers those with existing resources and technical skills. Gurstein argues that while open data has the potential to democratize information, it often reinforces existing inequalities. He emphasizes the need for a focus on "effective data use," which involves ensuring that all communities, particularly marginalized ones, have the necessary tools, skills, and support to utilize open data effectively. The paper advocates for policies and practices that make open data truly inclusive and beneficial for all, challenging the assumption that open data alone can lead to equitable outcomes.

Later on, Leonelli's paper (2013) delves into the concept of data commons within the Open Data movement, stressing the importance of making scientific data publicly accessible for broad reuse to advance knowledge creation. The paper highlights the multifaceted challenges involved in establishing data commons, including the need for robust regulatory frameworks, social and material infrastructures, and coordination among diverse stakeholders. Leonelli underscores the critical role of data scientists in curating and managing data, noting that their contributions are increasingly recognized as essential to scientific research. The paper also addresses the global political economy surrounding data, pointing out how open dissemination contests traditional views on competition, property, and privacy, particularly in sectors like pharmaceuticals and agriculture. Additionally, it discusses the financial and social costs of data sharing and the ongoing efforts to develop self-sustaining models for maintaining data repositories, emphasizing the need for sustainable solutions to support the infrastructure of data commons.

While Christine L. Borgman's book (2017) examines the evolving role of data in scholarly research, focusing on issues of data privacy, ownership, and misuse through case studies across various disciplines. Borgman highlights the growing risks associated with data digitization, especially in sensitive fields such as social sciences and healthcare, and stresses the need for ethical safeguards. The book explores the complexities of data ownership, revealing tensions between open access and control over research data, with particular concern about potential commercial exploitation. Borgman warns of the risks of data misuse and urges researchers to

carefully consider the ethical implications of their data practices. Throughout the book, she advocates for interdisciplinary collaboration, improved data management practices, and a cautious approach to data use, underscoring its broader social and ethical implications.

Baarbé, Blom, and De Beer's paper (2019) proposes the creation of an "Agricultural Data Commons" to improve food security in Africa. This concept involves establishing a shared, open-access repository of agricultural data for various stakeholders, including farmers, researchers, policymakers, and agribusinesses. The paper elaborates on how a data commons can address issues such as fragmented data and limited access, offering potential benefits for food security through enhanced decision-making and innovation. It also discusses challenges related to data ownership and governance and provides policy recommendations to support the development of such initiatives. The emphasis is on collaboration and the establishment of robust legal frameworks to facilitate effective and sustainable data sharing.

Advancing on this knowledge, Fairbairn and Kish (2023) dove deeper into the politics of open data and its implications for food and agriculture, and discuss how the release of agricultural data into the public domain, while beneficial for innovation and transparency, also involves complex political dynamics. For instance, corporate interests often shape data governance structures, potentially leading to privatization or restricted access. They argue that the "freedom" of data is not as straightforward as it seems and that open data initiatives must be carefully structured to ensure equitable benefits for all stakeholders, particularly small-scale farmers.

Most recently, Gil et al. (2025) developed a concept of sovereignty by design and argued that data systems in agriculture must be designed with respect to local sovereignty, recognizing the rights of local communities, farmers, and countries to control and benefit from their data. Their approach acknowledges the potential risks of data colonialism, where powerful global entities dominate agricultural data governance. They advocated for systems that center human values, like fairness, transparency, and participation, ensuring that agricultural data systems are inclusive and just.

2.5. Inference

Across the reviewed bodies of work, a strong convergence emerges around the importance of inclusive, adaptive, and socially standardized approaches to both environmental governance and

technology-society interactions. In SSF and broader environmental systems, knowledge co-production is recognized as vital for creating resilient and context-sensitive solutions, built on trust, inclusiveness, and iterative learning. Similarly, scholarship on socio-technical systems and information commons emphasizes that technologies, data, and digital infrastructures are deeply embedded in, and shaped by, social, political, and cultural dynamics. Whether in managing fisheries, designing information systems, or governing open data initiatives, a common thread is the call for interdisciplinary, participatory methods that integrate diverse knowledge systems and stakeholder voices. Across environmental, technological, and informational domains, governance is portrayed as a complex, evolving process that must balance technical innovation with social equity, democratic participation, and ethical stewardship.

Yet, despite this theoretical development, significant gaps persist. In knowledge co-production, scholars point to an insufficient grappling with entrenched power dynamics that often marginalize local and Indigenous knowledge systems. Similarly, in socio-technical studies and information commons research, operationalizing equitable governance remains a challenge, with real-world practices frequently falling short of ideals like inclusivity, transparency, and justice. Critical risks, such as the institutional capture of data by powerful interests, the financial and ethical costs of maintaining commons, and the rise of "data colonialism", are increasingly acknowledged but insufficiently addressed in practical governance frameworks. Across all fields, there is a clear need for more context-sensitive, adaptive, and enforceable models that explicitly confront inequalities, center community rights, and embed justice into the design of collaborative systems, whether they are environmental, technological, or informational.

Chapter 3

Methodology

Introduction

This research employed a mixed-methods case study approach to understand how digital systems, can support inclusive, locally relevant, and socially just information practices in SSF contexts. Given the complex, dynamic, and deeply contextual nature of SSF SES, where environmental, technological, and institutional factors converge, this methodological framework was chosen to capture both breadth and depth of understanding. The research integrated structured surveys, in-depth interviews, and participant observation to document stakeholders' perceptions, experiences, and interactions with the Information System platform. Drawing on both qualitative and quantitative strategies, and informed by ethnographic sensibilities, the study prioritized contextual immersion, reflexivity, and co-produced knowledge. This approach was aligned with the goals of a larger Social Sciences and Humanities Research Council (SSHRC) funded project, which seeks to support transitions from vulnerability to viability (V2V) in SSF through participatory, locally grounded, and justice-oriented research. The following sections describe the detailed methodological approach followed, including the study area, research design, methods, data analyses and limitations of the study.

3.1. Study Area

The Sundarbans, situated at the confluence of the Ganges and Brahmaputra Rivers across Bangladesh and India, constitute the world's largest contiguous mangrove forest ecosystem (Gopal and Chauhan, 2006). Spanning approximately 10,000 km², the region comprises nearly 200 islands interwoven by an intricate network of tidal rivers, creeks, and canals. About two-thirds of the Sundarbans lie in Bangladesh, while the remaining one-third is located in India (Mandal et al., 2019; Sen and Ghorai, 2019). This dynamic deltaic landscape is home to over seven million people, many of whom are deeply dependent on capture fisheries and other forms of SSF as primary sources of livelihood and subsistence (Pattanaik, 2021). SSF in the Sundarbans are diverse, ranging from traditional, low-capital, labour-intensive methods to more modern and mechanized practices. These fisheries contribute significantly not only to local and

regional food security and income but also to national economies, particularly in the context of developing countries (Chuenpagdee et al., 2005; Berkes & Nayak, 2018). However, the socio-ecological system of the Sundarbans faces growing stress due to a confluence of environmental and anthropogenic pressures. Climate change-related threats such as sea-level rise, salinization, and increased frequency of extreme weather events are compounded by unsustainable practices including overfishing, oil spills, and pollution from industrial effluents (Pattanaik, 2021; Islam, 2019). These stressors have led to critical challenges such as increased poverty, loss of livelihoods, human-wildlife conflict, illegal resource extraction, and even forced displacement in some areas (Inskip et al., 2013; Islam & Chuenpagdee, 2013). Despite these adversities, the persistence of SSF in the region suggests the presence of embedded resilience mechanisms, adaptive strategies, and community knowledge systems that remain underexplored. Recognizing these interlinked vulnerabilities and capabilities, the Sundarbans have been selected as a key research site within the SSHRC funded Vulnerability to Viability (V2V) Global Partnership. The initiative seeks to better understand and support the transition of SSF from conditions of vulnerability toward long-term viability, sustainability, and justice.

Two island villages from the Sundarbans were selected for this study, namely, Samshernagar and Kumirmari (Figure 1). Samshernagar, a village in the North 24 Parganas district of the state of West Bengal, is located in the buffer zone of the Sundarbans Tiger Reserve along the Kalindi and Raimangal Rivers. It has approximately 4,394 people in 1,145 households. It is geographically isolated and is located near the border with Bangladesh. While Kumirmari falls in the South 24 Parganas district of the state, near the Marichjhanpi Reserve Forest (near Sundarbans Tiger Reserve), and is surrounded by the Kurankhali and few other rivers. It has a population of approximately 17,451 in 4,344 households. Both villages are predominantly composed of around 78% Scheduled Caste (SC) populations and with about 8% of Scheduled Tribes (ST) populations. The community relies on agriculture, fishing (including wild captures and individual and community managed aquaculture), honey collection, and daily wage labour for livelihoods. Forest resources, such as fish, crabs, and non-timber products, are crucial to their economies. Located at the fringe of a protected area and sharing the border with Bangladesh, these communities face risks including tiger attacks, sea robbers, storms, cyclones, strict regulations, poverty, and low literacy. Fishing and honey collection from the forest are regulated

by the Forest Department through a Boat License Certificate (BLC), issued annually. Fishing is banned by the authorities annually for three months, typically between April to July, to protect breeding fish and crabs from overfishing. The presence of the Border Security Force (BSF) is prominent due to the sensitive border dynamics, and they play a regulatory role by granting additional fishing permissions to local fishers in order to prevent cross-border illegal activities. The local communities' livelihoods are deeply intertwined with mangrove ecosystems, relying on oral traditions passed down through generations, where knowledge encompasses understanding of tidal patterns, lunar cycles, and species behavior, which informs sustainable harvesting practices. In response to environmental changes and socio-economic pressures, the communities have adapted their traditional practices, including shifts from prawn seed collection to crab harvesting.

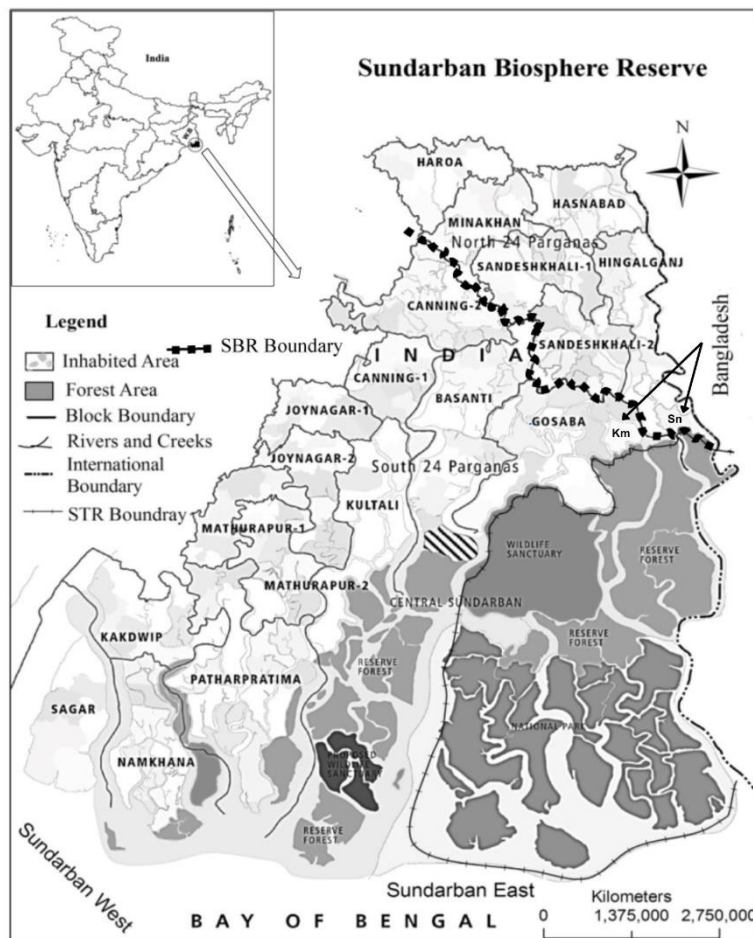


Fig. 1 Map of Study Area: Samshernagar (Sn) and Kumirmari (Km) villages of the Sundarbans Biosphere Reserve (adapted from: Mistri and Das, 2015)

3.2. Research Design

A mixed methodology was employed in this research. Mixed methods research is especially useful for studying complex systems where no single method can capture all dimensions of the issue. In the context of SSF, characterized by ecological uncertainty, livelihood vulnerability, and dynamic socio-institutional settings, mixed methods allow researchers to integrate quantitative data (e.g., patterns of resource use) with qualitative insights (e.g., cultural practices and institutional interactions). This combination supports a more comprehensive understanding of SSF systems and informs more context-sensitive and effective interventions (Creswell & Clark, 2011).

The quantitative component of this study employed structured surveys and interviews to systematically gather data on participants' experiences and expectations regarding the V2V-IS. Structured surveys are effective for collecting standardized data that can be measured and compared across different groups or time periods, facilitating the identification of patterns and trends. Moon and Blackman (2014) emphasize that such methods are particularly useful when researchers aim to test hypotheses or quantify variables within complex systems, as they allow for the collection of data that can be subjected to statistical analysis. In the context of SES, Shackleton et al. (2021) highlight that structured interviews and surveys can provide valuable insights into stakeholders' knowledge, perceptions, and behaviours. These methods enable researchers to capture a broad range of information from diverse participants, ensuring that the data reflects the multifaceted nature of human-environment interactions. By employing structured approaches, the study ensures consistency in data collection, which is crucial for comparing responses and drawing meaningful conclusions about the usability and perception of the V2V-IS among different user groups.

The qualitative component of this study involved conducting in-depth interviews and participant observations to explore the social and cultural dimensions that shape the adoption and use of the V2V-IS technology. According to Legard, Keegan, and Ward (2003), in-depth interviews allow researchers to access rich, detailed narratives by encouraging participants to share their experiences, perspectives, and meanings in their own words. This method is particularly effective in uncovering complex social processes, interpersonal relationships, and cultural

contexts that are not easily captured through structured instruments. Participant observations complemented the interviews by enabling the researcher to witness everyday practices, interactions, and environmental settings, thereby providing contextual grounding for the participants' accounts.

A case study' research design was adopted (Gerring, 2006) to investigate the use and perception of the test version of the IS in two villages in the Sundarbans region. Case studies are particularly suited for research that seeks to understand complex, context-dependent phenomena, where the boundaries between the phenomenon and its real-life setting are not clearly defined. In line with Gerring's emphasis on depth, richness, and contextual understanding, the case study approach enabled this research to capture the situated experiences of small-scale fishers and other stakeholders as they engaged with the V2V-IS platform. This method allowed for an in-depth exploration of the interplay between digital technology and the socio-ecological realities of coastal communities, providing insights into how such systems are integrated into everyday life and decision-making processes.

While not framed as a full ethnography, this study employed ethnographic approach throughout its fieldwork to complement structured survey and interview methods. These included participant observation, informal conversations, detailed field notes, photo documentation, and reflexive journaling. Such practices enabled deeper engagement with the everyday realities, social hierarchies, and cultural logics shaping the use and perception of the Information System. This ethnographic orientation was particularly valuable in understanding small-scale fishers' interactions with digital tools within their lived socio-ecological contexts. As Watson and Till (2010) emphasize, ethnography is not simply a method of data collection but a relational and reflexive way of knowing that allows researchers to explore how spatial and social processes are experienced on the ground. In line with their approach, this study prioritized embeddedness in local contexts and the ethical representation of all voices. Ethnographic attention also informed the revision of interview prompts and enriched the interpretation of data, allowing the research to move beyond surface-level responses and engage with underlying social logics, tensions, and power dynamics. This orientation was consistent with the researcher's commitment to positional reflexivity, ethical sensitivity, and amplifying local knowledge in the process of co-producing more just and contextually grounded understandings of SSF governance and digital inclusion.

Participants were identified using snowball sampling (Hay & Cope, 2021), a technique often employed in qualitative research when studying hard-to-reach or closely networked populations. This method relies on initial contacts who then refer researchers to further participants, helping to build trust and access within the community. It was particularly effective in the Sundarbans context, where formal participant lists were unavailable and trust-based relationships were essential for engagement. While snowball sampling can introduce sampling bias by potentially limiting diversity to the social networks of initial informants, this risk was mitigated by initiating multiple referral chains across different social and occupational groups, including small-scale fishers, NGO staff, government officials, and researchers, to capture a broad range of perspectives on the usability and relevance of the Information System platform.

This research was conducted as part of the Social Sciences and Humanities Research Council (SSHRC)-funded Vulnerability to Viability (V2V) Global Partnership, a transdisciplinary initiative that examines the persistent challenges confronting SSF across Asia and Africa. SSF communities often operate within complex social–ecological systems that are under pressure from environmental change and globalizing forces (Chuenpagdee, 2011), which are exacerbated by a lack of reliable information systems to support decision-making (Nayak, 2017; Dias et al., 2023). Such vulnerabilities are often intensified by structural inequalities, including gendered and power-laden relations that shape whose knowledge is valued and whose interests are represented in fisheries governance (Dias et al., 2023). In response to these challenges, this research contributed to the development and piloting of the V2V-Information System (V2V-IS), a mobile and web-based digital platform designed in collaboration with the Indian Institute of Technology (IIT) – Kharagpur. The V2V-IS aims to integrate locally relevant knowledge and case studies, support real-time monitoring, and enable inclusive, informed decision-making among SSF stakeholders. Ultimately, the system is envisioned as a knowledge-sharing tool that enhances communication across fisher communities, researchers, NGOs, and policymakers, thus supporting the broader transition of SSF from conditions of vulnerability toward viability.

To guide its initial design, a structured development process was followed by researchers at IIT-Kharagpur, beginning with a review of existing V2V literature and field-based needs assessments in Chilika (Odisha), India. Insights from various stakeholders informed the system’s architecture, leading to the development of a flexible, scalable platform with secure access,

multimedia data entry, and metadata tagging. Built using technologies like HyperText Markup Language (HTML) as basic building block of web pages, a server-side scripting language Hypertext Preprocessor (PHP), MySQL which is a database management system, and Flutter which is an open-source toolkit by Google for building mobile apps, the system was designed for both web and mobile use (Figure (i)). A trial version (Figure (ii)) was prepared for iterative refinement based on user feedback for its improvement according to local contexts and stakeholder priorities.

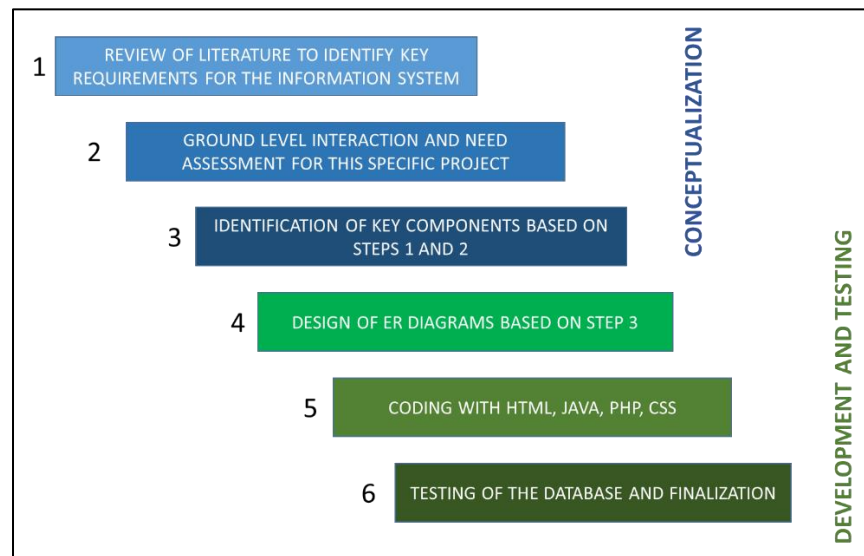


Fig. (i) Steps followed in the V2V-IS development

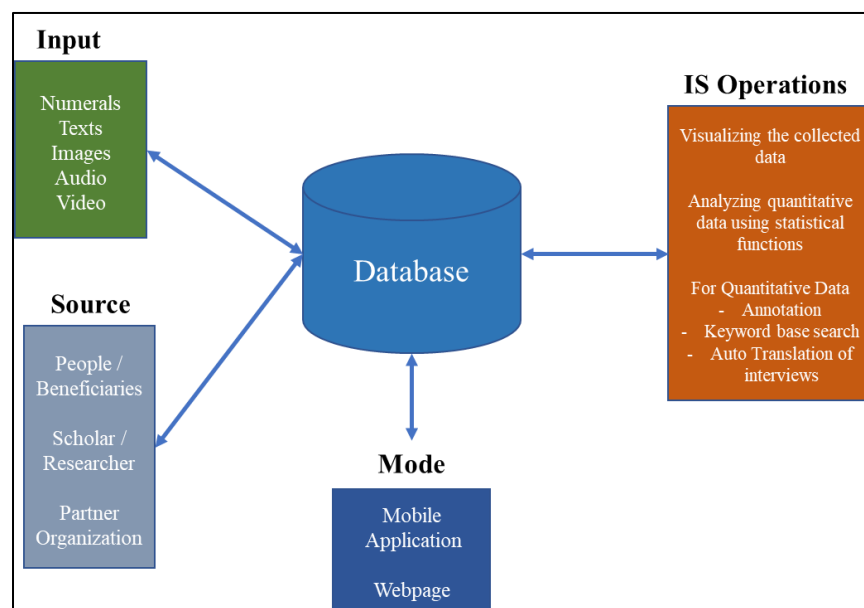


Fig. (ii) Schema of V2V-Information System

During fieldwork, a video of the trial version of the V2V-IS mobile application (see Figure 2) was demonstrated to participants at the beginning of each session. This demonstration served to familiarize participants with the purpose, structure, and functions of the application, such as how to access fisheries-related information, use location-based services, or navigate menus and features relevant to small-scale fishers. Ensuring this initial understanding was important not only to gather informed feedback but also to help participants engage meaningfully with the technology being assessed. Following the demonstration, data collection was carried out through in-person surveys and semi-structured interviews. This allowed the researcher to clarify questions, observe participant reactions, and adapt follow-up prompts in real time. Digital tools were used to support data collection, including mobile-based recording of survey responses, audio recordings of interviews (with consent), and photographic documentation of interactions or relevant field settings. This approach helped collect more detailed information and made sure important spoken and visual content was saved for later analysis.

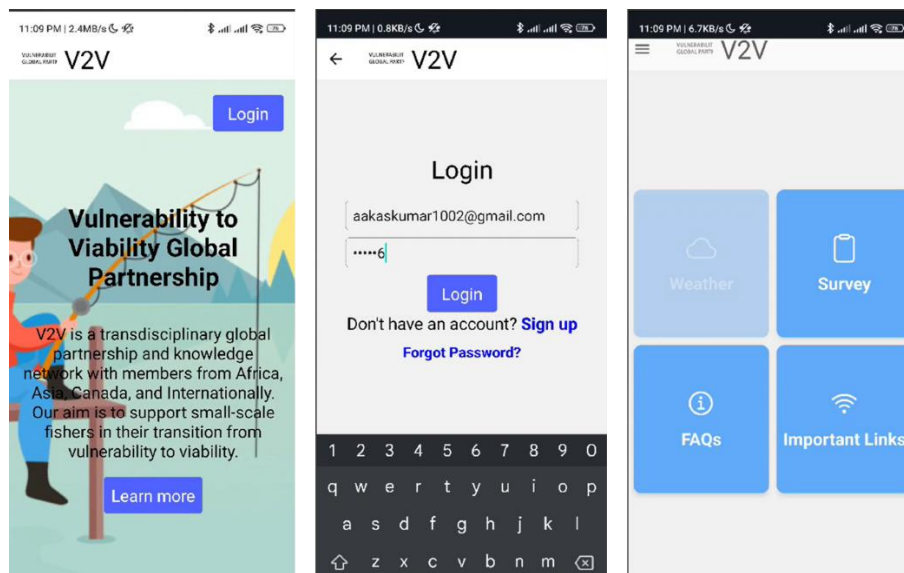


Fig. 2 Snapshot of the test version of the V2V-IS that was demonstrated to the research participants before the questionnaire and interview

To ensure methodological rigour and trustworthiness in the research process, a range of mixed-methods strategies were adopted. Purposeful sampling was used to select participants who were most knowledgeable about the local fisheries and technology context in the Sundarbans, ensuring depth and relevance of the data (Creswell & Creswell, 2018). A pilot study was conducted to refine interview protocols and survey instruments for clarity and cultural appropriateness. A field

journal was maintained throughout the research to record field notes, contextual observations, and reflections, enabling ongoing critical assessment of the research process. Rigour was further enhanced through peer consultations with subject experts and local researchers, which supported the interpretive credibility of the findings (Baxter & Eyles, 1997). Triangulation, using multiple data sources such as interviews, surveys, participant observations, and photographs, was employed to strengthen the validity of the findings by cross-verifying evidence. Reliability was addressed through transcript verification (respondent validation) and systematic coding procedures, ensuring consistency and transparency in data analysis (Creswell & Creswell, 2018).

A reflexive approach was central to the research design. Reflexive memos were maintained to record positionality, interpretive challenges, and evolving theoretical insights, promoting both transparency and ethical sensitivity (Baxter & Eyles, 1997). These memos helped in minimizing researcher bias and aligning findings with the overarching research objectives. As a married Indian woman from a conservative Bengali Brahmin family, the researcher's perspectives on sustainability and justice are shaped by lived experiences of gendered and professional variations. These experiences inform her sensitivity to power dynamics and social hierarchies in fieldwork, particularly when engaging with marginalized communities such as small-scale fishers. While her cultural familiarity and language ability facilitated trust-building and deeper understanding during fieldwork, her affiliation with a western academic institution positioned the researcher as a partial outsider. This dual identity necessitated constant reflexivity about insider–outsider dynamics, power asymmetries, and their influence on knowledge production. In this context, mindfulness of ethical responsibilities was practised, ensuring voluntary participation, informed consent, and respectful engagement throughout. Field interactions were approached with humility and a commitment to amplifying local voices rather than imposing external narratives.

In line with Creswell and Creswell's (2018) guidance, the qualitative analysis in this study employed both inductive and deductive approaches. An inductive strategy was used to allow patterns, themes, and categories to emerge naturally from the data, reflecting the participants' lived realities without being constrained by pre-existing frameworks. This approach ensured that the research remained open to unexpected insights and local nuances. Simultaneously, a deductive approach was applied by using theories and concepts identified during the literature

review as a lens to interpret the data. This dual strategy enhanced the depth and coherence of the findings, balancing openness to emergent understandings with attention to established knowledge about technology adoption and small-scale fisheries dynamics.

Ethical Considerations

This study adhered to the formal ethics process in accordance with the research ethics clearance guidelines established by the University of Waterloo's Office of Research Ethics (REB #46541 Ethics Clearance Certificate). The researcher completed the TCPS 2: CORE 2022 training prior to conducting fieldwork. For this work, she ensured that all participants' consent, voluntariness, and socio-cultural values were respected, even though the research was conducted outside of Canada. She was responsible for safeguarding participant identities and maintaining the confidentiality of all sensitive information. Informed consent was obtained from all participants before beginning data collection, which included participant observation while using the V2V-IS prototype, audio recording, photography, and the handling and reporting of confidential data.

3.3. Methods

Fieldwork was conducted between September and October 2024, with intermittent travel from Kolkata, West Bengal, to the selected villages. Prior to field deployment, the researcher collaborated with researchers at IIT-Kharagpur to plan logistics and refine data collection tools. Local contacts in the Sundarbans played a critical role in organizing accommodation, identifying entry points into communities, and coordinating travel across challenging terrain that included roadways, railways, and waterways. The researcher stayed with a tribal family in Samsbernagar, experiencing firsthand the realities of living in an ever-changing mangrove ecosystem. Despite environmental challenges such as heavy rains, high humidity, mosquito prevalence, and drinking water scarcity, the warmth and hospitality of the hosts deeply enriched her fieldwork experience. While the hosts consumed locally available water, the researcher was given packaged water due to different gastrointestinal capacities. In contrast, her stay in Kumirmari was more comfortable, with accommodation provided at a local NGO guesthouse, which offered private amenities and a consistent supply of electricity and water.

The study adopted a snowball sampling method, involving 55 participants representing a diverse range of stakeholders, including fishers, NGO workers, government officials, and academics. Preparation included engaging with NGOs and research institutions to identify appropriate participant categories, selecting initial contacts, and developing and piloting survey and interview instruments. Data collection was conducted in two phases. In the first phase, demographic information and Likert-scale responses were collected via structured surveys (Appendix 2: Survey and Interview Questions). This was followed by in-depth interviews that explored participants' perceptions, experiences, and interactions with information systems in their fishing-based vocations, along with an evaluation of the V2V-IS test application. Participant observations further complemented these insights by revealing socio-cultural nuances and everyday practices associated with technology use. This multi-pronged approach ensured the collection of rich, triangulated data from field settings embedded in the complex and dynamic context of the Sundarbans.

3.4. Data Analysis

The study employed a convergent parallel mixed-methods approach to data analysis, aligning with recommendation for integrating quantitative and qualitative findings to yield a comprehensive understanding of complex social phenomena. In this design, quantitative and qualitative datasets were analyzed independently using appropriate tools and techniques and then interpreted together to draw cohesive and integrated conclusions about the use, perception, and socio-institutional relevance of the V2V-IS among small-scale fishers in the Sundarbans.

Quantitative Analysis

Quantitative data, primarily gathered from structured survey responses, including demographic variables and Likert-scale items, were processed using Microsoft Excel. Charts were generated to illustrate the profile of the participants and the frequency of test application usage. These visualizations highlighted the evaluation of the test application by the participants. Basic descriptive statistical methods were applied to identify patterns related to system access, usage frequency, digital literacy levels, and typical demographic indicators. These numerical summaries helped in understanding general trends and variations across participant groups, as

well as identifying key associations between demographic factors and the perceived utility of the information system.

Qualitative Analysis

Qualitative data collected through in-depth interviews, participant observations, and field notes were systematically analyzed using NVivo software (version 15). The analysis followed a structured coding process as outlined by Adu (2019), designed to generate rigorous and transparent findings through progressive interpretation of the data. The analysis began with a familiarization phase, where all transcripts and observation notes were read multiple times to gain an in-depth understanding of participant perspectives and contextual nuances. This immersive step allowed for the researcher to identify recurring patterns, emotive expressions, and culturally specific terms that would inform the next stages of coding.

Following familiarization, an iterative coding process was applied. This involved segmenting the qualitative data into meaningful units and assigning them descriptive codes. Initial codes were generated inductively from the data while also guided by predefined concepts related to SSF, digital technology adoption, and livelihood strategies. NVivo's tools were used to highlight, categorize, and tag data segments systematically across transcripts. Subsequently, codes were organized hierarchically into broader themes, enabling the identification of relationships among the codes and facilitating thematic categorization. This step involved the clustering of similar codes under overarching themes. These themes were reviewed and refined to ensure consistency, coherence, and alignment with the research questions. Throughout the process, analytical memos were used to document the rationale behind coding decisions, reflect on emerging insights, and address potential biases. This reflexive practice contributed to research transparency and strengthened the trustworthiness of the findings.

3.5. Limitations of the Study

While this study was carefully designed to capture the complex realities of small-scale fisheries in the Sundarbans and the implementation of the V2V-IS, some limitations must be acknowledged.

- (i) The fieldwork for the research had to be limited to just one month (September–October 2025), which constrained the researcher's ability to include a higher number and cross-sections

of participants. These temporal constraints may have limited the depth of insight into long-term socio-ecological dynamics and adaptation strategies.

- (ii) The research, being a masters' thesis requirement, had to be confined to two island villages, which, although chosen for their ecological and socio-economic relevance, may not fully represent the diversity of SSF experiences across the broader Sundarbans delta. Variations in institutional access, infrastructural development, and exposure to digital technologies across other parts of the region may limit the generalizability of the findings.
- (iii) The socio-economic structure of the communities, including high poverty levels, low literacy rates, and dependency on volatile natural resource-based livelihoods, created difficulties in discussing more technical and comprehensive aspects of the trial IS design and information governance. Despite efforts to translate and contextualize research instruments, lower levels of digital literacy and exposure to advance technologies among participants occasionally constrained their ability to fully engage with the V2V-IS demonstration or provide detailed feedback.
- (iv) The use of snowball sampling, though effective in accessing hard-to-reach and closely networked populations, carries inherent risks of sampling bias. Although multiple referral chains were initiated to mitigate this, there remains the possibility that certain voices, particularly those less socially connected or more marginalized, were underrepresented in the dataset.
- (v) The technical demonstrations of the V2V-IS mobile app were conducted using a video of the same. While useful for eliciting participant feedback, this version may not have fully captured the functionality or usability of a functional digital system. As such, participant evaluations may have been based on perceived potential rather than sustained engagement with a workable platform.

Chapter 4

Interactions with Knowledge, Technology, and Governance in Sundarbans

Introduction

This chapter presents the findings of the study that investigated how social, cultural, and institutional factors influence small-scale fishers' engagement with knowledge, technology, and governance in the Sundarbans, as well as the systemic challenges that impede the effective adoption of advanced technologies. The results are organized around key thematic areas, including the culturally and linguistically grounded knowledge systems that underpin fishing practices; market dynamics and trade-related challenges affecting fisher livelihoods; the role of institutional support and governance mechanisms; gendered dimensions of participation and access; and the impact of ongoing environmental and political changes shaping adaptation strategies. Together, these findings illuminate the complex interplay between traditional ecological knowledge, socio-economic pressures, regulatory frameworks, and emerging technological interventions, highlighting both opportunities and barriers faced by Sundarbans fishers in sustaining their livelihoods amid rapid ecological and socio-political transformations. This contextual understanding provides the analytical foundation for the framework developed in this study, ensuring that the development of the information system remains embedded in local realities and responsive to the specific needs and constraints identified.

4.1. Knowledge Needs and Sources

4.1.1 Culturally & Linguistically Relevant Knowledge: Traditional knowledge in the Sundarbans is deeply integrated with fishing practices, passed down through generations, and interwoven with spiritual beliefs, such as reverence for *Bonbibi* (the local forest deity), and oral customs surrounding these beliefs. Fishers possess highly specialized knowledge of fish behaviour, migration patterns, and breeding seasons. They rely on environmental cues, including wind direction, tidal rhythms, and lunar cycles, to make fishing decisions. Techniques such as setting traps, locally known as *doon*, in shallow waters and catching crabs by wading through estuarine channels demonstrate their deep ecological awareness. Fish farmers apply this knowledge to cultivate fish, prawns, and crabs in individually or community-owned ponds, locally known as *khaal*, using a mix of saltwater from the rivers and freshwater from deep underground sources. They also understand and abide by the annual three-month fishing ban

imposed by the forest department, which is crucial for the revival of Sundarbans's biodiversity. Shared through informal networks and formal guidelines, this knowledge is crucial for navigating the environment, understanding ecological patterns, and resource gathering.

However, modernization, frequent environmental disasters, declining fish stocks, and external regulatory pressures are disrupting these knowledge systems. Also, the youth are increasingly moving away from SSF, due to its uncertainty in providing stable livelihood. Market-driven fishing practices and legal restrictions often conflict with traditional conservation ethics, leading to overexploitation and the gradual erosion of traditional fishing methods. To balance sustainability with livelihood needs, training in modern aquaculture techniques, crab farming, and sustainable wild capture practices were identified to be adapted to local language, literacy levels, and cultural nuances. This would ensure that fishers can adopt new techniques without losing their cultural identity. Many fishers, researchers and NGO workers emphasized that informal networks and experiential learning remain vital and can effectively complement scientific knowledge. Researchers also highlighted the challenges of gathering region-specific data on SSF, particularly in disaster-prone areas, advocated for a centralized digital platform that consolidates academic publications, meteorological data, and disaster reports to enhance research on environmental impacts. Merging local knowledge with applied information on soil, water and ecological sciences, along with waste management methods in helping these SSF towards profitability was identified by researchers and NGO members.

A critical challenge faced by fishers is the lack of accurate, early warning systems, as forecasts often fail to account for local variations. Due to limited literacy levels, most fishers rely on local communication networks, such as announcements from forest staff and local authorities or radio broadcasts. They are not allowed to carry any mobile phones (to seek help in emergencies) and large knives (to protect themselves) during fishing trips of seven to eight days in the forest. To protect themselves from sudden cyclones, tigers, snakes, crocodiles, and even sea robbers, they rely on the strong-rooted *Rhizophora mucronata* (*garjan*) trees or hide in narrow channels (also called *khaal*). They use ethnic medicines derived from forest resources (e.g., the juice obtained from the *dudul* tree or *Tetrameles nudiflora* to treat wounds, fever, digestive issues etc.) for illnesses and injuries. Integrating this traditional knowledge into modern safety and communication tools is also believed to enhance resilience and preparedness.

Some fish farmers in the study villages have begun integrating traditional ecological knowledge, gained through years of experience and passed down through generations, with modern aquaculture techniques introduced through NGO workshops, government programs, or personal experimentation. These farmers often learn through peer-to-peer exchange within their communities, observing the practices of neighbours or relatives and adapting successful methods. In some cases, they also consult with fisheries extension officers, local researchers, or NGO personnel to refine their techniques or troubleshoot challenges such as disease outbreaks or water salinity issues. However, despite their willingness to innovate and adapt, they face a critical gap: the lack of easily accessible, high-quality resources that are tailored to their local environmental conditions, cultural context, and literacy levels. Existing resources are often too technical, not available in the local language, or generalized to broader regions, making them less useful for the specific challenges faced in the Sundarbans. As a result, many of these fish farmers have expressed a clear demand for a user-friendly, localized system, ideally in Bangla and possibly multimedia-based, that could provide practical, timely, and place-based guidance on pond management, disease control, feed practices, and market access.

4.1.2 Market & Trade Insights: In Samsdernagar and Kumirmari villages, fishers sell their catch from the forest, and individual and community-managed ponds in local markets, known as *khuti*, or directly to fish traders. Crabs, often immature or underweight, are bought at lower prices and stored in specially designed water enclosures, where they are allowed to grow until they reach a more marketable and profitable size. Despite understanding the ecological consequences, fishers are forced to harvest immature crabs due to the sharp decline in fish and crab populations and the need to sustain their livelihoods. This unsustainable practice, combined with daily price fluctuations, further reduces their earnings as they are often compelled to sell at rates below market value.

A major challenge fishers face is the lack of access to reliable, real-time market data, which severely limits their ability to negotiate fair prices. Without a centralized platform or union to provide up-to-date information, they remain vulnerable to price manipulation by intermediaries. Some rely on informal communication channels, such as WhatsApp groups or unorganized local community networks, to receive market updates, but these sources are often inconsistent and

unreliable. The absence of market transparency, limited opportunities to adopt sustainable fishing practices, and unpredictable price variations contribute to economic instability.

To address these issues, fishers, along with NGO workers and researchers, emphasized the need for systems that provide real-time market information, financial resources, platform to form fishers' unions and share new fishing guidelines issued by the administration. Accessible and culturally relevant tools could empower fishers to make informed decisions, negotiate better prices, and improve their economic condition.

4.1.3 Institutional Support: Fisheries management in the Sundarbans seeks to balance sustainability with fisher livelihoods through strict regulations, such as a no-motorized-boat policy and seasonal bans on fishing. However, enforcement remains challenging due to unmonitored BLC rentals offered by non-fishers to poor capture fishers, weak catch data collection, and rising pressure on crab resources as fish populations are in decline. To counter these issues, authorities are promoting alternative livelihoods, such as ecotourism training and handicraft production, recognizing the growing uncertainty in SSF as a long-term economic option. Despite these initiatives, concerns persist that overfishing and weak institutional support will continue to strain the fragile ecosystem, while worsening the social and economic injustice borne by the SSF.

Institutions such as gram panchayats, NGOs, fisheries extension officers, and the forest department play a crucial role in supporting SSF in the Sundarbans through training, resource provision, and policy advocacy. However, existing support systems often fail to address the specific challenges of forest-based fishers who depend on wild aquatic resources like crabs, fish, and honey. Most of the fishers struggle with bureaucratic hurdles in obtaining legal permits in their name and lack access to structured training programs and financial aids tailored to their needs. Limited literacy and technological barriers further complicate their ability to navigate regulatory frameworks and secure fair market prices.

A structured knowledge transfer system is needed, one that blends traditional outreach with advanced tools to ensure timely and relevant information. Strengthening governance frameworks is equally critical, particularly in simplifying permit applications, improving access to legal assistance, and ensuring transparency in market transactions. Digital platforms are expected to

help streamlining information on fishing regulations, catch monitoring, and market rates, reducing dependency on intermediaries who often manipulate prices.

4.2 Gender dynamics

The transcripts highlighted multiple, deeply rooted obstacles faced by women in the capture fishing and aquaculture sectors in the study villages. Although women contribute significantly to both sectors, their participation is often undervalued and confined to supportive or labour-intensive roles such as cleaning fish, preparing nets, or managing household responsibilities. Access to essential resources, such as ownership of boats, fishing gear, formal permits like BLCs, and communication tools like basic phones and radios, remains largely under male control. This power imbalance restricts women's ability to engage in autonomous decision-making or to access timely information about market prices, weather updates, or fisheries regulation. Furthermore, while one of the women participants occupies a formal leadership position as Panchayat Pradhan, her actual empowerment appeared limited. Her decision-making is strongly influenced by her husband and a male NGO member, and she operates more as a mediator or spokesperson than as an independent policymaker. Her actions are shaped by existing power structures, with constrained capacity to challenge or reshape them.

Aquaculture, in contrast to wild fishing, is seen as a relatively safer and more socially acceptable domain for women. As such, women are more visibly involved in fish farming activities, including pond maintenance, feed preparation, and even major pond management. Some women, particularly those from relatively empowered households or those involved in self-help groups, have taken up more advanced responsibilities, integrating traditional aquaculture practices with modern techniques. Nevertheless, their leadership and control over decision-making remain limited. Many women continue to lack access to formal training programs, digital resources, and financial or institutional support that could enable them to scale their aquaculture operations.

These gender disparities are reinforced by prevailing social norms, which often discourage women from occupying public or leadership roles and impose expectations of domestic prioritization. Additionally, women's lower levels of literacy and restricted mobility hinder their ability to participate in training, form cooperatives, or advocate for their rights in formal

institutional spaces. Even in emerging livelihood areas such as ecotourism, crab fattening, and handicrafts, where women's participation is rising, systemic issues such as bureaucratic exclusion, digital illiteracy, and lack of access to capital and infrastructure continue to marginalize them. As a result, despite their growing involvement, women in SSF and aquaculture remain structurally disadvantaged and dependent on male intermediaries, both within the household and in broader institutional systems.

4.3 Administrative Agency

4.3.1. Local Governance Helps Mediate Conflicts with Authorities, but unevenly:

Panchayats and local governance bodies like Joint Forest Management Committees play an important role in mediating conflicts between fishers and authorities, especially regarding forest access, BLCs, and disputes over fishing rights. In proactive cases, panchayats advocate for fisher-friendly policies or intervene in BLC reassignments. However, in many, fishers reported little or no help, turning instead to informal networks or personal negotiations. Local governance effectiveness varies significantly depending on leadership capacity, political pressures, and institutional support, with some communities experiencing clear mediation, while others face indifference or inaction.

4.3.2. Widespread Distrust in Government Aid Distribution: Across the study villages, fishers expressed some distrust in government aid systems due to corruption, bureaucratic delays and/or possible favouritism. Marginalized fisher groups, such as SCs, tribal families, widows, and the recently registered, are especially affected. Many recounted denial of cyclone relief, unpaid tiger attack compensation, or misallocation of critical resources like BLCs and fishing identity cards. Even when benefits like ₹5000 compensation or ration support are received, they are often delayed or inconsistently distributed. As a result, many fishers rely on informal channels, like village money lenders, NGO support, or community networks to meet urgent needs. This lack of transparency and accountability reinforces systemic inequality and deepens the vulnerabilities of those already on the margins.

4.3.3. Exploitation by Defense and Forest Authorities: Fishers reported that they frequently face harassment, suspicion, or exploitation from forest guards, BSF personnel, and other

authorities, especially in sensitive or border regions. Those without proper documentation or official permits are particularly vulnerable to penalties, equipment confiscation, or physical threats. Simultaneously, power within local systems are often known to benefit wealthier or politically connected actors, such as large traders or influential fish traders, who navigate systems with ease, while poor fishers depend on costly, informal, or illegal arrangements. This structural imbalance sustains a system where subsistence fishers remain at risk and voiceless, despite their essential role in local economies.

4.4. Ongoing Changes

4.4.1 Political and Environmental Changes Push Fishers Toward Alternative Income

Sources: In the Sundarbans, traditional fishing livelihoods were reported to be under intense pressure due to escalating environmental hazards, like cyclones, tiger attacks, sea-level rise, and political constraints, such as costly or inaccessible BLCs, increasingly stricter forest regulations, and gear confiscation. These barriers have forced many fishers and crab collectors, including women and youth, toward alternative income sources like aquaculture, wage labour, paddy farming, ecotourism, and small businesses. While some acknowledged receiving temporary state support (e.g., ration schemes, compensation), access is uneven, and bureaucratic hurdles abound. Many remain vulnerable due to lack of legal protection, training, or consistent market access. The digital divide and forest department restrictions (e.g., phone bans) further constrain fishers' ability to adapt, despite the growing interest in mobile applications and online tools for weather and market information.

4.4.2 Short-Term Opportunities and Development vs. Long-Term Disruptions: Alternative livelihoods, like crab collection, aquaculture, and government job schemes, have been reported to offer short-term financial relief but are undermined by longer-term challenges: environmental degradation, market volatility, juvenile crab harvesting, and disease outbreaks in aquaculture. Infrastructure improvements post-cyclone (e.g., roads, cyclone shelters) have helped, but systemic issues persist, such as lack of union power, price manipulation by traders, and limited access to permits or subsidies. While mobile applications and digital tools are expected to reduce dependency on intermediaries and boost resilience, their use is anticipated to be restricted by poor internet access, low literacy, and the need for localized Bangla-language content. Fishers

expressed cautious optimism, seeing technology as a supplement, not a replacement, for traditional knowledge and collective strategies. Sustainable solutions must integrate community realities, ecological balance, and inclusive planning to transform temporary fixes into durable livelihood security.

Box 1 Voices from the Sundarbans: Knowledge, Technology & Governance

Participant identity	Themes			
	Knowledge Needs and Sources for Sustainable SSF	Gender dynamics	Administrative Agency	Ongoing Changes
Fisher	"On our trips, we carry medicines, but if they run out, we use the juice from Dudul tree seeds for upset stomachs." (Excerpt from transcript no. KT4)	"I am a 39-year-old woman practicing aquaculture on my husband's land and have recently expanded my venture by leasing a larger khaal from the local Panchayat." (Excerpt from transcript no. KT11)	"Making a living from fishing in the forest is becoming more challenging each year. The forest department has restricted us from lopping off dry branches for firewood to cook our food, insisting instead that we bring small cooking stoves, which are costly and difficult for us to afford." (Excerpt from transcript no. KT9)	"...we used to focus on prawns, but as the prawn population dwindled and the demand for crabs grew, we made the shift. Our family's livelihood depends heavily on this, but it has become more challenging over the years." (Excerpt from transcript no. KT11)
Fish Trader	"We receive daily crab prices via WhatsApp messages in village-based groups, which share updates from organized markets and international companies in Kolkata. We pay crab collectors based on these daily rates." (Excerpt from transcript no. ST10)	No relevant quote	No relevant quote	"The crab trading business is fraught with challenges. Disease outbreaks among crabs, disabilities among workers, and even deaths are not uncommon." (Excerpt from transcript no. KT17)

Administrator	<i>"Fishermen need daily updates on crab prices and weather conditions, but they rely on their experience and traditional knowledge to predict the weather."</i> (Excerpt from transcript no. ST17)	No relevant quote	<i>"Sometimes, the BSF stops fishermen and demands they do manual labor, like cutting weeds, filling holes, or repairing barbed wire at their camps. This delays the fishing trips by about an hour or more, without any payment, which is significant because the timing of high tide is crucial for crab catching."</i> (Excerpt from transcript no. ST17)	<i>"Sometimes, forest department officials allow fishermen who provide information about illegal activities to venture deeper into the forest for better catches. These informants get favorable treatment, like avoiding boat seizures, even without a BLC."</i> (Excerpt from transcript no. ST17)
Researcher/ Academic	<i>"Knowledge transfer to these fisheries happens mainly through training and support programs conducted by both government and non-governmental organizations. These initiatives focus on sustainable feeding practices, encouraging fishers to use local natural resources available in perennial ponds, seasonal water bodies, and homesteads, instead of relying on artificial sources like spirulina or commercial fish food. Information is mostly shared through face-to-face interactions and visual aids like simplified videos or photo presentations on smartphones, as text-based instructions are often ineffective due to limited time, interest, or literacy."</i> (Excerpt from transcript no. KT8)	No relevant quote	<i>"Each block development office in West Bengal has a fisheries extension officer, who provides resources like fish feed, nets, seedlings, and training, as well as support for pension and compensation schemes. These efforts are conducted through face-to-face meetings, village tours, and notices, which are sometimes missed by the target audience."</i> (Excerpt from transcript no. KT8)	<i>"When collecting shrimp or prawn seedlings, they often unintentionally catch other fish seedlings, which die if not kept in water and are discarded back into the river, harming non-target species."</i> (Excerpt from transcript no. KT8)

NGO Partner	<i>"International crab prices, which fluctuate daily, are often not communicated effectively by traders to the fishers, resulting in traders taking a larger share of profits." (Excerpt from transcript no. ST18)</i>	No relevant quote	<i>"The absence of BLCs exposes fishers to an insecure livelihood and increased risk, while government-provided alternative livelihood options have been insufficient. An unwritten agreement exists with the forest department, allowing fishers to catch crabs; if caught by patrols, fishers often pay with a portion of their catch or nets as a bribe." (Excerpt from transcript no. ST18)</i>	<i>"Traditional fishing techniques have become more extractive due to increased competition, with fishers using traps and cages for crabs and pulling them from mudflats." (Excerpt from transcript no. ST18)</i>
Joint Forest Management Committee	<i>"As a JFMC member, I've made it my duty to understand both the struggles of the people and the challenges faced by the forest department. I try my best to mediate between the two, sometimes having to be firm with my fellow villagers, while at the same time conveying their concerns and needs to the forest department and the Panchayat." (Excerpt from transcript no. KT35)</i>	No relevant quote	<i>"..., my father was killed in a tiger attack while collecting honey from the forest—without a permit. Because of this, we never received any compensation from the authorities." (Excerpt from transcript no. KT35)</i>	<i>"The fishermen in the Sundarbans are some of the poorest and most marginalized, often lacking formal education. Over the years, the situation has only become more challenging with the cessation of BLC licenses, which has disrupted the balance between maintaining sustainable crab catches and making a living." (Excerpt from transcript no. KT35)</i>

Chapter 5

Designing Information Systems for Equity and Sustainability: Enhancing Resource Access, Capacity Development, and Governance in Mangrove-Dependent Small-Scale Fisheries

Abstract

Effective management of small-scale fisheries requires equitable access to resources, market information, and collaboration, yet faces multiple challenges. Studies show that information systems can improve data accessibility and foster cooperation; however, gaps remain in integrating traditional knowledge into digital platforms, addressing power imbalances in fisheries governance, and developing a commons-based data-sharing system. Therefore, this study, part of the Vulnerability to Viability Global Partnership, aimed to assess how digital tools can enhance resilience and decision-making for small-scale fishers in the Sundarbans. Using mixed methods, including surveys and interviews, it explored stakeholder perceptions in Samsdernagar and Kumirmari villages. A test version of a mobile-based Vulnerability to Viability – Information System application was demonstrated to fishers, researchers, government officials, and non-government organization members, and their responses were recorded and analyzed. Most participants had mixed perceptions about application, though half of them indicated possible adoption. Fishers showed interest in real-time market rates and weather alerts through the tool but stressed the need for an intuitive, voice-enabled interface. However, obstacles like language barriers, low digital literacy, and power imbalances persist. The study calls for inclusive and ethical technology design, along with a user-friendly interface to enhance decision-making capacity, emergency preparedness, and communication, ensuring that digital tools empower small-scale fishers rather than exacerbate existing inequalities. Furthermore, sustainable technology adoption in small-scale fisheries requires continuous feedback, policy support, and economic stability to enhance fishers' resilience.

Keywords: Small-scale fisheries, information system, participatory design, knowledge coproduction, information commons, knowledge commons

5.1. Introduction

5.1.1 Background

Mangroves, along with other coastal ecosystems like coral reefs and seagrass beds, provide essential services such as food, water, and climate resilience to millions of people, particularly in regions like the Sundarbans, which houses the largest mangrove forests in the world (Steven et al. 2020; Sinclair et al. 2021). The area spans around 10,000 km², with 62% in Bangladesh and 38% in India and its favourable environmental conditions make it a crucial nursery for nearly 90% of commercially important aquatic species on India's eastern coast (Chandra and Sagar 2003). Fishing is the second most common livelihood after agriculture, supporting over 4.4 million people in the region (Berenji et al. 2021). However, these fisheries face significant challenges due to climate change, overfishing, and human activities, which have led to poverty, conflicts, and displacement (Hossain et al. 2018, Bhowmick 2024). Effective management of SSF requires access to diverse resources, including natural, human, and financial assets, alongside collaboration and capacity-building, especially to address the social and economic disparities faced by fishing communities (Bebbington 1999; Weeratunge et al. 2014). Critical capacity development and the decolonization of resource management are vital to overcoming systemic barriers and promoting community empowerment (Bockstael 2017).

In addressing these challenges, information systems play a crucial role by providing necessary data and fostering collaboration through tools like mobile technology and web portals (Chuenpagdee et al. 2019). These systems can support sustainable fisheries management by tracking fishing activities, ensuring regulatory compliance, and evaluating environmental impacts. However, gender and power dynamics, along with the integration of traditional knowledge, must be carefully considered to ensure equity and inclusivity, keeping in mind that information systems can either address or reinforce these issues depending on how they are designed, implemented, and embedded within specific social, cultural, and physical contexts (Elmhirst 2011; Nayak & Armitage 2018).

To ensure that governance innovations and capacity-building efforts genuinely promote social justice and sustainability, they must account for gendered power relations and traditional knowledge systems, particularly in how technologies and information systems are designed and

applied in diverse local contexts (Collins et al. 2019; Khan et al. 2018; Jentoft & Chuenpagdee 2015). Thus, a question arises: How can an information system enhance resource access, capacity development, and governance in SSF while addressing equity and sustainability? This paper explores the development of an inclusive information system for SSF, addressing challenges in data access, power dynamics, and community engagement. It examines various technological, social, and political factors, aiming to build upon a design that supports informed decision-making, livelihoods, and sustainable management, while incorporating local knowledge and multi-level governance.

5.1.2 Review of Existing Literature

While Information Systems (IS) and Information and Communication Technology (ICT) are central to transforming knowledge into usable forms—particularly in SSF—their effectiveness depends on how knowledge is understood, produced, and governed in context. IS are formal systems designed to provide relevant information for decision-making through structured data processing and communication (Langefors 1977), and ICT encompasses the tools and media used to process and communicate information (Heeks 1999). Together, they enhance efficiency, sustainability, and equity by improving access to information, communication, and decision-making processes in SSF. However, to ensure that such systems are genuinely inclusive and equitable, it is crucial to draw on broader perspectives that explore the social and political dimensions of technology use. Literature on knowledge coproduction highlights the importance of collaboration among diverse stakeholders and the integration of local knowledge through mutual learning. The society-technology interface further underscores that information systems are not neutral; they can reinforce or challenge existing power hierarchies depending on their design and implementation. Additionally, the concept of the information commons offers a governance perspective that promotes shared access, collective responsibility, and data sovereignty. These complementary bodies of work provide critical insights for designing information systems that are not only functional but also socially just and context sensitive.

Knowledge Coproduction

Co-production of knowledge is defined as, ‘iterative and collaborative processes involving diverse types of expertise, knowledge, and actors to produce context-specific knowledge and

pathways towards a sustainable future'. Knowledge co-production depends on context, goals, and interactivity; its effective monitoring uses participatory frameworks, key metrics, and continuous adaptation (Norström et al. 2020). Local knowledge provides real-time insights into fisheries, while scientific data offers a broader context for understanding changes and supports data sharing across systems (Ban et al. 2018). Yet, at the same time, it is important to consider technical and political factors in public service partnerships.

Goodwin (2019) examines Ecuador's water management, highlighting shifts between collective ownership and state control, and calls for more research on these dynamics. Muhl et al. (2023) stressed that knowledge co-production should go beyond technical issues, emphasizing the importance of information sharing, data sovereignty, and recognizing diverse knowledge systems, while also considering the influence of knowledge, power, and governance. Knowledge co-production integrates diverse expertise for sustainability, requiring participatory monitoring, adaptability, and balanced use of local and scientific data, while governance, power, and data sovereignty shape its outcomes.

Society-Technology Interface

Pinch and Bijker (1984) discussed that technology is socially constructed, shaped by cultural values, societal needs, and conflicts, while emphasizing that technology requires an interdisciplinary approach to understanding its development. Building on this idea, Latour (1992) argued that sociological analysis must include technology to fully understand societal processes. Later, MacKenzie and Wajcman (1999) reasoned that technology is shaped by social factors like gender and ethnicity, while critiquing technological determinism and highlighted path dependence, social construction, and actor-network theory, advocating for societal involvement in shaping technology. While Dorward et al. (2003) examined the interplay between markets, institutions, and technology in poverty reduction. Similarly, artisanal fishers in Unguja, Tanzania, rely on mobile phones and radios but struggle with poor connectivity and ICT training (Benard and Dulle 2017).

The Information System on Small-scale Fisheries (ISSF) is a web portal that consolidates data from 45 countries to improve SSF governance and decision-making (Chuenpagdee et al., 2019). More recently, Kiseni and Kwesigabo (2023) found that mobile phone use for agricultural information improved maize productivity among smallholder farmers in Tanzania's Kilolo

District. These works highlight the importance of understanding the interaction between technology, society, and human behavior. They challenge technological determinism and promote an interdisciplinary approach to studying technology. The authors stress the need to recognize the mutual influence between society and technology, offering a more nuanced view of how technological systems shape and are shaped by social processes. These studies highlight that technology must be shaped by societal values, needs, and institutions, challenging technological determinism. They stress the importance of an interdisciplinary approach to understand technology's development and impact, showing that its adoption depends on social, economic, and infrastructural factors.

Information Commons

Leonelli's paper (2013) discusses the concept of data commons in the Open Data movement, emphasizing the need for public access to scientific data to foster knowledge creation. It highlights challenges such as regulatory frameworks, infrastructure, and stakeholder coordination. Christine L. Borgman's (2017) book examined data privacy, ownership, and misuse in research, highlighting risks in fields like social sciences and healthcare. She advocated for ethical safeguards, better data management, and caution in data use. Gurstein (2011) critiqued the open data movement, arguing it often benefits the already privileged. He calls for policies that ensure marginalized communities can effectively use open data. Later, Baarbé, Blom and De Beer (2019) proposed an "Agricultural Data Commons" to improve food security in Africa by creating a shared data repository for better decision-making and innovation, while addressing challenges in data ownership and governance.

On the other hand, Frischmann, Madison, and Strandburg (2014) define knowledge commons as community-governed systems where shared cultural or informational resources are managed through rules, norms, and technologies, emphasizing how such resources are collectively produced, used, and sustained. Building on this, Qureshi et al. (2022) demonstrate how "knowledge commoning" can overcome social and technological barriers by enabling the collaborative curation and sharing of indigenous agricultural knowledge through supportive practices like scaffolding and technoficing. Extending this perspective, Dekker and Kuchař (2024) show that knowledge commons also underpin market governance, where communities create and maintain shared rules and norms that foster trust and cooperation, contrasting with

top-down, externally imposed systems. Data commons literature stresses equitable access, governance, and risks of exclusion in shared data use, while knowledge commons focuses on community-driven production and governance of shared knowledge. The key contrast lies in data commons addressing structural access issues, whereas knowledge commons emphasizes participatory, relational processes.

Hence, there is a need for deeper exploration of how knowledge co-production in SSF can better integrate diverse knowledge systems, while addressing power dynamics, data sovereignty, and governance issues. Additionally, there is a lack of understanding regarding the social construction of technology in the fisheries sector and the barriers to effective IS development and use, such as connectivity and training. Further investigation is also needed on the challenges surrounding information commons, particularly around ownership, privacy, and accessibility, to ensure equitable access to information and avoid reinforcing inequalities.

Alongside this, recent work on knowledge commons emphasizes the importance of community-driven processes for producing, governing, and sharing knowledge, highlighting that inclusive, bottom-up approaches can strengthen trust, support collaborative governance, and foster locally grounded innovation. However, some gaps identified in these studies are as follows: (1) integrating traditional knowledge into digital platforms, (2) equitable access to information for small-scale fishers, (3) addressing power imbalances in knowledge co-production, (4) ensuring the sustainability of ICT initiatives in low-resource settings, and (5) understanding how data and knowledge commons impact fisheries governance. To address these gaps, this study adopts a qualitative research design grounded in a combination of inductive and deductive approaches to understand fishers' experiences and knowledge in the Sundarbans, aiming to co-produce context-sensitive insights for the inclusive design of an information system.

5.2. Study Area and Methods

5.2.1. Study Area

Two villages were selected for this study, namely, Samshernagar and Kumirmari (Figure 1). Samshernagar, a village in the North 24 Parganas district of West Bengal, is located in the buffer zone of the Sundarbans Tiger Reserve along the Kalindi and Raimangal Rivers. It has approximately 4,394 people in 1,145 households. It is geographically isolated and is located near

the border with Bangladesh. While Kumirmari, falls in the South 24 Parganas district of the state, near the Marichjhanpi Reserve Forest (near Sundarbans Tiger Reserve), and is surrounded by the Kurankhali and few other rivers. It has a population of approximately 17,451 in 4,344 households. Both areas rely on agriculture, fishing (including wild captures and aquaculture), honey collection, and daily wage labour for livelihoods. Forest resources, such as fish, crabs, and non-timber products, are crucial to their economies. These communities face risks including tiger attacks, sea robbers, storms, cyclones, strict regulations, poverty, and low literacy. Fishing permits require a Boat License Certificate (BLC) for river or forest capture fishing. Border Security Force (BSF) presence is prominent, with additional fishing permissions granted near the Bangladesh border. Traditional knowledge plays a vital role in guiding sustainable fishing practices and resource management.

5.2.2. Methods

The research for this paper was part of the Social Sciences and Humanities Research Council (SSHRC)-funded “Vulnerability to Viability (V2V) Global Partnership”, which examines challenges in SSF across Asia and Africa. SSF communities facing structural and governance challenges, require inclusive decision-making, resource access, and digital tools for effective management (Perry et al. 2011; Nayak 2017; Dias et al. 2023). Governments shape SSF operations, and gender and power dynamics impact equity. Accurate data collection is critical but often limited (Bradley et al. 2019; Ramirez-Rodriguez 2011). This research thus aimed to contribute to the development of the V2V-IS, an information system integrating localized knowledge through a mobile and web-based application in collaboration with the Indian Institute of Technology (IIT)-Kharagpur, in India. The system is envisioned to consolidate case studies and enhance knowledge-sharing among SSF stakeholders, providing real-time monitoring and decision-making support for SSF stakeholders, providing real-time monitoring and decision-making support for SSF stakeholders in supporting their transition from vulnerability to viability.

To guide its initial design, a structured development process was followed by researchers at IIT-Kharagpur, beginning with a review of existing V2V literature and field-based needs assessments in Chilika (Odisha), India. Insights from various stakeholders informed the system’s architecture, leading to the development of a flexible, scalable platform with secure access,

multimedia data entry, and metadata tagging. Built using technologies like HyperText Markup Language (HTML) as basic building block of web pages, a server-side scripting language Hypertext Preprocessor (PHP), MySQL which is a database management system, and Flutter which is an open-source toolkit by Google for building mobile apps, the system was designed for both web and mobile use. A test version was prepared for iterative refinement based on user feedback for its improvement according to local contexts and stakeholder priorities.

A mixed methods approach of quantitative and qualitative methods was employed for data collection and analyses on the perception and usability of the V2V-IS (represented in Figure 3). Combining qualitative and quantitative methods allows for the integration of diverse perspectives and approaches to offer a more comprehensive understanding of complex issues compared to using either method in isolation (Creswell and Clark 2011). Quantitative survey methods, primarily utilized for tasks like prediction and extrapolation (Moon and Blackman 2014), consisted of surveys and interviews (Shackleton et al. 2021). Qualitative data were gathered through in-depth interviews (Legard et al. 2003) and participant observations to understand the cultural and social dimensions. Use of qualitative data collection instruments included both inductive and deductive approaches, which used a bottom-up approach for insights and propositions to emerge from the data, while also applying predetermined theories and concepts identified from the literature review (Creswell and Creswell 2018).

The study employed case study research (Gerring 2006) using snowball sampling (Hay and Cope 2021) to explore the use of technology in two Sundarbans villages, involving fishers, officials, NGO workers, and researchers. The test version of the V2V-IS mobile application (represented in Figure 2) was demonstrated to the participants individually, explaining its features and use. The survey and interviews was conducted in person, with data collected digitally, including photographs, and audio recordings. Research rigour was maintained through a combination of purposeful sampling, pilot testing, field journaling, and peer consultations. Participants were selected using purposive sampling to include fishers, and all other targeted stakeholders in the selected villages and beyond. This ensured relevance and depth in the data collected. A pilot study involving around two participants was conducted to refine interview and survey questionnaire, improving clarity and cultural appropriateness.

Throughout the fieldwork, a journal was maintained to document observations, contextual notes, and reflective insights, allowing for ongoing critical assessment of methods and interpretations. Peer consultations with subject experts and local researchers were held at key stages to review data interpretation and ensure credibility and cultural sensitivity in the analysis (Baxter & Eyles 1997). Validity was ensured through triangulation, while reliability will involve transcript verification and accurate coding (Creswell & Creswell 2018). Reflexivity and confidentiality minimized biases, fostering an empathetic approach to amplifying Sundarbans fishers' voices with integrity. Descriptive statistics and thematic coding were used for data analyses. Reflexive memos documented insights and challenges, ensuring transparency, minimizing bias, and aligning findings with the research objectives.

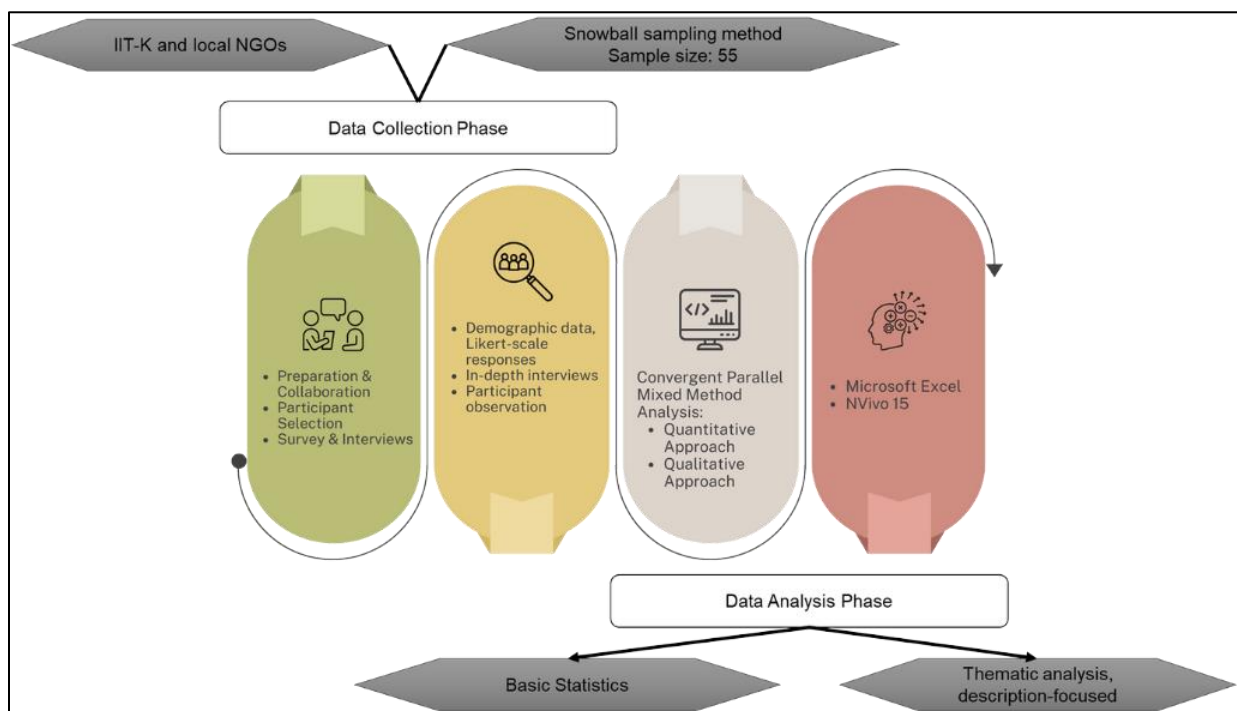


Fig. 3 Diagrammatic representation of methods (data collection and analyses) (Survey and interview questions have been provided in Appendix 2)

5.3. Results

5.3.1 Participant Profile and Information Access

The study's demographic findings (detailed distribution of each measure of attribute is tabulated below in Table 1) indicate that majority of the participants were middle-aged (35–55 years: 69.08%) and predominantly male (74.55%), with limited formal education (81.82%), reflecting

the socio-economic profile of small-scale fishers in the study sample. Fishing is the dominant livelihood, with most participants engaged in capture fishing or fish farming (81.14%), while a small percentage were researchers, NGO workers, government authorities and Joint Forest Management Committee (JFMC) member. The data also revealed challenges in regulatory compliance, as only 34.55% regularly renewed their BLC, while 27.27% renewed sporadically, or not at all.

Table 1 Participant demographics and status of fishing permits in Samshernagar and Kumirmari villages

Age Range (Years)	18-25	25-35	35-45	45-55	≥55	
Distribution (%)	3.64	12.73	30.9	38.18	14.55	
Gender	Male	Female				
Distribution (%)	25.45	74.55				
Education	No formal education	≤Matriculation	Matriculation	College	University	
Distribution (%)	21.82	60	5.45	5.45	7.27	
SSF Role	Fisher	Fish Trader	Administrator	Researcher/Academic	NGO Partner	Joint Forest Management Committee
Distribution (%)	82.14	3.57	5.36	3.57	3.57	1.79
Fishing Practice	River	Aquaculture	Forest (PA buffer)			
Distribution (%)	15.69	29.41	54.9			
Boat Licensing Certificate Renewal	Regularly	Sometimes	No	Not relevant		
Distribution (%)	34.55	16.36	10.91	38.18		

In terms of communication tools, basic mobile phones (32%) and radios (29%) are the primary sources of information (depicted in Figure 4), followed by smartphone (18%), local announcements by authorities (13%) and television (8%), underscoring limited access to advanced digital technologies. The participants who used basic phone as their primary source, accessed information through radio, local announcements and television as well. While the participants who used radio as their primary source, also used basic phone, local announcements, smartphone and television as well (Table 3). Participants had mixed perceptions of the V2V-IS test app, with neither strong positive or negative opinions (neutral responses) on usefulness and user-friendliness, though 50.9% showed a high likelihood of adoption (details are depicted in Figure 5).

Table 2 Detailed profile of participants

Sl. No.	ID	Gender	SSF Role	Age Range (years)	Fishing Practice	Education
1	KT-21	Male	Fisher	18-25	Forest (PA Buffer)	≤Matriculation
2	ST-13	Male	Fisher	18-25	Forest (PA Buffer)	≤Matriculation
3	KT-6	Female	Administrator	25-35	Not applicable	Matriculation
4	KT-22	Male	Fisher	25-35	Forest (PA Buffer)	≤Matriculation
5	KT-29	Male	Fisher	25-35	Aquaculture	College
6	ST-8	Male	Fisher	25-35	Forest (PA Buffer)	≤Matriculation
7	ST-12	Male	Fisher	25-35	River	College
8	ST-17	Male	Administrator	25-35	Not applicable	College
9	ST-20	Female	Researcher/Academic	25-35	Not applicable	University
10	KT-5	Male	Fisher	35-45	Aquaculture	Matriculation
11	KT-7	Male	NGO Partner	35-45	Not applicable	≤Matriculation
12	KT-9	Male	Fisher	35-45	Forest (PA Buffer)	No formal education
13	KT-18	Female	Fisher	35-45	River	No formal education
14	KT-19	Female	Fisher	35-45	River	No formal education
15	KT-24	Male	Fisher	35-45	Aquaculture	≤Matriculation
16	KT-25	Female	Fisher	35-45	Aquaculture	No formal education
17	KT-26	Female	Fisher	35-45	Aquaculture	≤Matriculation
18	KT-27	Male	Fisher	35-45	Aquaculture	≤Matriculation
19	KT-28	Male	Fisher	35-45	Aquaculture	≤Matriculation
20	KT-33	Male	Fisher	35-45	Aquaculture	≤Matriculation
21	KT-34	Female	Fisher	35-45	Aquaculture	≤Matriculation
22	ST-7	Male	Fisher	35-45	Forest (PA Buffer)	≤Matriculation
23	ST-9	Male	Fisher	35-45	Aquaculture	≤Matriculation
24	ST-10	Male	Fish Trader	35-45	Not applicable	≤Matriculation
25	ST-15	Female	Fisher	35-45	Forest (PA Buffer)	No formal education
26	ST-16	Female	Fisher	35-45	Forest (PA Buffer)	≤Matriculation
27	KT-1	Male	Fisher	45-55	Forest (PA Buffer)	≤Matriculation
28	KT-3	Male	Fisher	45-55	Forest (PA Buffer)	≤Matriculation
29	KT-4	Female	Fisher	45-55	Forest (PA Buffer)	≤Matriculation
30	KT-10	Male	Fisher	45-55	Forest (PA Buffer)	≤Matriculation
31	KT-11	Male	Fisher	45-55	Forest (PA Buffer)	No formal education
32	KT-12	Male	Fisher	45-55	Forest (PA Buffer)	≤Matriculation

33	KT-13	Male	Fisher	45-55	River+Aquaculture	≤Matriculation
34	KT-14	Male	Fisher	45-55	Forest (PA Buffer)	≤Matriculation
35	KT-16	Male	Fisher	45-55	Forest (PA Buffer)	≤Matriculation
36	KT-17	Male	Fisher/Fish Trader	45-55	Aquaculture	≤Matriculation
37	KT-23	Male	Fisher	45-55	Forest (PA Buffer)	No formal education
38	KT-30	Male	Fisher	45-55	Aquaculture	≤Matriculation
39	KT-31	Male	Fisher	45-55	Aquaculture	≤Matriculation
40	KT-32	Female	Fisher	45-55	Aquaculture	≤Matriculation
41	KT-35	Male	JFMC	45-55	Not applicable	≤Matriculation
42	ST-2	Male	Fisher	45-55	Forest (PA Buffer)	≤Matriculation
43	ST-3	Male	Fisher	45-55	Forest (PA Buffer)	≤Matriculation
44	ST-11	Male	Fisher	45-55	River+PA Buffer	≤Matriculation
45	ST-14	Male	Fisher	45-55	Forest (PA Buffer)	≤Matriculation
46	ST-18	Male	NGO Partner	45-55	Not applicable	University
47	ST-19	Male	Administrator	45-55	Not applicable	University
48	KT-2	Female	Fisher	≥55	Forest (PA Buffer)	No formal education
49	KT-8	Male	Researcher/Academic	≥55	Not applicable	University
50	KT-15	Male	Fisher	≥55	Forest (PA Buffer)	No formal education
51	KT-20	Female	Fisher	≥55	River	No formal education
52	ST-1	Male	Fisher	≥55	Forest (PA Buffer)	Matriculation
53	ST-4	Male	Fisher	≥55	Forest (PA Buffer)	≤Matriculation
54	ST-5	Female	Fisher	≥55	River	No formal education
55	ST-6	Male	Fisher	≥55	River+Aquaculture	No formal education

Table 3 Perception of V2V-IS test app according to use of technology to access information

Perception on Test App	Tools to access information					
	Local announcements	Radio	Television	Basic phone	Smartphone	
App moderately Helpful	8	18	3	16	9	18
App slightly Helpful	0	6	2	11	7	16
App not at all helpful	5	5	3	5	2	14
App moderately user friendly	7	16	3	14	9	12
App slightly user friendly	1	8	2	13	7	10
App not at all user friendly	5	5	3	5	2	8
App use quite likely	4	11	4	16	11	6
App use moderately likely	4	12	1	8	5	4
App use slightly likely	0	1	0	3	0	2
App use not at all likely	5	5	3	5	2	0

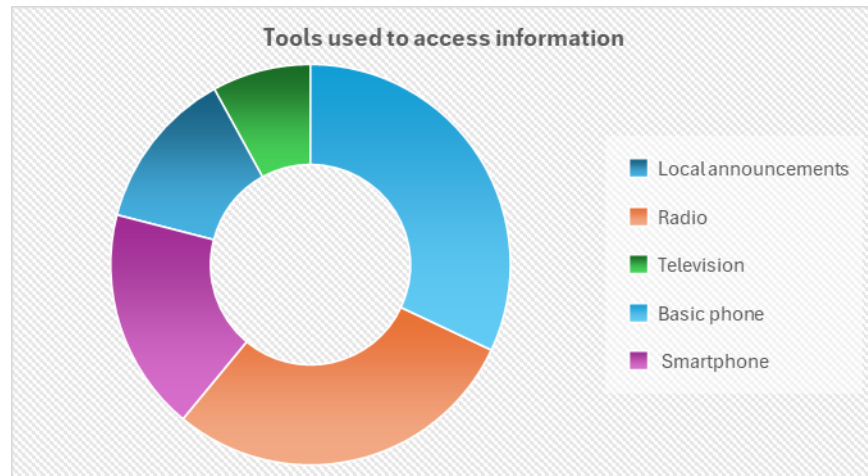


Fig. 4 A sunburst diagram depicting use of different primary tools in the study area to access information

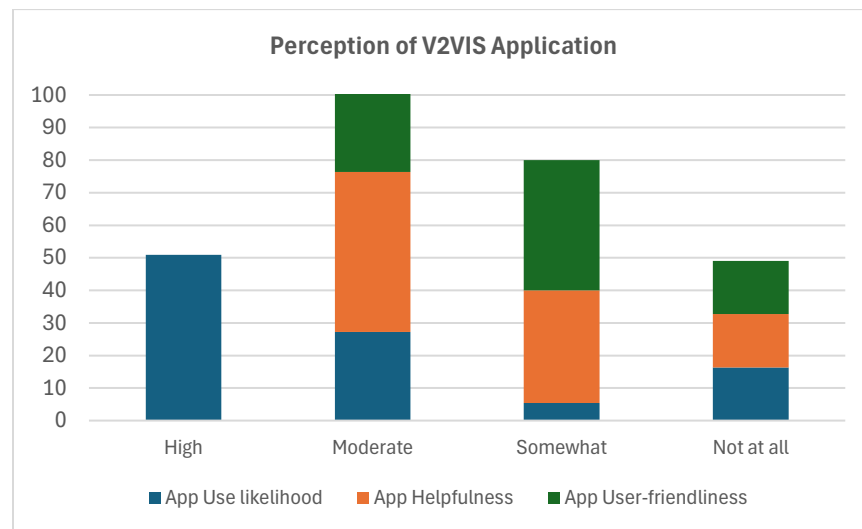


Fig. 5 Stacked columns depicting proportion of Likert scale perceptions on V2V-IS

5.3.2. Evaluation of the test application

Participants acknowledged that the test mobile application includes features like market prices for fish and crabs and weather updates. However, they expressed that it is not particularly useful due to its English-only interface and lack of critical, relevant information. They recognized some interesting features, such as a survey feature for gathering community input, and quick access to Frequently Asked Questions (FAQs) and regulatory links. However, they highlighted several key limitations that must be addressed for broader adoption. The absence of the local languages (e.g., Bangla) tends to exclude many fishers. Digital literacy barriers make navigation difficult,

emphasizing the need for a simplified, voice-enabled interface. Additionally, participants stated that the app should provide real-time market prices, fishing regulations, and licensing details to be more practical. Concerns were also raised about internet dependency, as many rural fishers lack consistent connectivity, underscoring the need for offline functionality. Most women fishers had the least access to information through the primary tools available (Figure 6); although some enjoyed more agency through aquaculture management (Table 2), only a couple of them possess a smartphone (Table 3). The women fishers also had minimal expectations or reservations from the test application (Figure 7).

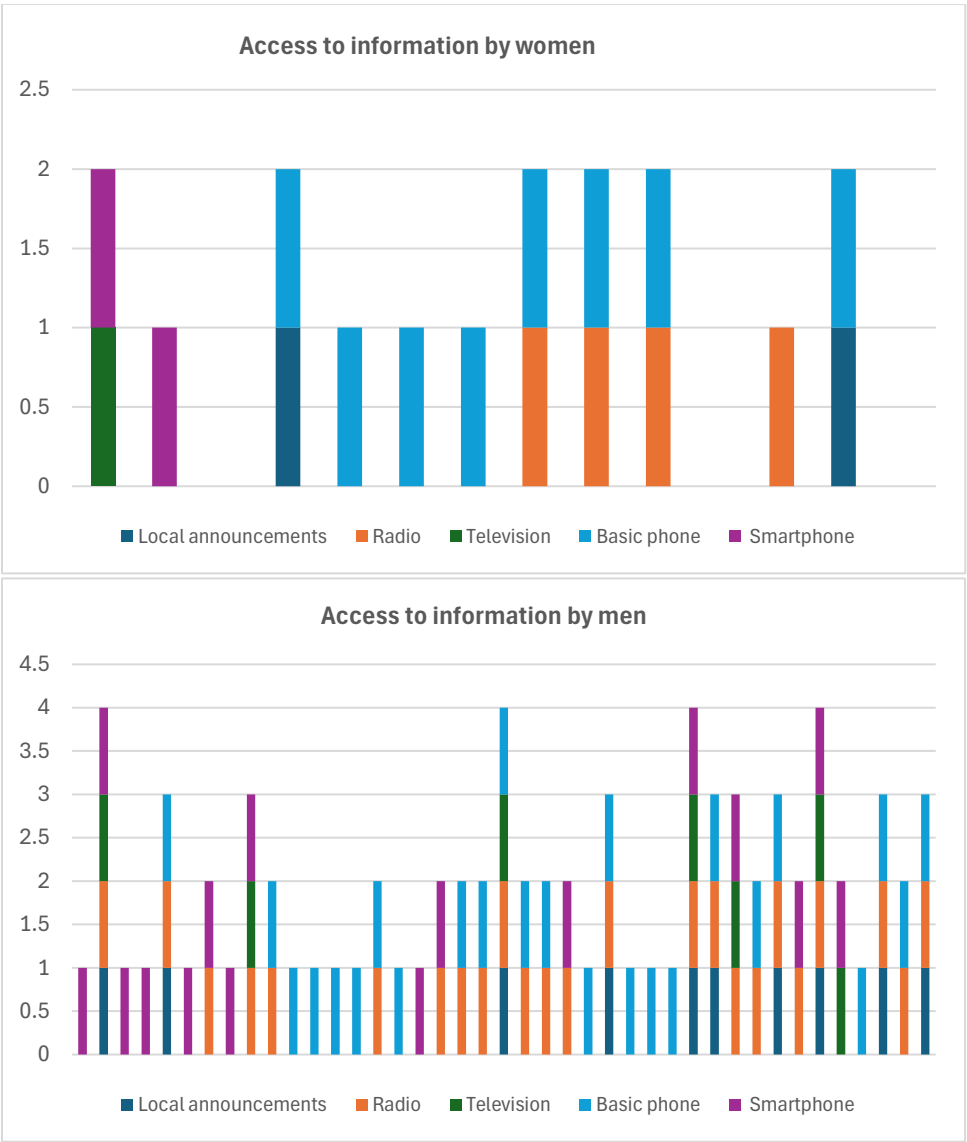


Fig. 6 Access to information through technology according to gender



Fig. 7 Perception of V2V-IS test app among male and female participants

SSF in the Sundarbans are undergoing rapid change due to environmental stress, modernization, and shifting economic aspirations. While fishers still draw on deep traditional knowledge and blend it with modern aquaculture techniques, they face ongoing challenges such as reduced productivity in the rivers and in fishponds, poor access to legal permits, erratic weather information, difficult emergency communication, and limited financial aid. Declining fish stocks and unstable livelihoods are pushing younger generations away from fishing, weakening knowledge transfer and local resilience. Both fishers and stakeholders, including NGOs and researchers, emphasized the value of integrating traditional knowledge into digital tools to improve resilience and safety. They called for systems that offer real-time updates, financial information, and platforms to strengthen fisher unions' bargaining power and regulatory access. Combining digital solutions with community-driven efforts was seen as key to supporting

compliance, enhancing sustainability, and building institutional capacity for long-term fisheries governance.

5.3.3. Expectation from an improved V2V-IS

Simplifying Administration: Many small-scale fishers (41 fishers – Table 5) recognized technology’s potential to streamline processes, such as securing BLCs, which are currently cumbersome and unjust. An advanced system could simplify the application and renewal process, ensuring fishers can operate legally without bureaucratic hurdles. The administration informed that a process has been initiated to transfer existing BLCs to the fishers’ name, while removing the holding of the intermediaries. This process will take time to reach all the stakeholders since it is a bureaucratic task. They also highlighted that a digital system could reduce administrative inefficiencies and improve access to necessary legal documentation.

An NGO representative suggested that such a system could reduce reliance on middlemen, further easing bureaucratic obstacles. However, the participants from the forest department expressed their skepticism about mobile technology’s ability to address the core challenges of small-scale fishers and crab collectors in the Sundarbans, such as extreme weather, fluctuating markets, and human-wildlife conflict. While they envisioned potential in technology for aquaculture, they emphasized that its success depends on structured support and training. Without proper capacity development, digital tools risk being underutilized or abandoned. The role of technology in supporting the above-mentioned efforts is anticipated to be hindered by logistical challenges, lack of local buy-in, and a need for more accessible systems for data collection and communication. The struggle to enforce regulations amidst resistance from intermediaries and the decline of traditional fisheries could further complicate the sustainability goals.

Enhancing Communication & Collaboration: Technology in SSF plays a limited yet evolving role, primarily through basic tools like radios, mobile phones, and local announcements. Advanced adoption is impeded by factors such as fishing trip restrictions, digital literacy gaps, and socio-economic challenges. While radios are still widely used for weather updates, younger individuals, who are increasingly shifting away from SSF, use smartphones mainly for social media and banking rather than fisheries-related tasks. Though some fishers use mobile phones

for market updates and trade (three fishers – Table 5), word-of-mouth remains the primary communication method.

Participants expressed strong interest in mobile apps offering real-time market rates, regulatory updates, safety alerts, and modern fishing techniques in Bangla, preferably through voice commands or videos to assist those with low literacy. However, according to the doubtful administration (forest official and JFMC member), systemic barriers like restricted fishing rights, unequal market access, and financial limitations would hinder full adoption. Limited access to smartphones and the internet further restricts collaboration among fishers, traders, and authorities. Some pictured digital platforms fostering community solidarity (five participants – Table 5), while others saw potential in technology for knowledge sharing, market transparency, and improved research collaboration. However, accessibility and usability remain critical concerns among participants for effective adoption.

Emergency Support: Digital exclusion in SSF impacts safety, as many fishers lack access to timely weather updates and emergency alerts. Among the fishers, six (Table 5) have started using smartphones for weather forecasts, but high recharge costs and unreliable networks limit their use. Mobile platforms using off-line mode with real-time alerts, combined with community-driven knowledge-sharing via audio or video, could enhance emergency preparedness and reduce risks.

Few (eight fishers - Table 5) stress the importance of integrating an SOS feature in mobile apps to alert others in emergencies, particularly in the context of sudden weather changes or wildlife encounters. This would improve safety by enabling real-time communication during crises. These fishers also advocate for an emergency messaging feature to contact authorities during emergencies, enhancing both safety and legal protection for fishers working in hazardous conditions.

Table 5 Summary of participants with responses

Topic	Number of Respondents
Fishers' concerns about transparency in pricing and market access	46
Participants' interest in mobile apps offering practical solutions	41
Recognized technology's potential to streamline processes	30
Concerns about misuse of technology	16
Fishers use smartphones for social media	13

Younger individuals increasingly shifting away from SSF	12
Integrating an SOS feature in mobile apps	8
Fishers use smartphones for weather forecasts, bank balance	7
Digital platforms foster community solidarity and collaboration	5
Fishers use smartphones for market updates and trade	3

Ensuring Equity & Security of Data Sharing: All the fishers (46 out of 55 participants - Table 5) expressed concerns about transparency in pricing and market access. Secure, localized digital platforms offering verified market rates, transaction histories, and government policy updates could improve trust, ensuring that even those with minimal technological literacy can make informed financial decisions.

Concerns about misuse of technology, particularly by sea dacoits, mostly from the neighbouring country, were prevalent among 16 fishers (Table 5). Secure digital solutions must be designed to protect users from theft and exploitation while ensuring that data-sharing benefits the community rather than outsiders.

A panchayat member suggested satellite-based alternatives to mobile apps due to unreliable network coverage. A researcher also raised concerns about digital literacy and the need for technology to be user-friendly to ensure equitable access, especially for fishers with limited technological knowledge. Ensuring that data sharing through the new system is secure and accessible is crucial for encouraging adoption among fishers, along with other direct stakeholders, ensuring their protection, and empowering them with the tools to improve their livelihoods.

Box 2 Quotes from participants on expectations from an ideal V2V-IS

Participant identity	Themes			
	Simplifying Administration	Enhancing Communication & Collaboration	Emergency Support	Ensuring Equity & Security of Data Sharing
Fisher	"...A mobile app that could help with BLC applications, renewals..." (Excerpt from transcript no. ST8)	"...simple, local language and incorporate video instructions..." (Excerpt from transcript no. KT7)	"... emergency messaging feature for use within the forest, connected to the village network, would be valuable so that BSF personnel and the forest department are aware of our activities and can ensure we are not involved in anything illegal..." (Excerpt from transcript no. KT12)	"...if information stored on a phone app were misused by dacoits..." (Excerpt from transcript no. ST1)

Fish Trader	<i>"We receive daily crab prices via WhatsApp messages in village-based groups, which share updates from organized markets and international companies in Kolkata." (Excerpt from transcript no. 10)</i>	<i>"Living in the last village of the country and state, we want our stories to reach a wider audience. I'm willing to support researchers and practitioners in telling our stories, as this may improve our lives and livelihoods." (Excerpt from transcript no. 10)</i>	No relevant quote	<i>"With proper support and resources, I believe I could teach these techniques to younger generations, passing on my knowledge through audio notes and video demonstrations..." (Excerpt from transcript no. KT17)</i>
Administrator	<i>"Due to high illiteracy rates, many locals rely on forest office staff to assist them with the online application process..." (Excerpt from transcript no. ST19)</i>	<i>"...villagers need to submit documents to the BSF officials at the zero point because our village borders Bangladesh..." (Excerpt from transcript no. ST17)</i>	<i>"If a mobile app were created, it should work without network coverage." (Excerpt from transcript no. ST17)</i>	<i>"We would like to monitor the catch data, the catch location and the means of catching crabs, however, due to technological and logistical constraints, we are unable to do that so far..." (Excerpt from transcript no. ST19)</i>
Researcher/ Academic	<i>"A well-designed smartphone app could help disseminate this information and combine traditional and modern knowledge." (Excerpt from transcript no. 8)</i>	<i>"...app that consolidates such crucial information, links to publications, and integrates meteorological data would be incredibly valuable, not just for me but for the wider..." (Excerpt from transcript no. ST20)</i>	No relevant quote	<i>"...minimizes technical errors..." (Excerpt from transcript no. ST20)</i>
NGO Partner	No relevant quote	<i>"The V2V-IS app could significantly aid coordination if all beneficiaries are included, but it must use simple, in our local language and also incorporate video instructions. Both men and women must be actively involved, and their feedback prioritized." (Excerpt from transcript no. KT7)</i>	No relevant quote	<i>"Without BLCs, fishers lack security and the ability to form unions or cooperatives, preventing them from bargaining for fair prices with traders." (Excerpt from transcript no. ST18)</i>

Joint Forest Management Committee	<i>"The situation in small-scale fisheries, especially crab catching, is far too complex and precarious to be addressed effectively through an app..."</i> (Excerpt from transcript no. KT35)	No relevant quote	No relevant quote	<i>"Technology, if it is to be introduced, must be accompanied by a clear understanding of our needs and be designed to integrate with the ways we work and live in the Sundarbans."</i> (Excerpt from transcript no. KT35)
--	---	-------------------	-------------------	---

5.4. Discussion

The Sundarbans presents a distinctive and complex context for exploring the design and application of the V2V-IS in SSF. Its unique geographical and ecological features, such as island-like remoteness, dense mangrove forests, and vulnerability to climate events, combine with layered political, regulatory, and social dynamics, including borderland governance, restricted access to forest and water resources, and deep-rooted socio-economic marginalization. These intersecting factors shape not only fishers' daily lives but also their capacity to access, interpret, and engage with digital technologies. While this study attempts to unpack these relationships, it is important to recognize its limitations in fully capturing the depth of local complexities and historical power asymmetries embedded in the region. The findings should therefore be interpreted as part of an ongoing, iterative process of learning and engagement, rather than a definitive account of IS adoption in the Sundarbans. With this in mind, the following sections discuss the results in detail, situating them within the broader debates on governance, equity, and technological inclusion in small-scale fisheries.

5.4.1. Demographic, governance and technological interpretation

The analysis highlights the socio-economic profile of small-scale fishers, mainly mature men with limited formal education, facing regulatory challenges and limited digital access, where most rely on basic phones and radios. The perceptions of the V2V-IS app were neutral, i.e., they were neither strongly supportive, nor against, the test app, although half of the participants showed adoption potential. The demographic findings align with global trends in SSF, where middle-aged, male-dominated participation is prevalent due to historical gender roles, the physically demanding nature of fishing, and the tradition of intergenerational livelihood transfer.

Limited formal education among fishers reflects broader structural challenges in fishing communities, which can hinder their ability to navigate complex regulatory frameworks (Kleiber et al. 2017; Rao and Sophia 2023). And studies show that younger fishers are more likely to exit or not join declining fisheries, highlighting the influence of economic expansion and diversification, along with local development in other sectors (Daw et al. 2012). These demographic patterns would influence the adoption of the V2V-IS, with middle-aged male fishers showing relatively greater openness to digital tools, despite facing structural challenges and digital barriers. However, the success of such technology depends on participatory development approaches, as research by Smidt and Jokonya (2022) suggests that personal characteristics, including literacy, health, and cognitive abilities, significantly impact digital adoption. Therefore, ensuring inclusivity in design and implementation is critical to maximizing the benefits of the V2V-IS across all user groups.

The prevalence of capture fishing and aquaculture underscores regional livelihood dependencies, mirroring trends in other middle- and lower-income countries where fishers face systemic challenges such as fluctuating markets, declining fish stocks, and restrictive policies, along with economic and regulatory challenges, due to power asymmetry (FAO 2022; Béné et al. 2016). While this study does not explicitly examine the socio-economic distinctions between aquaculture and capture fishing, it is important to acknowledge that the SSF sector in the Sundarbans may not be socially or economically uniform. Observations and broader literature (Kelkar and Arthur 2022) suggest that aquaculture is often more accessible to fishers with land, capital, or institutional support, whereas capture fishing, particularly in rivers and forests, is more commonly practiced by those with limited resources. These differences may influence how fishers interact with and benefit from digital systems.

If an IS focuses more heavily on aquaculture-related content, it could unintentionally favour better-resourced users while overlooking the specific needs of traditional, forest-based fishers. To promote fairness and inclusivity, the app must cautiously strive to reflect diverse livelihood practices by incorporating features relevant to capture fishers, such as regulatory updates and safety alerts through offline functionality, along with support for collective organization. Recognizing these variations, even in the absence of detailed empirical data, is crucial to

ensuring that digital interventions contribute to a more equitable and context-sensitive support system for all SSF stakeholders.

The low rate of BLC renewal suggests structural inefficiencies in fisheries governance, particularly in bureaucratic delays, high renewal costs, and limited awareness among fishers. These barriers reinforce power asymmetries, where regulatory systems often disadvantage small-scale fishers while favouring intermediaries or politically connected groups. Similar patterns have been documented by Pomeroy et al. (2017) on fisheries governance, where poor policy implementation and weak institutional support result in widespread non-compliance. Addressing these gaps would require streamlining licensing procedures and ensuring that fishers receive direct support in navigating regulatory requirements.

The results on technology use highlight the persistent digital exclusion, as most fishers rely on basic phones and radios rather than smartphones or other digital platforms. This aligns with research emphasizing that limited digital literacy, infrastructure deficits, and high costs of mobile handsets and data prevent fishers from fully benefiting from digital innovations in fisheries management (Hidayat et al. 2024, Lahiri et al. 2024). While digital tools like mobile-based market updates and weather forecasts have the potential to support SSF, their impact remains constrained by accessibility barriers. These insights indicate the need for digital literacy training, the development of assisted, localized, voice-enabled interfaces, and investments in rural connectivity to bridge the digital divide.

Participants' neutral perceptions of the V2V-IS test app indicate usability and accessibility challenges, consistent with previous studies on technology adoption in fisheries. The lack of local language support, complex navigation, and unfamiliarity with digital platforms likely contributed to the lukewarm reception. However, the high likelihood of future adoption suggests that fishers recognize the potential benefits of a well-designed information system, provided that it meets their specific needs. Future interventions should focus on co-developing digital tools with fishing communities, ensuring language inclusivity, simplified interfaces, and training programs to build user confidence. Additionally, regulatory simplification, such as reducing bureaucratic barriers to licensing and market participation, would enhance compliance and encourage technology adoption, ultimately strengthening small-scale fisheries' resilience, as has been demonstrated by Mittal et al. (2019).

Women play a vital but often undervalued role in SSF, particularly in aquaculture and also forest-based crabbing. Although they make up over a quarter of participants, their contributions remain largely invisible, and their involvement in decision-making is limited. Studies by Roy et al. (2023), Dasgupta et al. (2022), and Koralagama et al. (2017) identify intersecting barriers: less education, cultural norms, restricted mobility, limited access to resources, and exclusion from policy processes, that continue to constrain women's recognition and empowerment in the sector. This pattern is echoed globally. Frangoudes et al. (2019) highlight women's vital yet often invisible roles in SSF and call for gender-sensitive policies that go beyond recognition to restructure institutions, redistribute power, and ensure inclusive development. However, Oreglia and Srinivasan (2016) warn that ICTs alone cannot empower women, especially in rural areas. True empowerment requires addressing these structural barriers. Tools like V2V-IS can help by offering women group spaces, peer learning, and direct links to decision-makers, building digital skills, visibility, and participation to close the gender digital divide.

5.4.2. Challenges and opportunities in the integration of digital tools

Fishers rely on culturally embedded ecological knowledge, including oral traditions, environmental patterns, and indigenous fishing techniques, which are increasingly threatened by modernization, regulatory changes, and environmental degradation. Interactive knowledge exchange between fishers, researchers, and policymakers is essential to conserve these traditional practices while incorporating scientific advancements in aquaculture, sustainable fishing, and disaster preparedness. Easily available training modules tailored to fishers' literacy levels and local language could bridge the gap between traditional methods and modern techniques, ensuring that innovation does not erode cultural identity but enhances resilience and sustainability, while addressing socio-economic and ecological challenges. The thematic insights highlight the need for a participatory approach towards learning and innovation in developing the V2V-IS, where scientific and traditional knowledge systems are integrated to support SSF in the Sundarbans.

Research highlights various ways in which local languages have been integrated into IS for SSF and agricultural extension services. In the case of Mbenji Island small-scale fishery in Malawi, Haambiya et al. (2021) emphasize the use of ICT to enhance fishery management, with a focus on delivering information in local languages to ensure better understanding and accessibility for

the local fishing communities. Similarly, Mittal et al. (2019) discuss how ICT strengthens extension services in India by incorporating local languages into mobile platforms and voice-based technologies, ensuring that agricultural and fishery advice is accessible to farmers and fishers in their native tongues. Ramamritham et al. (2006) also explore ICT tools for agricultural extension, highlighting the inclusion of local languages through interactive voice response systems, which cater to the linguistic diversity in rural areas. Furthermore, Walker (2021) details the delivery of value-added weather advisories to small-scale farmers in South Africa via mobile apps, which include localized language options to ensure that weather-related information is comprehensible to farmers, especially in rural areas where language barriers can hinder effective communication. These examples collectively demonstrate the importance of including local languages in IS to ensure inclusivity, accessibility, and the effective dissemination of knowledge.

Research highlights various ways in which local languages have been integrated into IS for SSF and agricultural extension services. In the case of Mbenji Island small-scale fishery in Malawi, Haambiya et al. (2021) emphasize the use of ICT to enhance fishery management, with a focus on delivering information in local languages to ensure better understanding and accessibility for the local fishing communities. Similarly, Mittal et al. (2019) discuss how ICT strengthens extension services in India by incorporating local languages into mobile platforms and voice-based technologies, ensuring that agricultural and fishery advice is accessible to farmers and fishers in their native tongues.

Ramamritham et al. (2006) also explore ICT tools for agricultural extension, highlighting the inclusion of local languages through interactive voice response systems, which cater to the linguistic diversity in rural areas. Furthermore, Walker (2021) details the delivery of value-added weather advisories to small-scale farmers in South Africa via mobile apps, which include localized language options to ensure that weather-related information is comprehensible to farmers, especially in rural areas where language barriers can hinder effective communication. These examples collectively demonstrate the importance of including local languages in IS to ensure inclusivity, accessibility, and the effective dissemination of knowledge.

Government actors remain skeptical about the scalability of V2V-IS, whereas fishers feel that the new technology would be used to monitor or control them more tightly. Financial, legal, institutional, and relational challenges, as highlighted by Bradley et al. (2019), pose obstacles to

innovation, underscoring the need for collaborative development to build credibility. Jeffers et al. (2019) highlight how local fishers' feedback on an information system refines data collection, ensuring the technology is accessible, effective, and promotes better participation and resultant empowerment in fisheries management. Parallely, ICT tools help facilitate better information flow and enable communities to provide feedback on fisheries management practices, ensuring that local knowledge and concerns are considered in decision-making processes, as was demonstrated by Haambiya et al. (2021).

Additionally, decision support systems, as discussed by Kelly et al. (2022), developed in collaboration with fishers provides real-time data on ocean conditions, weather, catch history, and market trends, and improves decision-making, promotes data sharing, and strengthens fisheries management through industry-research partnerships. Furthermore, research by Biswas et al. (2024) call for a holistic approach to conservation that integrates traditional wisdom with contemporary scientific knowledge, recognizing the multifaceted and dynamic relationship between humans and mangroves which could enhance the relevance and utility of the V2V-IS.

Currently, fishers depend on informal networks, radio broadcasts, and verbal updates from local authorities, which are often inconsistent and insufficient. Establishing a centralized digital platform that consolidates real-time market prices, regulatory guidelines, meteorological updates, and environmental impact data can empower fishers with actionable insights. Such a system should allow for participatory data collection, where fishers contribute localized observations on fish stocks, weather patterns, and resource availability, ensuring that the platform remains dynamic and community driven. Therefore, a data sovereignty networks approach is critical for addressing the lack of reliable and accessible information for SSF. Beyond technological interventions, systemic challenges such as governance, economic instability, and power imbalances require structural policy reforms. Research by Calderwood (2022) and Haese et al. (2024) highlights the potential of inclusive digital solutions that incorporate participatory design, Artificial Intelligence (AI)-driven tools, and multi-functional applications to improve accessibility and sustainability. Past ICT initiatives in agriculture, such as India's *e-Choupal* and *Bhoomi* (Tiwari 2008), revealed the benefits of digital platforms for resource-poor communities while stressing the need for better connectivity, content, and infrastructure. Ensuring long-term success requires iterative improvements based on continuous user feedback, sustainability

planning, and clear policies on data ownership to protect fishers' interests (Nguyen et al. 2018). Without these considerations, digital interventions risk exacerbating inequalities rather than fostering inclusive and sustainable fisheries management.

Many fishers have limited access to smartphones and stable internet connectivity, making traditional app-based solutions inadequate. Voice-enabled commands, offline functionality, and audiovisual content in simple Bangla language is expected to improve usability and inclusivity. Existing digital agricultural platforms, such as aAQUA (Ramamritham et al. 2006) and Ethiopia's ICT tools (Anteneh & Melak 2024), demonstrate the potential of integrating multilingual and multimedia support for improved communication and resource tracking, holding the key for effective management.

Additionally, integrating community-driven safety features, such as an SOS function for emergency alerts and secure data-sharing mechanisms, would significantly enhance fishers' security while at sea. Also, some participants have suggested alternative satellite-based solutions to address the issue of unreliable network coverage in remote areas. Alongside these technological solutions, institutional support through digital platforms could streamline bureaucratic processes, such as obtaining and renewing BLCs, and ensure transparency in regulatory enforcement. Accordingly, the V2V-IS should be designed with ethical technology integration to overcome digital literacy barriers and infrastructural limitations, as emphasized by Magloo et al. (2025).

Moreover, market and trade challenges further underscore the necessity for technological interventions. Fishers currently lack access to real-time market data, which leaves them vulnerable to price manipulation by intermediaries. Digital platforms that provide verified pricing information, financial resources, and opportunities for collective bargaining could strengthen their economic stability. Furthermore, establishing registered fishing unions or cooperative networks would enable fishers to negotiate fair trade terms and share knowledge on sustainable harvesting practices. However, concerns regarding data security and the potential misuse of such systems by external actors, including market exploiters and criminal elements like foreign sea robbers, highlight the critical need for community governance in data management. Institutional engagement and empowerment must therefore align with technological advancements to ensure long-term sustainability. To this end, fishery governance

structures, such as gram panchayats, NGOs, and regulatory bodies, must collaborate to design policies that promote digital adoption while safeguarding fishers' rights and resource management capabilities (Bradley et al. 2019).

In addition, simplifying regulatory frameworks, providing legal assistance, and ensuring transparency in market transactions through digital tools could enhance compliance and reduce exploitation. Addressing fishers' concerns about restrictive regulations, such as bans on mobile phone use in fishing zones, while integrating technology-based safety solutions could not only improve regulatory efficiency but also bolster fishers' resilience against environmental and socio-economic risks. As Srivastava et al. (2021) emphasize, simplified user interfaces, culturally inclusive and intuitive designs, and minimal manual data entry are essential for ensuring accessibility, making these features critical for the success of such initiatives.

The adoption of digital technologies in SSF is also shaped by the broader interaction between society and technology, where regulatory concerns, technological infrastructure, and economic conditions influence uptake. Additionally, weak network infrastructure, an emphasis on technological advancements without addressing socio-economic realities, and unstable incomes create uncertainty around adoption. Lessons from fisheries and agriculture suggest that conservation efforts, while essential for preserving the region's unique biodiversity, often conflict with the livelihood needs of local communities who rely on natural resources for survival (Ghosh 2015; Mistri & Das 2015). They highlight the socio-economic challenges fishers face due to these regulations, including restrictions on fishing zones, and how such policies can affect their income and overall well-being. Both these papers emphasized the need for balancing conservation efforts with the livelihoods of fishers to ensure both environmental protection and economic stability.

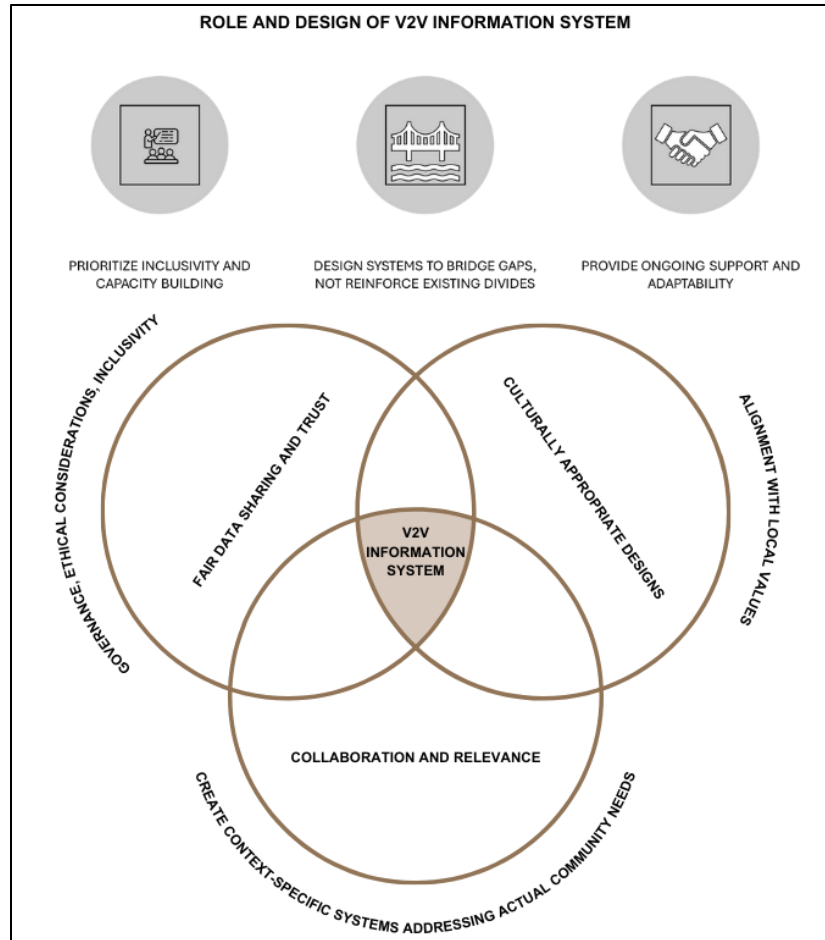


Fig. 8 Illustration of a proposed V2V-IS focusing on accessibility, capacity building, support, equity and resilience

The investigation emphasizes on developing the V2V-IS to an inclusive, adaptable knowledge management system for SSF, focusing on accessibility for all users, including those with limited literacy or digital skills as represented in Fig. 8. It advocates for bridging digital divides with localized, voice-enabled interfaces and offline capabilities, while promoting capacity building through participatory development and ongoing training. The system's evolution must be guided by continuous user feedback to ensure its relevance and sustainability. Addressing systemic issues like power imbalances and economic instability, the goal is to integrate ethical technology and community governance, ensuring long-term resilience and equity for fishers. Thus, the development of V2V-IS must be a platform that can enhance Sundarbans fishers' livelihoods, efficiency, resilience, and sustainability while preserving the region's unique socio-ecological fabric.

The themes discussed in the research directly address the gaps identified in the literature review by grounding them in the lived experiences of small-scale fishers in the Sundarbans, while also cautioning against the risks of poorly implemented digital interventions. First, the integration of traditional knowledge into digital platforms is demonstrated through fishers' reliance on indigenous ecological practices and the call for participatory systems that bridge scientific and local wisdom, emphasizing that innovation must enhance, not replace, cultural knowledge. Second, issues of equitable access are addressed by highlighting barriers such as low digital literacy, limited smartphone ownership, and financial constraints that disproportionately affect marginalized groups, especially women; proposed solutions include voice-enabled, offline-compatible, and Bangla-language interfaces. Third, power imbalances in co-production and governance are tackled by drawing attention to fishers' limited regulatory influence and emphasizing participatory design, data sovereignty, and institutional accountability.

However, if not carefully designed and governed, the V2V-IS risks reinforcing existing inequalities, increasing surveillance, and becoming a tool for regulatory control or market exploitation, particularly if middlemen manipulate access or if authorities misuse collected data. Fourth, the sustainability of ICT initiatives in low-resource settings is addressed through calls for ethical technology integration, iterative development based on user feedback, and robust local governance structures. Finally, the potential of data commons to improve fisheries governance is underscored through examples of community-driven decision-support systems, which allow fishers to actively shape resource management and challenge exploitative systems.

5.5. Conclusions and Reflections

This research set out to examine how an information system (V2V-IS) could be co-developed to support SSF in the Sundarbans by enhancing equity, inclusivity, and access to knowledge across diverse user groups. Rooted in qualitative, field-based inquiry, the study aimed to address key gaps in understanding how fishers engage with digital tools, particularly in resource-constrained, ecologically vulnerable, and socially heterogeneous contexts. While the research provides grounded insights into the experiences, needs, and aspirations of fishers, especially in relation to technology access, trust, and knowledge-sharing, there are limitations. The diversity of SSF actors, including distinctions between capture and aquaculture fishers, women and men, and more or less digitally confident users, proved difficult to fully capture in a single study.

Similarly, while the app development process reflected many co-design principles, the complexities of long-term adoption, evolving user priorities, and deeper power dynamics around resource access require continued attention. As such, this work should be viewed as part of an evolving, iterative exploration of how inclusive digital systems can be meaningfully embedded in complex social-ecological settings.

Despite these limitations, the research contributes to the growing discourse on equitable digital transformation in SSF by highlighting the potential of localized, co-produced information systems. The findings underscore the importance of building flexible, user-friendly platforms that embed traditional knowledge and accommodate low digital literacy through multimodal design (e.g., Bangla-language audio, offline functionality, voice commands). Equally important are support structures that extend beyond the interface itself. Approaches such as establishing village-level internet access hubs, encouraging device-sharing models, and pairing fishers with trained local “digital buddies” could help bridge digital divides and build trust among less confident users. Such models may be particularly valuable in supporting women, older fishers, and forest-based capture fishers who are often underserved in digital initiatives.

At the institutional level, aligning platforms like V2V-IS with national or state-led rural development and fisheries schemes could open pathways for policy integration and financial sustainability. Linking to tools such as the Matsyajibi Credit Card or real-time market updates might enhance the platform’s practical value, while also supporting its uptake. Additionally, governance structures that embed user feedback and community ownership, such as participatory evaluation mechanisms, grievance redressal systems, and community data commons, could help ensure accountability and transparency over time. These elements together point to a layered, equity-oriented approach that recognizes the differentiated realities of SSF actors.

Looking ahead, future work may explore how information systems like V2V-IS evolve once implemented, particularly in terms of their role in shaping governance practices, facilitating resource access, or altering power relations. More empirical research could also investigate the social and economic implications of designing for multiple user groups, such as aquaculture and capture fishers, and whether digital interventions can unintentionally reinforce existing inequalities. Longitudinal studies that examine how fishers’ trust in and engagement with such

platforms change over time would offer valuable insights into the sustainability of such initiatives. Likewise, deeper inquiry into community data governance, digital support ecosystems, and inclusive design strategies could help ensure that technologies not only serve but are co-governed by the communities they aim to empower. By maintaining a reflexive and adaptive orientation, future efforts can continue to build towards digital systems that support the resilience, dignity, and viability of small-scale fisheries in the Sundarbans and beyond.

Chapter 6

Discussion and Conclusion

This chapter synthesizes the study's key findings in relation to the central research questions, examining how small-scale fishers in the Sundarbans engage with IS amid intersecting challenges of digital inclusion, gendered access, and governance constraints. Drawing on empirical insights, it reflects on how localized knowledge systems, socio-political structures, and emerging digital interventions interact in shaping the lived realities of SSF communities, while also underscoring the importance of contextual grounding for achieving the study's objectives. Understanding social, cultural, and institutional dynamics is essential for identifying systemic barriers, situating stakeholder perspectives, and informing the design of systems that are not only technologically functional but also socially meaningful and trusted. The findings reaffirm that knowledge and information systems must be seen as iterative processes, emerging through cycles of interaction between traditional ecological practices, place-based social relations, and digital innovations, rather than as one-directional transfers of data or technology push. By linking these contextual insights with iterative design principles, the study advances a feedback mechanism between development, deployment, and lived experiences of use. In doing so, it integrates cross-cutting themes, including traditional ecological knowledge, gendered barriers, institutional dynamics, and technological potentials, to assess the viability of inclusive, context-sensitive information systems like V2V-IS. Ultimately, it shows that digital tools can support adaptive capacities and justice-oriented transitions, provided they are embedded within participatory frameworks that challenge exclusion, amplify local voices, and build resilience in ecologically and politically fragile regions.

6.1 Bridging knowledge gaps through a contextual approach

SSF in the Sundarbans are experiencing increasing stress from environmental degradation, modernization, and restrictive regulations, which are eroding traditional ecological knowledge passed down through generations. This indigenous knowledge, rooted in spiritual beliefs, oral traditions, and lived experiences, remains foundational to local practices of fishing, aquaculture, and risk navigation. However, barriers such as low literacy, lack of localized resources, and

policies restricting the use of mobile phones during forest expeditions hinder the fishers' ability to adapt (Altieri & Nicholls, 2017; Chen & Cheng, 2020).

Studies from other coastal contexts echo these concerns. Chowdhoree (2019) and Vögler et al. (2023) show how communities in Bangladesh and Uruguay rely on a mix of traditional coping strategies, such as interpreting tidal cues and using herbal medicine, yet remain vulnerable due to poor institutional support and inadequate early warning systems. These failures underscore the importance of hybrid models that combine traditional and scientific knowledge, especially in areas affected by micro-climatic variability.

Equally significant is the role of informal learning networks in sustaining knowledge exchange. Fishers and local actors in the Sundarbans consistently favour vernacular, experiential, and peer-to-peer modes of communication. This aligns with Zamiri and Esmaeili (2024), who advocate for Communities of Practice, storytelling, and mentorship in enhancing community resilience through localized learning.

To address communication and safety challenges, the integration of mobile information systems has emerged as a promising solution. Winschiers-Theophilus et al. (2013) highlight how mobile platforms in rural Africa preserved indigenous knowledge by delivering multimedia-enabled, culturally embedded content in local languages. Such systems, if adapted to Sundarbans' context in Bangla and designed for low-literacy users, could deliver real-time ecological alerts, localized training, and market data, reinforcing cultural identity while modernizing practice.

However, market instability and institutional neglect continue to force Sundarbans fishers into ecologically harmful strategies such as harvesting immature crabs. As Béné (2003) argues, poverty in SSF is not merely resource-based but structurally driven by weak institutional support and market exclusion. This is echoed in Chuenpagdee et al. (2006), who show that SSF, while crucial for food security, remain largely invisible in national statistics and policy discourse. The FAO's Voluntary Guidelines (2015) thus call for better access to market information, secure tenure, and fishers' inclusion in decision-making.

In the villages like Samshernagar and Kumirmari, some fishers rely on fragmented tools like WhatsApp for market information, which lack consistency and formal recognition. Participants

in the study demanded a centralized mobile system that integrates real-time prices, financial services, union-building tools, and policy updates. Anand et al. (2024) argue that such platforms are vital for enabling fishers to stabilize incomes and gain bargaining power within a more equitable ecosystem.

Despite the efforts of NGOs, panchayats, and government bodies in training and support, most interventions fail to reach marginalized, forest-based fishers, who face both ecological and bureaucratic exclusion. Jeffers et al. (2019), Tilley et al. (2021), and Bolognini et al. (2023) have documented how ICT integration improves governance and decision-making in SSF, yet challenges such as digital divides, infrastructure gaps, and lack of localized content persist.

Vögler et al. (2023) further confirm these global patterns of vulnerability, highlighting how weak regulations, exclusion from governance, and bureaucratic barriers reduce fishers' adaptive capacity. Such insights underline that while digital tools are necessary, they are insufficient unless paired with systemic reforms that recognize traditional knowledge, enhance local governance, and ensure inclusive participation.

In conclusion, the sustainable management of SSF in the Sundarbans requires a dual approach: the co-development of mobile information systems that respect cultural context and technological accessibility, and broader institutional reforms that empower fishers as knowledge-holders and decision-makers. Drawing on lessons from global studies, an integrated strategy that blends traditional wisdom with scientific and digital innovations is essential for building resilient, equitable, and ecologically sound fisheries.

6.2 Bridging the gender gap through technology

Women in capture fisheries and aquaculture contribute significantly to these sectors but continue to face gendered constraints such as limited decision-making power, unequal access to resources, and entrenched social norms. Galappaththi et al. (2022) highlight how women are excluded from fisheries governance due to systemic barriers like limited mobility, lack of formal permits and fishing gear, and social expectations that confine them to domestic and labour-intensive roles. These structural inequalities marginalize women's leadership potential and restrict their access to market information and training.

Earlier, Koralagama et al. (2017) emphasized that simply providing information is insufficient, technological interventions must be gender-sensitive and tailored to the specific needs of women, particularly those with low literacy or mobility. Voice-based interfaces, offline access, and localized content can help women bypass male intermediaries and participate more autonomously in fisheries decision-making.

Emeana et al. (2020) demonstrated in the agriculture sector that mobile systems can foster women's economic empowerment, but only when designed inclusively. Their research on m-Agri platforms underscores the importance of involving women in the design process to ensure systems align with their lived realities and address socio-cultural constraints. Sen (2021) extends this critique to forest governance, showing how institutional frameworks like the Forest Rights Act and Joint Forest Management perpetuate male dominance. Even when women hold formal leadership roles, such as a Panchayat Pradhan, they often remain influenced by male elites. Women's active roles in conservation are thus overshadowed, limiting their influence on decision-making processes.

Collectively, these studies call for a transformative approach to governance and technology design, one that combines inclusive policies (e.g., gender quotas, leadership training, and support for women's cooperatives) with context-sensitive digital tools. Such integration can dismantle entrenched patriarchal systems and enable women to access resources, build networks, and assert leadership in male-dominated spaces.

6.3 Governance dynamics

Local governance institutions such as Panchayats and JFMCs are central to negotiating access, resolving conflicts, and navigating regulatory systems in the Sundarbans. These bodies often assist fishers, such as by negotiating with the BSF or retrieving seized boats, but their effectiveness is uneven, shaped by leadership, local politics, and state engagement. This reflects findings by Béné et al. (2009), who documented similar patterns in sub-Saharan Africa, where co-management initiatives intended to empower local fishers were undermined by elite capture and weak institutional capacity.

Also, in the Sundarbans, inconsistent governance support often forces marginalized groups, tribal families, widows, and recent migrants, to rely on informal community networks or NGOs. Their experience of state welfare is marked by corruption, delayed aid, and discrimination, particularly in cyclone relief and tiger compensation schemes. Birkmann et al. (2022) found comparable patterns across Africa, Asia, and the Caribbean, where systemic governance failures and structural inequalities lead to public disillusionment and a shift toward non-state actors for basic support.

At the same time, enforcement of forest and fisheries regulations is marked by discretionary authority. Fishers lacking documentation report harassment, fines, or confiscation of gear, while better-connected actors navigate these systems with ease. This selective enforcement deepens livelihood precarity and reinforces structural inequities. Ertör (2023) similarly critiques how such asymmetries erode trust in the state and marginalize small-scale fishers under the guise of sustainability and regulation.

The broader regulatory environment aims to balance sustainability and livelihoods through mechanisms like fishing permits (BLCs) and alternative livelihoods such as ecotourism or handicrafts. However, low literacy and poor digital access often exclude the most vulnerable fishers from participating. Sen (2021) notes that local governance in the Sundarbans remains dominated by political interests, with marginalized voices sidelined in resource access and decision-making.

Global parallels exist. Salmi et al. (2022) found that local action groups in Finland and Sweden risk excluding small-scale fishers if programs are not designed to be inclusive and community led. Similarly, Jeffers et al. (2019) emphasize that limited education and income constrain the ability of fishers to access digital systems or comply with complex regulations. These critiques underscore the need for inclusive governance, one that simplifies permits, ensures transparent grievance mechanisms, and enables digital tools for low-literate, off-grid communities.

A more promising model comes from Anand et al. (2024), who designed a community-led, IoT-enabled digital ecosystem in Kerala. It delivers deep-sea communication, weather alerts, market information, and blockchain-based transactions to empower fishers directly. The system

promotes safety, fair pricing, and sustainability, showing that participatory digital infrastructure, when co-developed with communities, can bridge gaps in trust, equity, and access.

6.4 Precarious Adaptations

The changing socio-ecological landscape of the Sundarbans has compelled small-scale fishers to adopt a range of contingent adaptive responses in response to mounting climatic, ecological, and institutional pressures. Environmental hazards such as cyclones, sea-level rise, and tiger attacks, alongside institutional barriers like costly BLCs, gear confiscation, and restricted forest access, have undermined the viability of traditional fishing. As a result, fishers, particularly women and youth, are increasingly turning to aquaculture, wage labour, ecotourism, or micro-enterprises. However, these changes are less about choice and more about coping with exclusion and uncertainty, echoing similar findings in the Chilika Lagoon by Nayak (2017), who documented how ecological decline and shifting governance mechanisms disrupted traditional fishing economies.

While such diversification may offer temporary economic relief, it rarely translates into long-term security. Aquaculture, for instance, is often marred by disease outbreaks, premature crab harvesting, market volatility, and environmental degradation. The lack of formal training, weak legal safeguards, and inconsistent market linkages further perpetuate livelihood instability. Engle and van Senten (2022) argue that well-structured regulatory frameworks are essential for mitigating such risks and ensuring sustainable outcomes in aquaculture-based livelihoods, a condition largely unmet in current practice in the Sundarbans.

Digital interventions, particularly mobile-based technologies, have emerged as potential tools to support SSF by improving access to weather alerts, market information, and governance updates. However, Emeana et al. (2020) caution that without grounding these tools in users' socio-cultural realities, such as local languages, digital literacy, and device access, they may exacerbate existing inequities. Similarly, Salmi et al. (2022) warn that top-down technologies lacking community participation risk excluding the very populations they intend to empower. Field narratives from the Sundarbans reflect a tension that fishers are cautiously optimistic about

digital tools but stress that these must complement, not replace, vernacular knowledge and collective practices.

In due course, digital solutions must be co-developed, culturally embedded, and tailored to low-connectivity environments. However, for them to be effective, they must be integrated with broader measures like secure access to resources, stronger cooperatives, and inclusive governance models that centre ecological sustainability and community agency. Some suggestions and ideas for improving the V2V-IS which emerged from this research have been provided in Appendix A.

6.5 Conclusion

In conclusion, this research highlights the critical need for an inclusive, community-driven approach to the design and implementation of digital systems, particularly the V2V-IS, for SSF in the Sundarbans. The integration of traditional ecological knowledge with digital tools is essential for empowering local fishers, along with side-lined groups like women, who face systemic power imbalances and societal constraints that limit their access to resources and decision-making processes.

While digital tools, such as mobile applications, offer significant potential to provide timely weather updates, market data, and regulatory information, their effectiveness is contingent on overcoming challenges like the digital divide, language barriers, and low literacy. Therefore, technology needs to be co-designed with stakeholders, in order to complement, and not replace indigenous practices, enabling a participatory model of resource management rooted in both scientific and local knowledge, and avoid the imposition of top-down solutions that may inadvertently reinforce exclusions.

Furthermore, the study emphasizes the role of local governance structures, such as Panchayats and JFMCs, in facilitating access to resources and conflict resolution. However, these institutions are often undermined by corruption and elite capture, which leave marginalized groups, such as tribal households and women, relying on NGOs or informal networks for support. Addressing these institutional shortcomings is necessary for equitable technology adoption.

The findings also highlight the urgent need for inclusive policies and leadership training that empower women in fisheries and aquaculture. Without such interventions, the potential of digital tools to address gendered power imbalances will remain limited, as seen in the experiences of women fishers in the Sundarbans.

Ultimately, the success of technological interventions depends on their integration within a comprehensive, participatory framework that respects local realities, challenges exclusions, and supports collective agency. By ensuring that digital systems like V2V-IS are co-designed with the community, prioritize inclusivity, and align with local knowledge and governance structures, these tools can empower small-scale fishers, enhance livelihoods, and promote sustainable and equitable resource management in the Sundarbans.

References

- Adu, P., 2019. A step-by-step guide to qualitative data coding. Routledge.
- Agapito, M., Chuenpagdee, R., Devillers, R., Gee, J., Johnson, A.F., Pierce, G.J. and Trouillet, B., 2019. Beyond the basics: improving information about small-scale fisheries.
- Agusa, Y., Fujihashi, T., Endo, K., Kuroda, H. and Kobayashi, S., 2021. Development of seawater temperature announcement system for improving efficiency of fishery industry. *Journal of Information and Telecommunication*, 5(1), pp.62-82.
- Altieri, M.A. and Nicholls, C.I., 2017. The adaptation and mitigation potential of traditional agriculture in a changing climate. *Climatic change*, 140, pp.33-45.
- Anand, S., Enayati, M., Raj, D., Montresor, A. and Ramesh, M.V., 2024. Internet over the ocean: A smart IoT-enabled digital ecosystem for empowering coastal fisher communities. *Technology in Society*, 79, p.102686.
- Anderies, J.M., Janssen, M.A. and Ostrom, E., 2004. A framework to analyze the robustness of social-ecological systems from an institutional perspective. *Ecology and society*, 9(1).
- Anteneh, A. and Melak, A., 2024. ICT-based agricultural extension and advisory service in Ethiopia: a review. *Cogent Food & Agriculture*, 10(1), p.2391121.
- Aura, C.M., Nyamweya, C.S., Njiru, J.M., Odoli, C., Musa, S., Ogari, Z., Abila, R., Okeyo, R. and Oketch, R., 2019. Using fish landing sites and markets information towards quantification of the blue economy to enhance fisheries management. *Fisheries Management and Ecology*, 26(2), pp.141-152.

- Ban, N.C., Frid, A., Reid, M., Edgar, B., Shaw, D. and Siwallace, P., 2018. Incorporate Indigenous perspectives for impactful research and effective management. *Nature ecology & evolution*, 2(11), pp.1680-1683.
- Baarbé, J., Blom, M. and De Beer, J., 2019. A proposed" agricultural data commons" in support of food security. *The African Journal of Information and Communication*, 23, pp.1-33.
- Baxter, J. and Eyles, J., 1997. Evaluating qualitative research in social geography: establishing 'rigour' in interview analysis. *Transactions of the Institute of British geographers*, 22(4), pp.505-525.
- Bebbington, A., 1999. Capitals and capabilities: a framework for analyzing peasant viability, rural livelihoods and poverty. *World Development*, 27(12), pp.2021-2044.
- Benard, R. and Dulle, F., 2017. Application of ICT tools in communicating information and knowledge to artisanal fishermen communities in Zanzibar. *Knowledge Management & E-Learning*, 9(2), p.239.
- Béné, C., 2003. When fishery rhymes with poverty: a first step beyond the old paradigm on poverty in small-scale fisheries. *World development*, 31(6), pp.949-975.
- Béné, C., Belal, E., Baba, M.O., Ovie, S., Raji, A., Malasha, I., Njaya, F., Andi, M.N., Russell, A. and Neiland, A., 2009. Power struggle, dispute and alliance over local resources: analyzing 'democratic' decentralization of natural resources through the lenses of Africa inland fisheries. *World Development*, 37(12), pp.1935-1950.
- Béné, C., Arthur, R., Norbury, H., Allison, E.H., Beveridge, M., Bush, S., Campling, L., Leschen, W., Little, D., Squires, D. and Thilsted, S.H., 2016. Contribution of

- fisheries and aquaculture to food security and poverty reduction: assessing the current evidence. *World development*, 79, pp.177-196.
- Berenji, S., Nayak, P.K. and Shukla, A., 2021. exploring values and beliefs in a complex coastal social-ecological system: a case of small-scale fishery and dried fish production in Sagar Island, Indian Sundarbans. *Frontiers in Marine Science*, 8, p.795973.
- Berkes, F. and Nayak, P.K., 2018. Role of communities in fisheries management: “one would first need to imagine it”. *Maritime studies*, 17, pp.241-251.
- Bhandari, A., Bohara, A. and Satyal, S.R., 2014. ICT innovation in disseminating agriculture information in 4 village development committees of Gulmi District. *Development*, 57(75), p.132.
- Bhowmick, D., 2024. Political ecology of climate change in Sundarbans, India: Understanding well-being, social vulnerabilities, and community perception. *Environmental Quality Management*, 33(3), pp.371-382.
- Binder, C.R., Hinkel, J., Bots, P.W. and Pahl-Wostl, C., 2013. Comparison of frameworks for analyzing social-ecological systems. *Ecology and society*, 18(4).
- Birkmann, J., Liwenga, E., Pandey, R., Boyd, E., Djalante, R., Gemenne, F., Leal Filho, W., Pinho, P., Stringer, L. and Wrathall, D., 2022. Poverty, livelihoods and sustainable development.
- Biswas, C., Channarayapatna, S. and Pandey, C.N., 2024. Livelihood and Beyond Relations of Local Communities with Sundarban Mangroves.
- Bockstael, E., 2017. Critical capacity development: an action research approach in coastal Brazil. *World Development*, 94, pp.336-345.

- Bolognini, L., Frittelloni, C., Perretta, F., Scanu, M. and Grati, F., 2023. From Crisis to Opportunity: Developing a Virtual Marketplace to Enhance Sustainability and Resilience in Small-Scale Fisheries. *Fishes*, 8(5), p.272.
- Boiral, O. and Heras-Saizarbitoria, I., 2017. Managing biodiversity through stakeholder involvement: why, who, and for what initiatives? *Journal of Business Ethics*, 140(3), pp.403-421.
- Borgman, C.L., 2017. Big data, little data, no data: Scholarship in the networked world. MIT press.
- Bose, H., 1986. Information Science: Principles and Practice. New Delhi: Serling Publishers.
- Bradley, D., Merrifield, M., Miller, K.M., Lomonico, S., Wilson, J.R. and Gleason, M.G., 2019. Opportunities to improve fisheries management through innovative technology and advanced data systems. *Fish and fisheries*, 20(3), pp.564-583.
- Calderwood, J., 2022. Smartphone application use in commercial wild capture fisheries. *Reviews in Fish Biology and Fisheries*, 32(4), pp.1063-1083.
- Chandra, G. and Sagar, R., 2003. Fisheries in Sundarbans: problems and prospects. Available at SSRN 2084014.
- Chavance, P., Morand, P., Thibaut, L. and Bâ, M., 2007. Challenges and difficulties of cooperation between fisheries information systems—Experiences in six West African developing countries. *Ocean & coastal management*, 50(9), pp.713-731.
- Chen, T.L. and Cheng, H.W., 2020. Applying traditional knowledge to resilience in coastal rural villages. *International Journal of Disaster Risk Reduction*, 47, p.101564.

- Chowdhoree, I., 2019. Indigenous knowledge for enhancing community resilience: An experience from the south-western coastal region of Bangladesh. *International Journal of Disaster Risk Reduction*, 40, p.101259.
- Chuenpagdee, R., Degnbol, P., Bavinck, M., Jentoft, S., Johnson, D., Pullin, R. and Williams, S., 2005. Challenges and concerns in capture fisheries and aquaculture. *Fish for life: interactive governance for fisheries*. Amsterdam University Press, Amsterdam, The Netherlands, pp.25-40.
- Chuenpagdee, R., Liguori, L., Palomares, M.L.D. and Pauly, D., 2006. Bottom-up, global estimates of small-scale marine fisheries catches, *Fisheries*.
- Chuenpagdee, R. ed., 2011. *World small-scale fisheries: contemporary visions*. Eburon Uitgeverij BV.
- Chuenpagdee, R., Rocklin, D., Bishop, D., Hynes, M., Greene, R., Lorenzi, M.R. and Devillers, R., 2019. The global information system on small-scale fisheries (ISSF): a crowdsourced knowledge platform. *Marine Policy*, 101, pp.158-166.
- Census of India. (2011). Office of the Registrar General and Census Commissioner, New Delhi. Available online at: https://www.censusindia.gov.in/2011census/population_enumeration.aspx
- Collins, A.M., Grant, J.A. and Ackah-Baidoo, P., 2019. The glocal dynamics of land reform in natural resource sectors: Insights from Tanzania. *Land use policy*, 81, pp.889-896.
- Cooke, S.J., Nguyen, V.M., Chapman, J.M., Reid, A.J., Landsman, S.J., Young, N., Hinch, S.G., Schott, S., Mandrak, N.E. and Semeniuk, C.A., 2021. Knowledge co-production: A pathway to effective fisheries management, conservation, and governance. *Fisheries*, 46(2), pp.89-97.

- Creswell, J.W. and Clark, V.L.P., 2011. Designing and Conducting Mixed Methods Research. SAGE.
- Creswell, J.W. and Creswell, J.D., 2018. Research design: Qualitative, quantitative, and mixed methods approaches. Sage publications.
- Dasgupta, S., Wheeler, D. and Ghosh, S., 2022. Fishing in Salty Waters: Poverty, Occupational Saline Exposure, and Women's Health in the Indian Sundarban. *J. Mgmt. & Sustainability*, 12, p.1.
- Daw, T.M., Cinner, J.E., McClanahan, T.R., Brown, K., Stead, S.M., Graham, N.A. and Maina, J., 2012. To fish or not to fish: factors at multiple scales affecting artisanal fishers' readiness to exit a declining fishery. *PLoS One*, 7(2), p.e31460.
- Dekker, E. and Kuchař, P., 2024. Markets and knowledge commons: Is there a difference between private and community governance of markets? *Public Choice*, 201(3): 533-553.
- Dias, A.C.E., Armitage, D., Nayak, P.K., Akintola, S.L., Arizi, E.K., Chuenpagdee, R., Das, B.K., Diba, S.A., Ghosh, R., Isaacs, M. and Islam, G.M.N., 2023. From vulnerability to viability: A situational analysis of small-scale fisheries in Asia and Africa. *Marine Policy*, 155, p.105731.
- Donner, J., 2009. Mobile-based livelihood services for individuals, small farms and micro & small enterprises in Africa: Pilot and early deployments. In *Conference on Development and Information Technologies. Mobile Phones and Internet in Latin America and Africa: What Benefits for the Most Disadvantaged*, pp. 23-24.

- Dorward, A., Poole, N., Morrison, J., Kydd, J. and Urey, I., 2003. Markets, institutions and technology: Missing links in livelihoods analysis. *Development policy review*, 21(3), pp.319-332.
- Durán, Y., Gómez-Valenzuela, V. and Ramírez, K., 2023. Socio-technical transitions and sustainable agriculture in Latin America and the Caribbean: a systematic review of the literature 2010–2021. *Frontiers in Sustainable Food Systems*, 7, p.1145263.
- Elmhirst, R., 2011. Introducing new feminist political ecologies. *Geoforum*, 42(2), pp.129-132.
- Emeana, E.M., Trenchard, L. and Dehnen-Schmutz, K., 2020. The revolution of mobile phone-enabled services for agricultural development (m-Agri services) in Africa: The challenges for sustainability. *Sustainability*, 12(2), p.485.
- Engle, C.R. and van Senten, J., 2022. Resilience of communities and sustainable aquaculture: Governance and regulatory effects. *Fishes*, 7(5), p.268.
- Ertör, I., 2023. ‘We are the oceans, we are the people!’: fisher people’s struggles for blue justice. *The Journal of Peasant Studies*, 50(3), pp.1157-1186.
- Fairbairn, M. and Kish, Z., 2023. Setting data free: The politics of open data for food and agriculture. *new media & society*, 25(8), pp.1935-1959.
- Food and Agriculture Organization (FAO) of the United Nations, Rome, 2015. Voluntary guidelines for securing sustainable small-scale fisheries in the context of food security and poverty eradication.
- FAO. (2022). The State of World Fisheries and Aquaculture 2022. Towards Blue Transformation. Rome, FAO. <https://doi.org/10.4060/cc0461en>
- Feoli, E. and Nauen, C.E., 2001. ACP-EU Fisheries Research Initiative. Proceedings of the INCO-DEV International Workshop on Information Systems for Policy and

- Technical Support in Fisheries and Aquaculture Los Baños, Philippines, 5-7 June 2000. ACP-EU Fisheries Research Report.
- Fisher, J.B. and Fortmann, L., 2010. Governing the data commons: Policy, practice, and the advancement of science. *Information & management*, 47(4), pp.237-245.
- Frangoudes, K., Gerrard, S. and Kleiber, D., 2019. Situated transformations of women and gender relations in small-scale fisheries and communities in a globalized world. *Maritime Studies*, 18(3), pp.241-248.
- Freduah, G., Fidelman, P. and Smith, T.F., 2018. Mobilising adaptive capacity to multiple stressors: Insights from small-scale coastal fisheries in the Western Region of Ghana. *Geoforum*, 91, pp.61-72.
- Frischmann, B.M., Madison, M.J. and Strandburg, K.J., 2014. Governing knowledge commons. In *Governing knowledge commons*. Oxford University Press. pp.1-44.
- Galappaththi, M., Armitage, D. and Collins, A.M., 2022. Women's experiences in influencing and shaping small-scale fisheries governance. *Fish and Fisheries*, 23(5), pp.1099-1120.
- Gammage, L.C. and Jarre, A., 2020. Using structured decision-making tools with marginalised fishers to promote system-based fisheries management approaches in South Africa. *Frontiers in Marine Science*, 7, p.477.
- Garces, L.R., Silvestre, G.T., Stobutzki, I., Gayanilo Jr, F.C., Valdez, F., Saupi, M., Boonvanich, T., Roongratri, M., Thouc, P., Haroon, I. and Kurup, K.N., 2006. A regional database management system—the fisheries resource information system and tools (FiRST): Its design, utility and future directions. *Fisheries Research*, 78(2-3), pp.119-129.
- Gerring, J., 2006. *Case study research: Principles and practices*. Cambridge University Press.

- Ghose, R., 2001. Use of information technology for community empowerment: Transforming geographic information systems into community information systems. *Transactions in GIS*, 5(2), pp.141-163.
- Ghosh, P., 2015. Conservation and conflicts in the Sundarban biosphere reserve, India. *Geographical Review*, 105(4), pp.429-440.
- Gianelli, I., Ortega, L., Pittman, J., Vasconcellos, M. and Defeo, O., 2021. Harnessing scientific and local knowledge to face climate change in small-scale fisheries. *Global Environmental Change*, 68, p.102253.
- Gibson, K., Rose, D.B. and Fincher, R., 2015. Manifesto for Living in the Anthropocene (p. 182). Punctum books.
- Gil, R.M., Ryan, M. and García, R., 2025. Sovereignty by design and human values in agriculture data spaces. *Agriculture and Human Values*, pp.1-26.
- Goodwin, G., 2019. The problem and promise of coproduction: Politics, history, and autonomy. *World Development*, 122, pp.501-513.
- Grassle, J.F., 2000. The Ocean Biogeographic Information System (OBIS): an on-line, worldwide atlas for accessing, modeling and mapping marine biological data in a multidimensional geographic context. *Oceanography*, 13(3), pp.5-7.
- Grati, F., Azzurro, E., Scanu, M., Tassetti, A.N., Bolognini, L., Guicciardi, S., Vitale, S., Scannella, D., Carbonara, P., Dragičević, B. and Ikica, Z., 2022. Mapping small-scale fisheries through a coordinated participatory strategy. *Fish and fisheries*, 23(4), pp.773-785.
- Gurstein, M.B., 2011. Open data: Empowering the empowered or effective data use for everyone? *First Monday*.

- Haambiya, L., Mussa, H. and Mulumpwa, M., 2021. A review on the use of Information Communication Technology (ICT) in fisheries management: A case of Mbenji Island small-scale fishery in Malawi. *African Journal of Food, Agriculture, Nutrition and Development*, 20(7), pp.17113-17124.
- Haese, A., Rouhani, Q., Mabasa, N., Trollope, B., van Zyl, C. and Chisenga, P., 2024. Addressing Accessibility of Online Platforms for Low-Literacy Users in Small-Scale Aquaculture.
- Hall, G.B. and Close, C.H., 2007. Local knowledge assessment for a small-scale fishery using geographic information systems. *Fisheries Research*, 83(1), pp.11-22.
- Hariyanto, H. and Anwar, M., 2019, April. Socio-technical approach to agricultural information systems development. In 1st International Conference on Advanced Multidisciplinary Research (ICAMR 2018) (pp. 469-474). Atlantis Press.
- Hay, I. and Cope, M., 2021. *Qualitative Research Methods in Human Geography*. Oxford University Press.
- Heeks, R., 1999. Information and communication technologies, poverty and development. Development informatics working paper (5), Institute for Development Policy and Management.
- Heeks, R., 2012. Deriving an ICT4D research agenda: a commentary on ‘Information and communication technologies for development (ICT4D): solutions seeking problems?’. *Journal of Information Technology*, 27, pp.339-341.
- Hess, C. and Ostrom, E., 2003. Ideas, artifacts, and facilities: information as a common-pool resource. *Law and contemporary problems*, 66(1/2), pp.111-145.

- Hidayat, R., Cindrakasih, R.R., Feriyanti, Y.G. and Razali, G., 2024. The Use of Modern Information Technology (IT) in Extension Services: A Case Study on IT Utilization Among Farmers and Fishermen. *INTERACTION: Jurnal Pendidikan Bahasa*, 11(2), pp.905-915.
- Hossain, P.R., Ludwig, F. and Leemans, R., 2018. Adaptation pathways to cope with salinization in south-west coastal region of Bangladesh. *Ecology and Society*, 23(3).
- Horta, S. and Defeo, O., 2012. The spatial dynamics of the whitemouth croaker artisanal fishery in Uruguay and interdependencies with the industrial fleet. *Fisheries Research*, 125, pp.121-128.
- Hsu, W.W., Wang, S.Y., Hong, W.S., Hu, R.H., Yu, C.J. and Tasi, H.Y., 2019, October. Portable fisheries assistant systems for small scale fisheries management. In 2019 IEEE Eurasia Conference on IOT, Communication and Engineering (ECICE) (pp. 10-13). IEEE.
- Huxham, M., Dencer-Brown, A., Diele, K., Kathiresan, K., Nagelkerken, I. and Wanjiru, C., 2017. Mangroves and people: local ecosystem services in a changing climate. *Mangrove Ecosystems: A Global Biogeographic Perspective: Structure, Function, and Services*, pp.245-274.
- Inskip, C., Ridout, M., Fahad, Z., Tully, R., Barlow, A., Barlow, C.G., Islam, M.A., Roberts, T. and MacMillan, D., 2013. Human-tiger conflict in context: risks to lives and livelihoods in the Bangladesh Sundarbans. *Human ecology*, 41, pp.169-186.
- Islam, M.M., Sunny, A.R., Hossain, M.M. and Friess, D.A., 2018. Drivers of mangrove ecosystem service change in the Sundarbans of Bangladesh. *Singapore Journal of Tropical Geography*, 39(2), pp.244-265.

- Islam, S.N., 2019. Sundarbans a dynamic ecosystem: an overview of opportunities, threats and tasks. *The Sundarbans: A Disaster-Prone Eco-Region: Increasing Livelihood Security*, pp.29-58.
- Jeffers, V.F., Humber, F., Nohasiarivelo, T., Botosoamananto, R. and Anderson, L.G., 2019. Trialling the use of smartphones as a tool to address gaps in small-scale fisheries catch data in southwest Madagascar. *Marine Policy*, 99, pp.267-274.
- Jentoft, S. and Chuenpagdee, R., 2015. Interactive governance for small-scale fisheries. *Global Reflections*. Dordrecht, MA: Springer.
- Kabir, K.A., Saha, S.B. and Phillips, M., 2019. Aquaculture and Fisheries in the Sundarbans and Adjacent Areas in Bangladesh: Resources, Productivity, Challenges and Opportunities. *The Sundarbans: A Disaster-Prone Eco-Region: Increasing Livelihood Security*, pp.261-294.
- Kelkar, N. and Arthur, R.I., 2022. A review of governance and tenure in inland capture fisheries and aquaculture systems of India.
- Kelly, C., Michelsen, F.A., Reite, K.J., Kolding, J., Varpe, Ø., Berset, A.P. and Alver, M.O., 2022. Capturing big fisheries data: Integrating fishers' knowledge in a web-based decision support tool. *Frontiers in Marine Science*, 9, p.1051879.
- Khan, F.N., Collins, A.M., Nayak, P.K. and Armitage, D., 2018. Women's perspectives of small-scale fisheries and environmental change in Chilika lagoon, India. *Maritime Studies*, 17, pp.145-154.
- Kisena, M.T. and Kwesigabo, E.M., 2023. Assessing the Contribution of Mobile Phone Agricultural Information on Maize Productivity: A Case Study of Kilolo District,

- Tanzania. *European Journal of Theoretical and Applied Sciences*, 1(6), pp.1096-1105.
- Kleiber, D., Frangoudes, K., Snyder, H.T., Choudhury, A., Cole, S.M., Soejima, K., Pita, C., Santos, A., McDougall, C., Petrics, H. and Porter, M., 2017. Promoting gender equity and equality through the small-scale fisheries guidelines: experiences from multiple case studies. *The small-scale fisheries guidelines: global implementation*, pp.737-759.
- Kooiman, J., Jentoft, S., Bavinck, M. and Pullin, R., 2005. *Fish for life: interactive governance for fisheries* (p. 432). Amsterdam university press.
- Koralagama, D., Gupta, J. and Pouw, N., 2017. Inclusive development from a gender perspective in small scale fisheries. *Current Opinion in Environmental Sustainability*, 24, pp.1-6.
- Lahiri, B., Kurmi, R.K., Singh, S.K., Ghosh, A., Pal, P., Kumar, S.T.P., Nirmalkar, C. and Debnath, A., 2024. Determinants of Digitised Farm Information Outreach in Aquaculture: A Case of Mobile Phone Application for Smallholder Fish Farmers in North East India. *Journal of the Knowledge Economy*, pp.1-39.
- Langefors, B., 1977. Information systems theory. *Information Systems*, 2(4): 207-219.
- Latour, B. (1992). *Where Are the Missing Masses? The Sociology of a Few Mundane Artifacts*. In W. E. Bijker & J. Law (Eds.), *Shaping Technology/Building Society: Studies in Sociotechnical Change* (pp. 225-258). MIT Press.
- Legard, R., Keegan, J. and Ward, K., 2003. In-depth interviews. *Qualitative research practice: A guide for social science students and researchers*, 6(1), pp.138-169.

- Leonelli, S., 2013. Why the current insistence on open access to scientific data? Big data, knowledge production, and the political economy of contemporary biology. *Bulletin of Science, Technology & Society*, 33(1-2), pp.6-11.
- Léopold, M., Guillemot, N., Rocklin, D. and Chen, C., 2014. A framework for mapping small-scale coastal fisheries using fishers' knowledge. *ICES Journal of Marine Science*, 71(7), pp.1781-1792.
- Lewins, R., 2001. Consensus building and natural resource management: a review. Centre for the Economics and Management of Aquatic Resources, University of Portsmouth.
- Lima, M.S.P., Oliveira, J.E.L., de Nóbrega, M.F. and Lopes, P.F.M., 2017. The use of Local Ecological Knowledge as a complementary approach to understand the temporal and spatial patterns of fishery resources distribution. *Journal of Ethnobiology and Ethnomedicine*, 13, pp.1-12.
- Luna-Reyes, L.F., Zhang, J., Ramón Gil-García, J. and Cresswell, A.M., 2005. Information systems development as emergent socio-technical change: a practice approach. *European Journal of Information Systems*, 14(1), pp.93-105.
- MacKenzie, D., & Wajcman, J. (Eds.). (1999). *The Social Shaping of Technology* (2nd ed.). Open University Press.
- Mackrell, D., Kerr, D. and Von Hellens, L., 2009. A qualitative case study of the adoption and use of an agricultural decision support system in the Australian cotton industry: The socio-technical view. *Decision Support Systems*, 47(2), pp.143-153.
- Magesa, M.M., 2015. Linking rural farmers to markets using ICTs. CTA.
- Mallalieu, K.I., 2015. Rejuvenating ACP small-scale fisheries using ICTs. CTA.

- Magloo, A.H., Wanjari, R.N., Sidiq, M.J., Abbass, Z. and Ganie, P.A., 2025. Overcoming IT Barriers in Fisheries and Aquaculture. In *Information Technology in Fisheries and Aquaculture* (pp. 265-278). Singapore: Springer Nature Singapore.
- Manning, L., 2024. Innovating in an uncertain world: understanding the social, technical and systemic barriers to farmers adopting new technologies. *Challenges*, 15(2), p.32.
- Mistri, A. and Das, B., 2015. Environmental legislations and livelihood conflicts of Fishermen in Sundarban, India. *Asian Profile*, 43, pp.389-400.
- Mišura, A., Jahutka, I., Dadić, V. and Suić, J., 2004. Information system of fishery in Croatia. In *Geographical Information Systems in research & practice. Croatian Information Technology Association–GIS Forum, University of Silesia, Zagreb* (pp. 92-103).
- Mittal, S., Mehar, M. and Hariharan, V.K., 2019. Information and communication technologies for strengthening extension services to reach the last mile in India. In *Agricultural Extension Reforms in South Asia* (pp. 255-274). Academic Press.
- Moon, K. and Blackman, D., 2014. A guide to understanding social science research for natural scientists. *Conservation biology*, 28(5), pp.1167-1177.
- Muhl, E.K., Armitage, D., Anderson, K., Boyko, C., Busilacchi, S., Butler, J., Cvitanovic, C., Faulkner, L.A., Hall, J.A., Martynuik, G. and Paul-Burke, K., 2023. Transitioning toward “deep” knowledge co-production in coastal and marine systems: examining the interplay among governance, power, and knowledge. *Ecology and Society*, 28(4).
- Nayak, P.K., 2017. Fisher communities in transition: Understanding change from a livelihood perspective in Chilika Lagoon, India. *Maritime Studies*, 16, pp.1-33.
- Nayak, P.K. and Armitage, D., 2018. Social-ecological regime shifts (SERS) in coastal systems. *Ocean & Coastal Management*, 161, pp.84-95.

- Nayak, P.K. and Berkes, F., 2019. Interplay between local and global: Change processes and small-scale fisheries. *Transdisciplinarity for small-scale fisheries governance: Analysis and practice*, pp.203-220.
- Neitzel, S.M., van Zwieten, P.A., Hendriksen, A., Duggan, D. and Bush, S.R., 2017. Returning information back to fishers: Graphical and numerical literacy of small-scale Indonesian tuna fishers. *Fisheries Research*, 196, pp.96-105.
- Norström, A.V., Cvitanovic, C., Löf, M.F., West, S., Wyborn, C., Balvanera, P., Bednarek, A.T., Bennett, E.M., Biggs, R., de Bremond, A. and Campbell, B.M., 2020. Principles for knowledge co-production in sustainability research. *Nature Sustainability*, 3(3), pp.182-190.
- Nugroho, S.B., Susilowati, I., Thohir, M., Prastyadewi, M.I. and Suciati, I., 2021. Fishermen behavior in the use of information and communication technologies (ICTs) in Central Java Province, Indonesia: Comparative study in Pati and Pemalang regencies. *Aquaculture, Aquarium, Conservation & Legislation*, 14(5), pp.2698-2707.
- Nguyen, V.M., Young, N. and Cooke, S.J., 2018. Applying a knowledge–action framework for navigating barriers to incorporating telemetry science into fisheries management and conservation: a qualitative study. *Canadian Journal of Fisheries and Aquatic Sciences*, 75(10), pp.1733-1743.
- Ogbeide, O.A. and Ele, I., 2015. Smallholder farmers and mobile phone technology in Sub-Saharan Agriculture. *Mayfair Journal of Information and Technology Management in Agriculture*, 1(1), pp.1-19.
- Oreglia, E. and Srinivasan, J., 2016. ICT, intermediaries, and the transformation of gendered power structures. *MIS Quarterly*, 40(2), pp.501-510.

- Ostrom, E., 1990. *Governing the commons: The evolution of institutions for collective action*. Cambridge university press.
- Oviedo, A.F.P. and Bursztyn, M., 2017. Community-based monitoring of small-scale fisheries with digital devices in Brazilian Amazon. *Fisheries Management and Ecology*, 24(4), pp.320-329.
- Parmar, I.S., Soni, P., Kuwornu, J.K. and Salin, K.R., 2019. Evaluating farmers' access to agricultural information: Evidence from Semi-arid region of Rajasthan State, India. *Agriculture*, 9(3), p.60.
- Perry, R.I., Ommer, R.E., Barange, M., Jentoft, S., Neis, B. and Sumaila, U.R., 2011. Marine social–ecological responses to environmental change and the impacts of globalization. *Fish and Fisheries*, 12(4): 427-450.
- Petrik, M. and Serge Raemakers, D., 2018. The case for supporting small-scale fisheries governance through ICT.
- Pinch, T.J. and Bijker, W.E., 1984. The social construction of facts and artefacts: Or how the sociology of science and the sociology of technology might benefit each other. *Social studies of science*, 14(3), pp.399-441.
- Pomeroy, R., Parks, J., Mrakovcich, K.L. and LaMonica, C., 2016. Drivers and impacts of fisheries scarcity, competition, and conflict on maritime security. *Marine Policy*, 67, pp.94-104.
- Qureshi, I., Bhatt, B., Parthiban, R., Sun, R., Shukla, D.M., Hota, P.K. and Xu, Z., 2022. Knowledge commoning: Scaffolding and technoficing to overcome challenges of knowledge curation. *Information and Organization*, 32(2): 100410.

- Ramamritham, K., Bahuman, A., Duttagupta, S., Bahuman, C. and Balasundaram, S., 2006, May. Innovative ICT tools for information provision in agricultural extension (December 2005). In 2006 International Conference on Information and Communication Technologies and Development (pp. 34-38). IEEE.
- Ramirez, R., 1999. Stakeholder analysis and conflict management. In *Cultivating peace: conflict and collaboration in natural resource management*. IDRC, Ottawa, ON, CA.
- Ramirez-Rodriguez, M., 2011. Data collection on the small-scale fisheries of México. *ICES Journal of Marine Science*, 68(8), pp.1611-1614.
- Rao, N. and Sophia, J.D., 2023. Identity, sociality and mobility: understanding internal fisher migration along India's east coast. *Maritime Studies*, 22(4), p.42.
- Rahman, T., Ara, S. and Khan, N.A., 2020. Agro-information service and information-seeking behaviour of small-scale farmers in rural Bangladesh. *Asia-Pacific Journal of Rural Development*, 30(1-2), pp.175-194.
- Roy, A., Manna, R.K., Ghosh, S., Sahu, S.K. and Das, B.K., 2023. Assessment of women's contribution in small-scale fisheries in Indian Sundarbans: Issues, strategies, and way forward for sustainability. *Fisheries Management and Ecology*, 30(4), pp.378-391.
- Sabu, M. and Shaijumon, C.S., 2014. Socio-economic impact of information and communication technology: A case study of Kerala marine fisheries sector. *International Journal of Information Dissemination and Technology*, 4(2), pp.124-129.
- Salmi, P., Linke, S., Siegrist, N. and Svendsen, K., 2022. A new hope for small-scale fisheries through local action groups? Comparing Finnish and Swedish experiences. *Maritime Studies*, 21(3), pp.309-323.

- Sari, I., Ichsan, M., White, A., Raup, S.A. and Wisudo, S.H., 2021. Monitoring small-scale fisheries catches in Indonesia through a fishing logbook system: Challenges and strategies. *Marine Policy*, 134, p.104770.
- Seddiky, M.A., Giggins, H. and Gajendran, T., 2020. International principles of disaster risk reduction informing NGOs strategies for community based DRR mainstreaming: The Bangladesh context. *International journal of disaster risk reduction*, 48, p.101580.
- Sen, A., 2021. A political ecology of forest conservation in India: Communities, wildlife and the state. Routledge.
- Shackleton, S., Bezerra, J.C., Cockburn, J., Reed, M.G. and Abu, R., 2021. Interviews and surveys. In *The Routledge Handbook of research methods for social-ecological systems*. pp. 107-118.
- Sinclair, M., Vishnu Sagar, M. K., Knudsen, C., Sabu, J., & Ghermandi, A., 2021. Economic appraisal of ecosystem services and restoration scenarios in a tropical coastal Ramsar wetland in India. *Ecosystem Services*, 47, 101236.
- Smidt, H.J. and Jokonya, O., 2022. Factors affecting digital technology adoption by small-scale farmers in agriculture value chains (AVCs) in South Africa. *Information Technology for Development*, 28(3), pp.558-584.
- Srivastava, A., Kapania, S., Tuli, A. and Singh, P., 2021. Actionable UI design guidelines for smartphone applications inclusive of low-literate users. *Proceedings of the ACM on Human-Computer Interaction*, 5(CSCW1), pp.1-30.
- Steven, A., Addo, K.A., Llewellyn, G., Ca, V.T., Boateng, I., Bustamante, R., Doropoulos, C., Gillies, C., Hemer, M., Lopes, P. and Kairo, J., 2020. Coastal development: Resilience, restoration and infrastructure requirements. World Resources Institute,

Washington DC Available online: www.oceanpanel.org/blue-papers/coastal-development-resilience-restoration-and-infrastructure-requirements.

Tilley, A., Dos Reis Lopes, J. and Wilkinson, S.P., 2020. PeskAAS: A near-real-time, open-source monitoring and analytics system for small-scale fisheries. *PloS one*, 15(11), p.e0234760.

Tilley, A.L., Song, A., Menon, A.J., Cohen, P.J. and Manuel, M.A., 2021. Emerging Information and Communication Technologies for Monitoring India's Marine small-scale fisheries, Opportunities for Inclusion, Risks of Exclusion. *Journal of the Indian Society of Coastal Agricultural Research*, 39(2), pp. 80-94.

Tiwari, S.P., 2008. Information and communication technology initiatives for knowledge. *Indian Journal of Agricultural Sciences*, 78(9), pp.737-47.

van Maurik Matuk, F.A., Verschuuren, B., Morsetto, P., Krause, T., Ludwig, D., Cooke, S.J., Haverroth, M., Maeesters, M., Mattijssen, T.J., Keßler, S. and Lanza, T.R., 2023. Advancing co-production for transformative change by synthesizing guidance from case studies on the sustainable management and governance of natural resources. *Environmental Science & Policy*, 149, p.103574.

Villasante, S., Gianelli, I., Castrejón, M., Nahuelhual, L., Ortega, L., Sumaila, U.R. and Defeo, O., 2022. Social-ecological shifts, traps and collapses in small-scale fisheries: Envisioning a way forward to transformative changes. *Marine Policy*, 136, p.104933.

Vögler, R., Soto, D., Quinones, R.A., Martínez, G., D'Ambrosio, L., Alaggia, S., Surroca, A. and Pérez, F., 2023. Vulnerability assessment of the pink shrimp small-scale fishery to climate change in southwestern Atlantic brackish coastal lagoons (Uruguay). *Ocean & Coastal Management*, 245, p.106864.

- Walker, S., 2021. Value-added weather advisories for small-scale farmers in South Africa delivered via mobile apps. *Irrigation and Drainage*, 70(3), pp.505-511.
- Watson, A. and Till, K.E., 2010. Ethnography and participant observation. *The SAGE handbook of qualitative geography*, 1, pp.121-137.
- Weeratunge, N., Béné, C., Siriwardane, R., Charles, A., Johnson, D., Allison, E.H., Nayak, P.K. and Badjeck, M.C., 2014. Small-scale fisheries through the wellbeing lens. *Fish and Fisheries*, 15(2), pp.255-279.
- Winschiers-Theophilus, H., Rodil, K., Zaman, T., Yeo, A. and Jensen, K., 2013, July. Mobile technologies for preservation of indigenous knowledge in rural communities. In 2013 8th International Conference on Information Technology in Asia (CITA) (pp. 1-4). IEEE.
- Wiyono, E.S., Raharjo, S.S. and Permana, S.M., 2018. Fishermen acceptance on introduction of fishing technology: Perception and its development strategies. *Aquaculture, Aquarium, Conservation & Legislation*, 11(3), pp.666-677.
- Zamiri, M. and Esmaeili, A., 2024. Methods and technologies for supporting knowledge sharing within learning communities: A systematic literature review. *Administrative Sciences*, 14(1), p.17.

Appendices

Appendix A – Recommendations towards inclusive and sustainable digital intervention

Some additional suggestions that may be helpful in advancing the design of the V2V-IS are as follows:

(i). Participatory Stakeholder Engagement and Co-Creation: It is recommended that the V2V-IS design involve not only local fishers but also NGOs, government actors, and academics in continuous, participatory design and development processes. This can be achieved through regular focus group discussions, community consultations, and collaborative workshops, ensuring that the platform reflects the unique needs and aspirations of diverse stakeholders. Such a participatory approach would not only improve the relevance and inclusivity of the system but also increase the sense of ownership and engagement from all involved parties, enhancing the system's long-term success and adaptability.

(ii). Contextualized Capacity Building and Training: To effectively integrate V2V-IS into SSF communities, especially vulnerable groups such as women and marginalized fishers, context-specific training programs may be developed. These programs may be designed to enhance digital literacy, particularly in relation to the V2V-IS platform's functionalities. It is proposed that training not only focus not only on basic technology skills, but also on how the platform can empower fishers with actionable information to improve their livelihoods, enhance market access, and engage in effective resource management. Capacity-building programs could be made accessible to different age groups and educational backgrounds and should use a combination of in-person, video, and audio formats to accommodate low-literacy users.

(iii). Addressing Technological Barriers and Expanding Infrastructure: Acknowledging the digital divide in remote SSF communities, the V2V-IS could explore innovative solutions to mitigate technological barriers. This may perhaps include establishing mobile phone-based platforms with low-bandwidth requirements, solar-powered devices, or community-managed Wi-Fi hubs. Additionally, creating partnerships with telecommunication companies to offer subsidized data packages for fishers or leveraging existing government infrastructure (such as rural e-governance centers) may help improve accessibility.

(iv). Iterative and Responsive Design through Continuous Feedback Loops: The success of V2V-IS hinges on continuous adaptation based on real-time user feedback. Establishing a robust feedback loop through digital and offline channels (e.g., community radio programs, phone surveys, or SMS-based feedback systems) would ensure that the system evolves in response to user needs. It is suggested that periodic evaluations and participatory assessments be built into the platform's governance model, allowing users to express concerns, suggest improvements, and identify emerging challenges. These feedback mechanisms might be inclusive, ensuring that all stakeholders, including marginalized groups, are able to voice their experiences and expectations.

(v). Fostering Cross-Sector Partnerships for Holistic Support: The V2V-IS is envisaged to foster multi-sectoral partnerships that go beyond the technology sector, involving experts from fisheries management, local governance, health, education, and gender studies. Collaboration between these sectors could ensure that the platform not only supports livelihoods but also enhances community well-being. Such partnerships may facilitate cross-cutting solutions, such as providing fishers with health information, access to financial literacy training, or connections to social services, which can help strengthen community resilience against economic and environmental shocks.

Appendix B: Interview and Survey Questions

Part A: Qualitative data (responses for Part A will be followed up with in-depth interviews)

Audio recording begins here.

1. Application to Knowledge Commons:

- How do you currently access and share knowledge related to SSF management?
- In your experience, how effective are existing information systems in facilitating knowledge sharing and collaboration among stakeholders in SSF management?
- What challenges and opportunities do you see in leveraging digital platforms and data-sharing mechanisms to support the transition to more sustainable and viable fishing practices?

2. Perceptions on Mobile App Usage:

- Do you own a smartphone or any other mobile device?
- Have you ever used a mobile app for fishery management? If yes, what is the name of the app?
- Is the test app (V2V-IS) helpful in managing fishing activities?

1	2	3	4	5	6 I do not know
---	---	---	---	---	--------------------

(Scale: 1-5, where 1 is not at all helpful, and 5 is extremely helpful)

- How likely are you to use this V2V-IS app for fishery management? Why?

1	2	3	4	5	6 I do not know
---	---	---	---	---	--------------------

(Scale: 1-5, where 1 is not at all, and 5 is extremely likely)

- What are the main barriers to using mobile technology in your daily fishery operations?

3. Usability and Accessibility of the V2V-IS app:

- Do you find the V2V-IS prototype user-friendly for fishery management?

1	2	3	4	5	6 I do not know
---	---	---	---	---	--------------------

(Scale: 1-5, where 1 is not at all user-friendly, and 5 is extremely user-friendly)

- Do you find the V2V-IS app efficient in storing and accessing fishery-related information? Is the data in your language?
- What other fishery-related information did you find while using the V2V-IS app prototype?
- What are the main barriers to using this technology in your daily fishery operations?

4. Data Collection and Reporting:

- a. What types of data do you find valuable to collect and report using a mobile app? (e.g., catch data, market prices, weather conditions, location for fishing)
- b. How frequently would you be willing to input data into the V2V-IS app?
- c. What challenges do you foresee in collecting and reporting data through the V2V-IS app?

5. Integration with Existing Systems:

- a. How important is it for a mobile app to integrate with existing fishery management systems or regulations?
- b. Would you prefer a standalone mobile app or one that integrates with other software, or platforms used in fishery management?

6. Feedback and Support:

- a. Were you provided with orientation, technical support, and training for using the V2V-IS app?
- b. Did you find any mechanisms available in the V2V-IS app for providing feedback and suggestions for improving the same?

7. Privacy and Security:

- a. Are you aware of the data privacy and security aspects within the V2V-IS mobile app?
- b. Do you think that the confidentiality and integrity of data collection through the V2V-IS app is sufficient? If not, how can this be incorporated into the app?

8. Future Expectations:

- a. What other improvements would you like to see in the V2V-IS app to continue to use it for small-scale fishery management?
- b. Are there any additional comments or suggestions you would like to share regarding the V2V-IS app?

9. Pilot Testing:

- a. Would you be willing to participate in a follow-up round of testing the subsequent version of the prototype of the V2V-IS app? If yes, please provide your contact information.
- b. Is there anything else you would like to share or discuss regarding the development and implementation of the mobile app for small-scale fishery management?

10. Current Practices and Challenges:

(This section is specifically oriented towards fisherfolks)

- a. What type of fishing practices do you follow?
☐ Inland ☐ Aquaculture ☐ Coastal/mangrove
- b. What methods do you currently use for fishery management?

☐ Co-management ☐ Community-based ☐ Ecosystem-based

c. What are the species you fish you catch? How often do you fish? Can you tell me the quantity of fish you catch and sell?

d. What are the main challenges you face in managing your SSF?

e. How do you currently track fish stocks, catch data, and fishing activities?

11. Interdisciplinary Approach:

(This section onwards is oriented towards all the stakeholders)

a. How important do you think interdisciplinary collaboration is in understanding and addressing challenges faced by SSF?

b. In your opinion, what disciplines are most crucial for studying and improving the sustainability of SSF?

c. How do you think insights from different disciplines, such as marine biology, economics, sociology, and information systems, can contribute to the management of SSF?

12. Focus on Rules and Norms:

a. What are the existing rules and norms governing SSF in your community? Are they effective?

b. Are there any specific rules or norms that you believe could be improved to better support the transition of SSF to viability?

13. Action Arenas and Levels:

a. Can you define the different levels of decision-making involved in SSF management in your community?

b. What interactions and conflicts do you observe across these decision-making levels, and how do they impact your role in the fishery?

c. How do different organizations contribute to decision-making processes in SSF management?

14. Design Principles:

a. Do you believe that the design principles, such as clearly defined boundaries and collective choice arrangements, are reflected in the management of SSF in your community?

b. How effective do you think current management strategies are in aligning with these design principles?

15. Application to Knowledge Commons:

a. How do you currently access and share knowledge related to SSF management?

b. In your experience, how effective are existing information systems in facilitating knowledge sharing and collaboration among stakeholders in SSF management?

c. What challenges and opportunities do you see in leveraging digital platforms and data-sharing mechanisms to support the transition to more sustainable and viable fishing practices?

Part B: Quantitative data

This section will gather some demographic information, such as your age, gender, and other relevant details, to help identify trends in how different groups perceive and use the information system. Please note that this data will not be used to identify you individually.

Demographic Information of Participants:

1. What is your role in the small-scale fishery industry?

- ☐ Fisherman ☐ Fisherwoman ☐ Fishery Manager ☐ Government official
☐ Researcher/Academic ☐ NGO Partner ☐ Other (specify)

2. How many years of experience do you have in the fishery industry?

- ☐ Less than a year ☐ 2-5 years or more ☐ Ten years or more ☐ Twenty years or more

3. Which age category do you belong to?

- ☐ 18-25 years ☐ 26-35 years ☐ 36-45 years ☐ 46-55 years ☐ 56 years or above

4. What is your gender identity?

- ☐ Female ☐ Male ☐ Prefer to self-describe

5. What is your educational background?

- ☐ No formal education ☐ Elementary school ☐ College ☐ University

6. Is fishing your primary livelihood?

- ☐ Yes ☐ No

7. Do you have a fishing license? How often do you renew it?

- ☐ Yes, regularly ☐ Yes, sometimes ☐ No ☐ Not relevant.

Appendix C: Photographs from the field



Photo 1: A fisher couple setting their net to catch fish from the forest river, Samshernagar



Photo 2: With less than bare minimum supplies for survival three fishers spend several days in the river, Samshernagar



Photo 3 (a and b): Aquaculture practitioners looking for better profits and health of their ponds through an improved information systems



Photo 4 (a and b): Mud crabs from River Kurankhali in the Sundarbans and fish catch from a household pond in the Kumirmari village



Photo 5: A community-owned *khaal* at Kumirmari village



Photo 6: An individually owned fishpond at Kumirmari village