Mangrove-Dependent Small-Scale Fisher (SSF) Communities in the Sundarbans – Vulnerable yet Viable

by

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Author's Declaration

I hereby declare that I am the sole author of this 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.

Abstract

Sundarbans social-ecological system is the largest remaining mangrove wetland in the Asian continent. Its ecological subsystem is comprised of mangroves of Sundarbans shared between India and Bangladesh, which are complex ecosystems on the verge of obliteration. Along with diverse flora and fauna, they support the livelihoods and culture of millions of small-scale fisheries communities which make up the social subsystem of Sundarbans. 7.5 million people reside in the Sundarbans and around 40,000 households are dependent solely on small-scale fisheries. Mangrove cover have been reduced by 35% in the recent years by the combined action of natural and anthropogenic drivers of change such as cyclones and extensive shrimp aquaculture. There were other active drivers as well, but the major ones were selected for the case studies.

Recurrent cyclones uproot mangroves and damage fishponds, boats, and fishing gear. Conversion of mangrove wetlands and agricultural lands by non-fishers and large-scale fishing fleets, into fragmented shrimp culture ponds create fishing pressure on the Sundarbans as well as competition between them and the small-scale fisher communities. These factors result in multidimensional vulnerabilities affecting the ecosystem and small-scale fisheries, through effects like habitat loss, fragmentation, overexploitation of resources, loss of livelihoods, lack of opportunities and migration. There is a lack of understanding of the interaction and interconnection between mangroves and small-scale fisheries on a vulnerability and viability perspective as well as on a social-ecological system's perspective.

The purpose of this research is to assess the vulnerability of small-scale fisheries and examine ways in which communities that depend on them can achieve viability. The objectives of this study are– (a) to identify and describe the drivers of change impacting mangroves as well as the small-scale fisheries communities in Sundarbans social-ecological system; (b) to analyse the vulnerabilities experienced by the mangroves and small-scale fisheries communities in Sundarbans social-ecological system, and (c) to examine the key response strategies and pathways to viability of the mangrove dependent small-scale fisheries communities in Sundarbans social-ecological system.

The study embraces a qualitative approach. An in-depth systematic review of literature as well as case studies has been used to meet the objectives.

Ultimately, the results of this thesis indicate that sustainable ways of fishing and a regulatory system to oversee the management of the forests must be formulated to protect the future of both. The pathways of viability discussed in the thesis derived from the coping and adaptive responses of small-scale fishers would play an important role in ecosystem sustainability and livelihood stability.

Keywords – Mangroves, Small-Scale Fishers, Drivers of Change, Vulnerability, Cyclones, Shrimp Aquaculture, Wellbeing, Capitals, Resilience, Responses, Coping, Adaptation, Viability

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List of Abbreviations

HDWG – Human Dimensions Working Group

I-ADApt – Assessment based on Description and responses, and Appraisal for a Typology

IMBeR – Integrated Marine Biosphere Research

NGOs – Non-Governmental Organizations

SES – Social-Ecological System

SLR – Systematic Literature Review

SSF – Small-Scale Fisheries

SSFs – Small-Scale Fishers

SSHRC – Social Sciences and Humanities Research Council

V2V – Vulnerability to Viability

Chapter 1 - Introduction

1.1. Background

Mangrove wetlands are complex socioecological systems that are on the verge of obliteration (Hogarth, 1999; Pant & Singh, 2021). They are experiencing major challenges because of climate change, urbanization, industrialization, and aquaculture intensification (Armitage et al., 2017; Maina et al., 2021). Nearly half a billion people rely on the ecosystem services of these mangrove forests, coral reefs, seagrass beds and associated fisheries (Sinclair et al., 2021; Wilkinson & Salvat, 2012). The area covered by mangroves is estimated to be around 15-20 million hectares which is about 0.7 percent of the world's inland forests (Gopal & Chauhan, 2006). Before industrialization, they contributed to two-thirds of the world's coastal regions; presently, less than half of them are left because of high human interferences (Chacraverti, 2014; Pant & Singh, 2021; Sinclair et al., 2021). In fact, they currently make up to 0.12% of the total area of land worldwide, which is known to support a major part of the world's fisheries sector (Polidoro et al., 2010).

Small-scale fishers (SSFs) contribute to 90 percent of the 120 million people engaged in capture fisheries globally (FAO, 2015; Perry et al., 2011). 97% of the world's fishermen reside near coasts and are dependent on nearshore, estuarine, and coastal fisheries. This yields 75% of the world's fish harvest (Pauly, 2007; Pauly & Christensen, 1995). Roughly 210 million SSFs live within a 10 km radius of mangroves worldwide (Hutchison et al., 2014). SSF contribute to two-thirds of the global fish catch destined for direct human consumption, yet an estimated 5.8 million fishers in the world earn less than $1 per day which have been significantly increasing in the past decade (FAO, 2015). There is no global definition for SSF because they are highly diverse, and include low-technology, low-capital fishing methods, rudimentary fish processing and marketing, as well as modernized and sophisticated gear and technology that fishers own and operate. These SSF communities make critical contributions to nutrition, food security, local livelihoods, and national economies, especially in developing countries (Berkes & Nayak, 2018; Chuenpagdee et al., 2005; Chuenpagdee, 2011; Nayak & Berkes, 2019).

Despite these differences, all SSFs are strongly anchored in local communities (Chuenpagdee, 2011).

This research is based on a transboundary mangrove reserve shared between India and Bangladesh, Sundarbans, and its SSFs as a social-ecological system (SES), which happens to be the largest mangrove reserve in the Asian continent (FAO, 2007). The region has been experiencing numerous threats from natural (cyclones, floods, erosion, salinization) and anthropogenic (extensive agriculture and aquaculture, unsustainable coastal development) drivers of change which affect the SSF communities and their livelihoods by pushing them to vulnerability (Banerjee et al., 2012; Hoq, 2007).

Additionally, the drivers of change have a significant influence on the mangroves of Sundarbans as they are continuously being destroyed, degraded, exploited and misunderstood (Polidoro et al., 2010). There is a huge disconnect between mangroves and SSFs because of these drivers. This interplay has not only created a gap in research but also provided a significant theory of the interaction and interconnections between the ecological and human dimensions of the Sundarbans SES. To understand the ground reality there is a need for a critical theoretical comprehension of the Sundarbans from a SES perspective. Therefore, my research focuses on these mangroves and SSF communities to help them move from a state of vulnerability to viability (V2V).

This study is undertaken as part of a Social Sciences and Humanities Research Council (SSHRC) Partnership Grant project entitled Vulnerability to Viability (V2V): Global Partnership for building strong small-scale fisheries communities at the University of Waterloo, which brings together an international and interdisciplinary team of scientists, practitioners, policy, and community actors to work collaboratively to co-develop an integrated understanding of SSF vulnerability, and to explore what would make them viable.

1.2. Purpose, Objectives and Research Questions

The purpose of this research is to assess the vulnerability of the mangroves as well as the dependent SSFs and their communities in Sundarbans SES and examine ways in which they can achieve viability. Three objectives guide this research:

- to identify the threats and describe the drivers of change affecting the Sundarbans and its SSFs and their communities.
  (a) What are the natural and anthropogenic drivers affecting Sundarbans mangroves?
  (b) How do the drivers affect the fisher communities?
- to analyse the multidimensional vulnerabilities experienced by the mangroves and SSFs and their communities.
  (a) How do the drivers affect the ecological and social subsystems?
  (b) How do these vulnerabilities affect the wellbeing, livelihood capitals and resilience of the fisher communities?
- to examine key response strategies of the mangrove dependent SSFs and their communities and describe the pathways to viability.
  (a) What are the coping and adaptive responses adopted by these communities?
  (b) How do these communities move from V2V?

The first objective serves to identify and elaborate the major problems in the region to understand the key drivers affecting the Sundarbans SES. To this end, possible methods to work in the area will be investigated. This can be done by laying out all the active drivers in the region and selecting the ones that have the maximum impact.

In context of V2V, the second objective concerns the interpretation of the vulnerabilities that arise due to these drivers, which influence the wellbeing, livelihood capitals, and resilience of SSFs and their communities. This study will look at the vulnerabilities of both the components of the SES, i.e., mangroves and associated species (ecological) and SSF communities (social). This will broaden our ideas about the connecting link between the two subsystems.

The final objective is focused on the transition from V2V. Indeed, some vulnerabilities are difficult to avoid, but this analysis can be used to understand methods that may be employed for this process of V2V. This can be done by examining the existing coping and adaptive responses of SSF communities to the vulnerabilities addressed. The sustainable responses that exist can be practiced more often to move to viability.

1.3. Literature and Significance of the Study

Sundarbans as a SES has two components – the mangroves and associated species as ecological subsystem and SSF communities dependent on these forests and waters for sustenance as the social subsystem. The backbone of the Sundarbans is majorly dependent on capture fisheries. These wetlands are spread across India and Bangladesh; the majority of it being in the latter (Chacraverti, 2014). This area which is known for its dense mangrove forests and fish resources experiences recurrent cyclones, tourism and aquaculture-driven pollution, human-wildlife conflict, deforestation for coastal development, agriculture, and aquaculture (Abdullah-Al-Mamun et al., 2017; Banerjee et al., 2012; Mukherjee et al., 2012). The livelihoods of fishers dependent on the ecosystem for its services are influenced along with the ecosystem itself. The environmental impacts create vulnerabilities that affect the well-being and capitals which makes the SSF communities adopt coping and adaptive strategies in order to move to viability (Gopal & Chauhan, 2006; Mukherjee et al., 2013).

Vulnerability is a concept with multiple parameters - SES resilience, well-being, and livelihood capitals – to indicate the level of risk (Berkes & Nayak, 2018). Viability is the ability of a community to address those risks, and to adapt to the changing environment, with or without external help (Berkes & Nayak, 2018; Nayak & Berkes, 2019). Even though these concepts have been individually explored in different projects, they have not been linked with multiple parameters together. The whole concept of V2V is rather new in the field of coastal commons, where we not only look at the stressors affecting the wellbeing of communities, but also try to make them less vulnerable by identifying pathways to viability (Berkes and Nayak, 2018). Mangrove ecosystems have never been the center of focus for researchers when it comes to linking SSF communities in the context of vulnerability and viability. Understanding the links would help bridge the gap and result in sustainable livelihoods, fisheries, and ecosystem.

1.4. Methods and Methodology

The methodology of this research embraces a qualitative approach based on a systematic literature review (SLR) and case studies. SLR technique will be used to obtain journal articles from online databases by using key words to be adopted from the

objectives and research questions. Along with the review of literature, the template designed by Integrated Marine Biosphere Reserve (IMBeR) and Human Dimensions Working Group (HDWG), called I-ADApt (Assessment based on Description and responses and Appraisal for a Typology) will be filled according to the findings. This will shed light on the status of current research on vulnerability and viability of the region. Additionally, all the sources will be organized in Zotero which is an online reference manager. This would be done based on the key words used to search journal articles from the online databases like SCOPUS and JSTOR.

1.5. Gaps and Expected Outcomes

The study addresses the following: first, what are the key social-ecological factors that are influencing vulnerability among SSFs and mangroves in the Sundarbans delta? Second, what are the key coping and adaptive strategies to limit vulnerability and increase viability of SSF and the mangroves? The coping and adaptive strategies would help give an idea about the existing responses of the communities as a reference for pathways to viability.

There are ongoing studies on coastal commons, mostly about the socio-political aspects and interactive governance for SSF, along with socio-ecological regime shifts as a response to environmental change. Despite that, there is a lack of understanding of the socioeconomic as well as ecological dynamics of vulnerability and viability. Also, little is known about the interaction of mangrove ecosystems and SSF communities. The natural resources continue to decline despite major advances in scientific understanding of how ecosystems and human populations interact, and the application of considerable conservation and management efforts at different scales. Greater effort will be required to curb against damage from over-exploitation, pollution and global climate change in the future (Wilkinson & Salvat, 2012).

Research on the mangroves and SSF suggests a more robust understanding of human-resource interactions is needed to strengthen theories about collective action and sustainable governance. As this is a first of its kind research focusing on a hybrid model including vulnerability and viability, it will be identifying a wide variety of issues. By analyzing them, it would be providing strategies to tackle the issues altogether. It has

important implications for mangrove management practices and the ecosystem services that mangrove forests provide. It can also bring forward the policy and implementation gaps in assessing natural and anthropogenic stressors on SSF communities.

Being a part of a global project and as pioneer research, this study provides numerous opportunities for communities to move from V2V by alerting Non-Governmental Organizations (NGOs), scientists, and researchers to possible solutions. Hopefully, this type of finding will alert governments to focus on these communities and develop policies that protect SSF and mangrove ecosystem viability. The knowledge on changes in mangrove forests and dependent communities and its stressors/drivers are critical for understanding the subsequent depletion of mangrove ecosystem services as well as induced vulnerability in the SSF communities. This would not only aim in reducing vulnerability, but also help in maintaining ecosystem sustainability.

1.6. Thesis Overview

The thesis comprises six chapters in total – (1) Introduction, (2) Literature Review, (3) Methods, (4) and (5) Results, and (6) Conclusion.

Chapter 1 describes the background of the study, purpose, objectives and research questions, methods and methodology, significance, and research gaps. It also provides a roadmap to the thesis.

Chapter 2 defines the key concepts, terms, and theories of the thesis work. It is a review of literature found on online databases regarding the interaction between mangrove ecosystems and SSFs from a social, ecological, political, and economic perspective. It also describes the various parameters of vulnerability, well-being, capitals, and their connection with adaptive responses shown by the fishermen communities.

Chapter 3 depicts the methods and methodology used for the research work. It elaborates the procedure of the systematic literature review in detail with an in-depth study on the research area along with illustration of the I-ADApt template.

The results and discussion have been split into two chapters – chapter 4 discusses the impacts of two different drivers of change on the Sundarbans and SSF along with the multidimensional vulnerabilities induced. Chapter 5 examines the coping and adaptive

response strategies adopted by the SSF. Chapter 4 meets objectives 1 and 2 whereas chapter 5 focuses on objective 3.

Chapter 6 draws on the findings and discussions presented throughout the thesis to suggests which responses can help move the SSF from V2V.

Chapter 2 – Literature Review

Concepts and theories to understand vulnerability and viability in mangrove-dependent small-scale fisheries

2.1. Introduction

This chapter will elaborate the major literature areas and its sub-sections in depth. The key theories included in this thesis are – Mangroves, SSF communities, Drivers of Change, Vulnerability, Wellbeing, Livelihood Capitals, Resilience, Responses, and Viability. These literature areas are selected for the thesis from the objectives and research questions at hand that not only guide the problem statement but also serve the purpose of the research. They also are individual topics by themselves with numerous definitions that will require some elaboration. The next section will focus on the mangroves and SSF communities as a SES and will aim to describe their links worldwide. Other sections of this chapter will touch on the notions of moving from V2V within a SES context which is a fairly new concept in the world of SSF. The parameters of 'V2V' – well-being, capitals, resilience will also be discussed in this chapter. These literature areas were used as keywords for SLR which is the method used for this chapter as well as chapters 4 and 5.

2.2. Mangroves-dependent SSF as a SES

Mangroves are woody salt-tolerant plant species found along the tropical and sub-tropical coastlines (Luther & Greenberg, 2009). They can be considered as a SES that shelters a variety of mangrove, invertebrate, fish, amphibian, reptile, bird, and animal species along with the livelihoods of millions of coastal communities that derive ecosystem services from them (Ajai & Chauhan, 2017; Berkes et al., 2000; Hogarth, 1999; Lee et al., 2014; Polidoro et al., 2010). These coastal communities are comprised of 500 million people who have dedicated their livelihoods to different sectors – agriculture, fisheries, and forestry sector (Barnes-Mauthe et al., 2013; Eriksson et al., 2016). But the communities involved in SSF play a key role in the functioning of the ecosystem, where they contribute to poverty reduction, food security, sustainable livelihoods, forest, and resource management (De la Torre-Castro et al., 2014).

A SES can be understood as a dynamic and complex ecosystem, consisting of ecological and social subsystems that interact with each other in a sustainable and resilient fashion while utilizing the resources provided by the system (Berkes et al., 2000; McGinnis & Ostrom, 2014). McLeod et al., (2005), recognized multiple characteristics of ecosystems that consist of multiple components interacting with each other – human, natural, biotic, or abiotic which are benefitted by humans and their activities that affect these ecosystems directly or indirectly, both positively and negatively. This SES framework will be used in this thesis to meet the objectives. Sundarbans will be the research area under focus because it is the largest continuous mangrove forest in the transboundary regions of India and Bangladesh (FAO, 2007).

Mangroves – There are around 110 mangrove species in the world and Asia reports more than 50 of them (FAO, 2007). They are evergreen yet deciduous plants that grow in brackish water and intertidal regions like riverbanks, lagoons, estuaries (Mukherjee et al., 2014). They have an exceptional salt filtration system and root system that can cope with the regular tidal wave action with saltwater inundation (Blasco et al., 2001). Only a few mangrove species have the ability to tolerate the wide ranges of salinity, temperature and moisture that make up the mangrove community. They are comparable to Amazon Rainforests as they have high levels of above ground as well as below ground biomass (Ray et al., 2011, 2013). Polidoro et al., (2010) estimated that these ecosystems raise around $1.6 billion every year worldwide through its ecosystem services. They protect coastal regions from storm surges and tsunamis, control soil erosion, provide food and shelter, sequester carbon, and regulate nutrient cycles (Abdullah-Al-Mamun et al., 2017; Costanza et al., 2014; Lee et al., 2014; Robertson & Alongi, 1992).

These plants act as breeding grounds and nurseries for many juvenile fishes, crabs, and shrimps (Lee et al., 2014). This is because of the variety and abundance of feed for these species, less pressure from predators and the complex structure of the mangrove roots. This function of mangroves provisions food that supports communities living near mangroves and are dependent on the ecosystem services of the mangrove wetlands and forests (Polidoro et al., 2010). These communities are called mangrove dependent SSFs. This concept is used throughout the thesis in the context of Sundarbans, a

transboundary mangrove forest of ecological importance sheltering millions of SSF and contributing to national and international economy (UNESCO World Heritage Centre, 1987, 1997).

SSF Communities - About 97% of the world's fishers reside near the coasts (Pauly, 2007). Developing countries are in a critical need of SSF as their natural resource consumption has been increasing tenfold (Polidoro et al., 2010). SSF communities rely totally on the mangrove ecosystem for their food and income. Their economic condition is backed up through fisheries and related professions. There is no exact definition of SSF as it varies from place to place, but FAO, (2015) defined them as a group of fishing communities contributing to 75% of the global fish catch by using low technology, low capital, rudimentary fish catching, processing, and marketing methods as well as modernized and sophisticated fishing gear and technology that they own and operate.

SSFs represent around 90% of the 120 million people engaged in capture fisheries globally and around 5.8 million of them earn less than $1 a day (FAO, 2015). Nearly 250 million people, including fishers and non-fishers, live within a 10 km radius of mangroves globally (Hutchison et al., 2014). These communities are also marginalized in the context of most national policy priorities (Berkes & Nayak, 2018; Islam & Chuenpagdee, 2013; Nayak & Berkes, 2019). Islam and Haque, (2004) stated that *Penaeus monodon* or tiger shrimp is one of the major species of shrimp in India and Bangladesh used for industrial bottom trawl fishing which helps many SSF communities by contributing to their income. This implied that mangroves served as an important part in the life cycle of these fishes and crustaceans (Islam & Haque, 2004). Despite policy neglect, the survival of many SSF suggests that they possess certain strengths and forms of resilience which are little studied and poorly understood.

There have been numerous works in the past few decades on mangrove ecosystems and their services, conservation strategies, involvement of dependent communities in their management but none from the perspectives of drivers of change vulnerability and viability together (Ajai & Chauhan, 2017; Berkes et al., 2000; Berkes & Turner, 2006; Costanza et al., 2014; Eriksson et al., 2016; Hogarth, 1999; Polidoro et al., 2010; Robertson & Alongi, 1992; Spalding, 2010).

2.3. Drivers of Change in the Sundarbans and around the World

Drivers of change is a concept employed in many disciplines like agriculture, architecture, engineering, environment, business, management and economic and human development (Arlett et al., 2010; Assessment, 2005; Booth et al., 2006; Geist & Lambin, 2002; Grumbine et al., 2012; Hameri & Hintsa, 2009; Hazell & Wood, 2008; Kirsch et al., 2011; Lead et al., 2005; Nayak & Armitage, 2018; O'donnell et al., 2001; Vecchiato & Roveda, 2010; Wise, 2002). The theory of drivers of change designated in this thesis has been elaborated by Nayak & Armitage, (2018), who discussed the concept in the context of anthropogenic and socio-economic drivers generating a rapid change accelerating regime shifts in the SES. Accordingly, a driver of change can be understood as a natural or human-influenced action or event that causes a series of changes either directly or indirectly on the SES (Assessment, 2005). The following congregation of different types of drivers is adopted from the aforementioned paper by Nayak & Armitage, (2018).

Table 1 – Description of types of Drivers of Change (Nayak & Armitage, 2018)

Type	Definition
Natural	A change occurring in the SES that is induced by nature or driven by natural pressures that are unavoidable and unstoppable. Example – Natural disasters, geo-hydrological disturbances
Anthropogenic	A change that is occurring due to human influence on the environment which has significant impacts on the social, economic, and ecological components of nature. Example – Opening of artificial sea mouth in Chilika Lagoon, India; Extensive shrimp aquaculture in Tam Gang Lagoon, Vietnam.
Fast and Slow	These are understood as variables in a regime shift which also contribute to drivers of change. Some events that induce rapid changes can be termed as fast variables (like hydrological changes) whereas some events that take comparatively longer time in

	inducing change can be termed as slow variables (like erosion, sea-level rise).

FAO, (2007) reported that many large mangrove forests are found in the Asian subcontinent. Sundarbans is the largest one, supporting 7 million people and the growth of mangroves until cyclone SIDR hit the region affecting 35% of its vegetation cover (Bhowmik & Cabral, 2013). Similarly, coastal mangrove belts worldwide have been reducing in the past century because of anthropogenic pressures and natural disasters (Hayashi et al., 2019; Osland et al., 2017). Currently, the mangroves have been degraded by 35%, with an average of 2.1% loss per year, globally (Valiela et al., 2001; zu Ermgassen et al., 2021). Asian subcontinent experiences loss in mangroves tenfold when compared to the other continents (Thomas et al., 2017). A non-uniform increase and decrease of mangroves was observed by Thomas et al., (2017), which can be explained by the rate of deforestation for coastal development and tropical storms.

Sundarbans is famous for its marine and estuarine fish resources as well as a UNESCO World Heritage Site and Ramsar Site (Ramsar Sites Information Service, 1992, 2019; UNESCO World Heritage Centre, 1987, 1997). This region was preserved by the Britishers under the Forest Act in 1875 for its commercialization (Hoq, 2007). It is located in the estuary of river Ganges, Brahmaputra and Meghna, constituting an area of 1 million hectares in Bangladesh (~ 60%) and India (~ 40%) (Banerjee et al., 2012). Several people are involved in fishing activities as capture fisheries is the major contributor of the state's economic development. These are now being lost at an alarming rate because of anthropogenic factors (clearing of forests for aquaculture and agriculture, harvesting for construction materials, paper pulp, fuelwood) and natural drivers (recurrent storms, erosion, sea level rise) (Chacraverti, 2014; Rivillas-Ospina et al., 2014; Ouyang et al., 2017; Prosser et al., 2018).

These factors affect the SSF communities by increased occurrences of migration, overfishing, occupational displacement, human-wildlife conflict and lack of livelihood alternatives (Abdullah-Al-Mamun et al., 2017; Guha & Roy, 2016; M. M. Islam & Chuenpagdee, 2013; Loucks et al., 2009; Ortolano et al., 2017; Vivekananda et al.,

2014). People have been shifting to extensive aquaculture to obtain foreign exchange earnings, reducing poverty, promote economic growth and development, and increase food security (Chacraverti, 2014). Industrial aquaculture has been able to meet the increasing global demands for marine products (Thomas et al., 2017). Due to all these factors, SSF communities have been pushed towards vulnerability. Some of the major drivers of change are outlined in Table 2 below.

Table 2 – Natural and Anthropogenic Drivers of Change

Drivers	**Examples**	**Source**
Natural	Cyclones, Flooding, Salinization, Erosion, Sea-level rise, Geohydrological changes	(Blythe et al., 2014; Hossain et al., 2018; Lara et al., 2009; Malakar et al., 2018; Mendelsohn et al., 2012; Moniruzzaman et al., 2018; Paul, 2009; Thomas et al., 2017)
Anthropogenic	Conversion of lands for Aquaculture, Agriculture, Coastal Development, Unsustainable Development Practices, Deforestation, Pollution, Tourism	(Aburto-Oropeza et al., 2008; Banerjee et al., 2012; S. K. Chakraborty, 2011; Knowler et al., 2009; Kumar, 2012; Lotze et al., 2006; Osland et al., 2017; Primavera, 2000; Salunke et al., 2020; Worm et al., 2006)

2.3.1. Natural Drivers –

Increased incidences of cyclones, flooding, salinization, erosion, sea-level rise in the coastal areas have been studied by scholars worldwide, who defined these occurrences as natural disasters caused by extreme weather events, climate change and global warming. Accordingly, this thesis will refer to them as natural disasters. This is because they occur naturally, and no action of humans directly drives it.

Cyclones and Flooding – Mangroves regenerate every 2 to 3 years from seedling to a shrub. The Asian subcontinent experiences major tropical storms that wipe out large portions of mangroves every 2-3 years (Paul, 2009; Thomas et al., 2017). Blythe et al., (2014) stated that cyclones have become more prevalent along the coasts of Mozambique, which made the local people vulnerable to future droughts and inland flooding eventually causing more than 800 casualties. Occurrence of this kind cause extreme occupational hazards during fishing along the coasts of Maharashtra (Malakar et al., 2018). Most of the damages caused by tropical cyclones are concentrated in North America, East Asia and the Caribbean which is an impact of global climate change with the potential to increase in specific oceans and their basins (Mendelsohn et al., 2012).

The high winds and storm surges uproot mangroves and submerged aquatic vegetation, creating short-term anoxic or hypoxic conditions (Blasco et al., 1992). Flooding is natural in coasts but when the water does not recede, it causes rotting of mangroves, health issues of coastal communities and reverses geohydrology. Along with ecological and economical damage, they also hamper the livelihoods dependent on fisheries as the storms destroy their houses, boats, and other fishing gears (Sen, 2020). This in turn leads to a disconnect with the fisheries sector and the people urging them to migrate in search of a safer and financially promising place (Moniruzzaman et al., 2018).

Salinization and Erosion - The rivers draining into their subsequent coasts have the ability to drag down sediments, salts and silt to the deltas causing sedimentation (Elliot, 2002). These contribute to the ecosystem dynamics as well as to the geomorphology and hydrology of the region, which naturally causes the salinity gradient to increase. Similarly, other drivers like cyclones and flooding lead to the increase in the salinity of soil, ponds and drinking water (Hossain et al., 2018). Salinization is also a direct impact

of cyclones and flooding which changes the pH balance of the water causing death of vegetation, certain fish, and crustaceans. It also affects the health and sanitation of the SSF communities dependent on these waters (Lara et al., 2009). Along with salinization, these sediments and silt cause soil erosion near the creeks and rivulets that de-stabilizes the biota due to the lack of mangroves near them. Ultimately, it leads to the displacement of the SSF communities (Hossain et al., 2018).

2.3.2. Anthropogenic Drivers –

The coastal development that led to the degradation of mangroves has been taking place since industrialization. Agriculture, aquaculture, pollution, and tourism have accelerated the process. Because these drivers are a result of human action, they are called anthropogenic (Banerjee et al., 2012).

Developmental activities and tourism – The modification of the waterways by construction of channels and canals has also resulted in threatening the existence of mangroves (Chakraborty, 2011). The increased human disturbances in coastal areas since industrialization of the mid 1800s led to worldwide ecosystem degradation and ecological imbalance (Lotze et al., 2006; Worm et al., 2006). The exploitation of the mangrove habitat has led to a domino effect where the ecosystem services as well as the communities depending on it are suffering (Linden & Jernelov, 1980).

Gopal and Chauhan, (2006), argue that oil exploration is an emerging threat to coastal ecosystems. Their paper states that Sundarbans Biosphere Reserve has been widely exploited for honey and timber extraction, prawn, crab, and deep-sea fisheries. There has been an increase in the number of barrages, dams and embankments in relation to erosion and flood control programs and also for diverting the water for agricultural, household and industrial purposes upstream of the rivers (Banerjee et al., 2012). This has led to sedimentation and siltation, which event to a significant reduction in fish and other aquatic biodiversity. While researching tourism and aquaculture in the Gulf of California, Aburto-Oropeza, et al., (2008) found a positive relation between mangrove abundance and fishery which is also seen in Sundarbans. The study stated that tourism-driven destruction of mangroves also created a huge strife among fishing communities because of lack of food security and finances. They argue that their approach in

mangrove ecosystem services impacting positively on local fishing communities can be vital for decision-making on efficient and sustainable use of coastal wetlands (Aburto-Oropeza et al., 2008).

Aquaculture and agriculture - Shrimp aquaculture is a widespread practice in India (Banerjee et al., 2012; Manoj & Vasudevan, 2009). It is considered a somewhat traditional practice that changed with the advent of commercial aquaculture in India, especially in Kerala and West Bengal (Salunke et al., 2020). Suddenly, in the 1990s, there was an increasing demand for brackish water shrimp and its production skyrocketed from 3868 tons in 1980 to 130,805 tons in 2005, making India the world's fourth largest producer (FAO, 2005). Knowler et al., (2009) finds that West Bengal contributes to 34% of the potential shrimp cultivation lands in the Indian Subcontinent, attracting developmental projects and large-scale fisheries for aquaculture. Eriksson et al., (2015) argues that management of SSF has been neglected when compared to industrial aquaculture.

Growth of the mangroves was impaired by the high salt content in the soils because of the unsustainable shrimp aquaculture practices in Brazil (Ferreira & Lacerda, 2016). Additionally, huge mangrove lands have been converted for the purpose of aquaculture and agriculture (Kumar, 2012; Primavera, 2000). Consequently, people migrating into the mangrove areas looking for opportunities compete with the people who are already working there.

SSFs have been unrecognized and unregistered by management agencies as they lack a universal definition due to their incidental description (Berkes et al., 2000; Chuenpagdee & Jentoft, 2009). Although these communities are found worldwide, 'small-scale' still is a clear descriptor of this group of fishing communities unified by social, structural, and institutional characteristics, thereby affecting their governance (Eriksson et al., 2015).

2.4. Vulnerability to Viability (V2V)

Vulnerability and viability are concepts that include multiple parameters – wellbeing, livelihood capitals, resilience, coping and adaptive responses – to indicate the state of

the system or community at a certain time of risk and ability of the same to survive given the unfavorable conditions (Nayak & Berkes, 2019). According to Chuenpagdee and Jentoft, (2018), SSF vulnerability can be perceived as "multidimensional, complex, highly dynamic and relational". Individually, these disciplines provide a 'tunnel vision' look at vulnerability (Brown, 2014; Faulkner, Brown, & Quinn, 2018; Aguilar-Perrera, et al., 2017). It is a state of susceptibility resulting from lack of livelihood assets – ecological, human, physical, social, and financial (Fischer, 2014; Béné, et al., 2011). There are a number of vulnerability indices that have been used for examining the measure of exposure of environment or society to any type of hazards (Edmonds et al., 2020; Flanagan et al., 2011; Wolkin et al., 2015). These indices have numerous indicators that have a numerical value and are considered for a quantitative research approach. But as this study embraces a qualitative research approach, it focuses on discussing vulnerability from a qualitative aspect using I-ADApT which is discussed in Section 2.6 of this chapter.

Viability can be defined as a state when the communities develop resiliency towards potential risks, obtain satisfactory livelihood capitals and move forward to achieve social well-being disregarding vulnerabilities and externalities. Vulnerability is used as an umbrella term that encompasses individual concepts of well-being, livelihood capitals and resilience. To analyze the multidimensional vulnerabilities and examine the pathways to viability, this thesis draws concepts from wellbeing (Armitage et al., 2012; McGregor, 2008; Weeratunge et al., 2014), livelihood capitals (Chen et al., 2013), resilience (Berkes et al., 2000; Berkes & Turner, 2006; Holling, 1973) and coping and adaptive responses (Nayak, 2017; Walker et al., 2004).

2.4.1. Wellbeing

Wellbeing is defined more of a social behavior concept as it is "*a state of being with others, where human needs are met, where one can act meaningfully to pursue one's goals and where one enjoys a satisfactory quality of life*" (McGregor, 2008,p3). It has three dimensions – material, relational, and subjective- influencing the level of vulnerability and viability within a specific context (Andrews et al., 2021; McGregor, 2008; Weeratunge et al., 2014). Each of the parameters used to define wellbeing is

connected to the livelihood assets, community and ecosystem resilience. Wellbeing is understood as an outcome that is attributable to the parameters of vulnerability. It can also be used as a comprehensive method to address the issues of livelihoods of SSF communities from a SES's perspective (Charles et al., 2012).

Wellbeing has been used to influence variety of public policies in health and international development sector (Coulthard, 2012). Coulthard, (2012) also stated that wellbeing contributes to sustainable SSF as by delivering an in-depth analysis of social impacts of SSF vulnerability as well as providing insights on SSF communities behavior. Figure 1 describes the state of social wellbeing when viewed through a three-dimensional perspective and examples of each dimension.

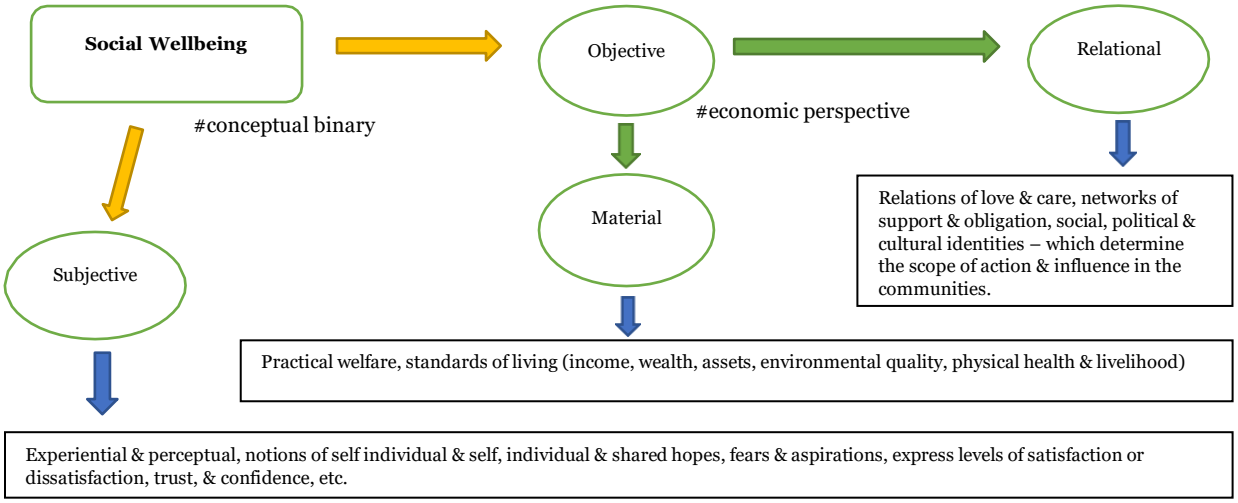

Figure 1 - 3D View of Social Wellbeing (Weeratunge et al., 2014)

2.4.2. Livelihood Capitals

Livelihood capitals includes human, social, natural, physical, and financial capital (Chen et al., 2013). Chen, et al., (2013), thoroughly evaluated livelihood capitals in China's community-based co-management projects for commons governance. The paper also puts forth the indicators of each of the capitals which are discussed in table 3. It was estimated from a study on fishing communities in Sri Lanka, that better education and literacy rates help in the capacity building of these capitals (Silva & Yamao, 2007).

Table 3 – Indicators of livelihood assets (Chen et al., 2013)

Capitals	Indicators

Physical	Household fixed assets, durable goods, access to benefits
Natural	Perception of mangroves, management of the wetlands and fisheries
Human	Skills and knowledge regarding fisheries and mangroves
Financial	Income and Expenditures
Social	Family decisions, community participation and membership, social networking

These capitals are linked to the variables affecting vulnerability, local institutions and governance linked to collective action whose effects vary with the indicators of social capital (Mwakubo & Obare, 2009). If there is any change in the natural capitals, it is likely related to the positive approach of ecosystem sustainability. While capacity building and skill development boosts human capitals in effective management of fisheries and mangroves. Mwakubo & Obare, (2009), linked these capitals with the variables observed in Lake Victoria, Tanzania which were floods, droughts, and diseases. Chen, et al., (2013) argued that income and expenditure as financial capitals are key components for social well-being. Regardless, each of the indicators of the livelihood assets are related to the well-being of SSF communities in one way or another.

2.4.3. Resilience

Resilience has been explored by many scholars over the past three decades (Armitage et al., 2012; Berkes & Turner, 2006; Folke, 2006). It is usually defined as the ability and capacity of an ecosystem or community to cope and adapt to change and develop in relation to global issues like human security and well-being, biodiversity conservation, growth, and development, etc. (Bebbington, 1999; Bousquet et al., 2016; Holling, 1973).

Holling (1973) first proposed the concept of resilience in relation to the environment. Gradually, this approach was discussed in several other disciplines. Folke, (2016) stated that "*The SES resilience approach emphasizes that social-ecological systems need to be managed and governed for flexibility and emergence rather than for maintaining stability*". For example, the mangrove ecosystems and fisheries can never be in a static state: they are dynamic and complex; hence resilience is a phenomenon which involves

"*adapting, improving and innovating*" accordingly and simultaneously (Folke, 2016). Once achieved, this process leads to well-being and sustainability. Furthermore, this acts as the best indicator for coping and adaptive responses in relation to viability.

2.5. Coping and Adaptive Responses

SSF communities respond to certain threats with a variety of actions which can lead them to viability. An adaptive response is defined as the immediate response to a rising problem in a manner that alleviates or resolves the stressor (Nayak, 2017). Adaptive responses are the coping responses when practiced for a duration of time or general responses that have become the usual reaction for any problem (Nayak, 2017). These responses, when practiced following the appropriate guidelines, may become the pathways to viability from vulnerability.

The best way to create resilience in the targeted natural system is by using gear-based management techniques so as to restrict specific varieties of fishes which are ecologically significant (Cinner et al., 2009). To enhance the potential adaptive responses in the communities as well as the mangrove ecosystems, a selective restriction method as proposed by Cinner et al, (2009) may be employed. His research focused on coral reef ecosystems in Papa New Guinea and Kenya; these reefs are close to the shore and show similar kind of responses to stressors when compared to the mangroves onshore.

Barlow, et al., (2010) explains that migration itself is a coping response among SSF communities to vulnerabilities. Following storms, search for economically stable jobs in nearby states, lack of fish catches, less market values or no market interference many choose to leave, and a few choose to stay. This action was seen as a viable option which has different meaning for the SSFs. The perception of viability for SSFs was unlike the definition of viability by academicians. Along with this Sundarbans is a national park known to house the majestic Royal Bengal Tigers with the ability to swim, crocodiles, and King Cobras. Tigers are known to attack the fisher folk when they are out in the forests with their cattle or for foraging. There is a whole village of SSF communities which has 'tiger widows', females who have lost their spouses to gruesome tiger attacks.

These are conflict species that are one of the many stressors that push SSF to vulnerability.

Aye, et al., (2019), conducted a study on Myanmar's mangroves and the dependency of communities on the ecosystem services. The study showed that the economic benefits acted as an incentive for the communities and hence there was improved management of the natural resource. Institutional intervention for skill development and capacity building led to a boost in income, as well as more modern technology being used for fishing and for agriculture. The latter led to less costly and less frequent repairs, which altogether led to the community being resilient to natural as well as anthropogenic stressors (Aye et al., 2019). The well-being of the community was a cobweb of all the components interplaying with each other.

Co-management is an option to better manage fisheries as an ecosystem service along with the ecosystem in order to induce coping and adaptive responses in the communities dependent on it (Pomeroy & Williams, 1994). Partelow, et al., (2018), tried to identify the challenges for co-management in the mangrove ecosystems in Brazil. The marginalized communities here were dependent on the small-scale crab fishery for their livelihood. They have to be empowered so as to integrate them in the developmental policies and help them participate in ecosystem management as well. This will not only make them resilient but also provide them with incentives to cope and adapt to the changing environment (Partelow et al., 2018).

As described by Shaffril et al., (2017), the adaptation responses in SSF communities can be linked with the improvisation in "*fishing routines, strengthening social relationships, managing fishermen's climate change knowledge, facilitating the community's learning of alternative skills, involving fishermen in climate change adaptation planning, and enhancing fishermen's access to credit*". Strategies can be modified accordingly, with the help of stakeholders. The primary step for increasing coping and adaptive response capacity is to enable and enhance the knowledge of fishermen on natural changes, along with learning and strengthening alternative skills (Shaffril et al., 2017). Broad scale strategies might include government agencies and other organizations restoring ecosystems by mangrove afforestation programs.

Additionally, periodical assessment, capacity building and skill development trainings on sustainable aquaculture and related activities would make the fishers more resilient (Shaffril et al., 2017).

2.6. Conceptual Framework using I-ADApT

Altman et al., (2011) proposed an ecosystem-based management (EBM) approach in Gulf of Maine marine ecosystem, where he focuses on a framework on the magnitude and importance of multiple stressors in ecosystems. This EBM approach can be applied to any target ecosystems to identify human impacts on ecosystem services (Altman et al., 2011). Several other approaches and tools have been initiated through global partnerships to identify and propose strategies to deal with ecosystem. A prominent example is the conceptual and methodological framework I-ADApt which would be used in this thesis work.

I-ADApt (Assessment based on Description and responses and Appraisal for a Typology) is a methodological tool developed by the Integrated Marine Biosphere Research (IMBeR) and Human Dimensions Working Group (HDWG) (Bundy et al., 2016). It applies a template to capture standardized information across study sites. In doing so, the framework provides: (1) a 'descriptive' component to capture key dimensions of vulnerability and viability (ecological, social and economic, etc.); (2) an 'appraisal' component to reflect on various responses to change and their outcomes; (3) an 'interactive' component to engage with SSF communities, deepen understanding and develop capacity; and (4) a 'typology' dimension to enable comparative assessment, learning and guidance for governance (Bundy et al., 2016). I-ADApt enables SSF managers, researchers, and local stakeholders to: (1) make decisions efficiently by capturing a full range of vulnerability dimensions, (2) improve their response in a timely manner by engaging critical actors, and (3) evaluate where to most effectively allocate resources to reduce vulnerability, build strength and develop capacity to enhance the viability of SSF communities (Integrated Marine Biosphere Research, 2015).

The framework is designed to incorporate individual global issues and connecting them from V2V using the questions from the I-ADApt template for the survey and interview guides. Figure 2 is the framework that will be followed to fill the questionnaire

according to the findings. The figure is a smart-art representation of how well-being, capitals and resilience along with mangrove management among SSF can lead the community from V2V. These interconnected and interlinked sectors go hand in hand under the umbrella of V2V, and they serve the notion of ecological sustainability and livelihood stability against potential drivers of change. I-ADApt is going to set the base for V2V as it includes a summary of the situation covering all these sectors in detail.

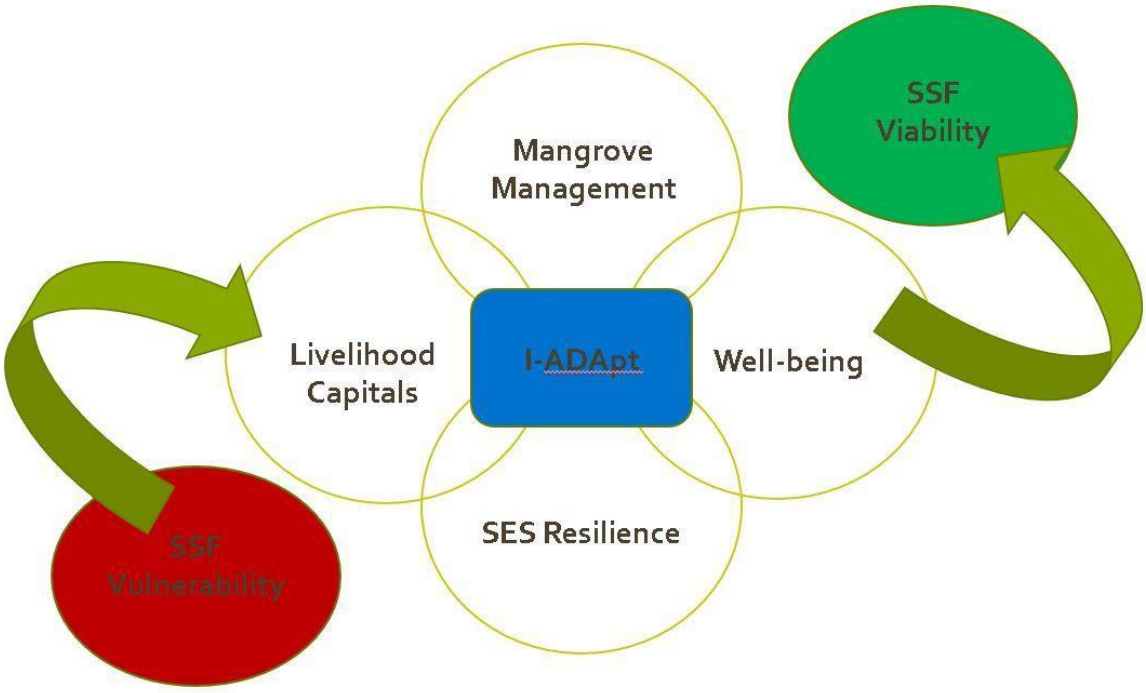

Figure 2 - Conceptual Framework using I-ADApt Template

The bubbles in the figure above represent the major sectors that require significant attention. *SSF Vulnerability* and *SSF Viability* has already been defined in section 2.4. and *wellbeing*, *livelihood capitals* and *resilience* has been elaborated in sections 2.4.1., 2.4.2., and 2.4.3. respectively. *Mangrove management* may be understood as the supervision of the mangrove forests and wetlands. All these four sectors interact with each other to move SSF from V2V. If wellbeing and capitals are better along with higher resilience, the management of the forests would be better as well.

The questions in the I-ADApt template are all interlinked and would indicate whether the communities are vulnerable or not; if they are, the status and level of vulnerability

they are exposed to are identified as well. After getting the information, measures and strategies would be proposed for viability. The framework would also help integrate all the knowledges acquired from relevant stakeholders and enable the SSF communities to define their state of vulnerability and pathways to viability.

2.7. Takeaways

This chapter touched on all the theories and conceptual framework used in this thesis. The literature areas were discussed in brief using traditional literature review as well as some findings from SLR. SLR technique will be discussed in Chapter 3 in detail which is the principal method used in this research work. The global and regional instances provided an idea and foundation for the objectives of to move smoothly to results and discussion using the methods discussed and research approach in the next chapter.

Chapter 3 - Methodology

A brief description of the research area, approach, methods, and limitations

3.1. Introduction

In this study, I would like to learn the key factors influencing the ecological status of the mangrove forests in the research area and SSF communities by pushing them to vulnerability. The holistic approach of the research is to protect the mangroves for the survival of the dependent communities and vice-versa. This chapter focuses on the approach, philosophy, and methods used for conducting the research along with a detailed review of the literature on the research area. It also discusses the limitations of the research on a methodological and a strategical level. Additionally, my reflection of the research and methodology transformation will be elaborated at the end of the chapter discussing the transitioning of the research approach from mixed methods to qualitative due to COVID-19 pandemic.

The research is based on a case study and the methodology embraces a qualitative approach. It does not use a blueprint approach; it identifies various possibilities for a solution and guided by the core values of complexity. Given the wide varieties of research questions and methods the research is a blend of pragmatic, constructive and transformative philosophies that work together (Creswell & Creswell, 2017). With the use of all three worldviews, it is easier to focus on theory, problems and change altogether. Within the identified worldviews of the research, the methods used for meeting the objectives is an in-depth systematic literature review with the help of Zotero reference management software. Additionally, this thesis will look at case studies carved out of significant data and information collected from SLR that focus on the major drivers of change. Finally, an I-ADApt template for assessing the results based on a designed questionnaire will be included in the thesis Annexure.

3.2. Research Area

Figure 3 – Map of Sundarbans in India and Bangladesh (Vivekananda et al., 2014)

Sundarbans, Sundarban or *Shundorbon* all refer to the largest remaining coastal mangrove belt in Asia spreading across east India and southern Bangladesh. Regardless of the number of names given to the place, the meaning behind them has always been the same and are termed after the mangrove species *Heritiera fomes* (Sundari tree in local language) (Gopal & Chauhan, 2006). The area is inundated by brackish water because of the tidal wave action which supports the growth of diverse salt-tolerant plant species, mangroves, and varieties of fishes, wildlife, and other aquatic species. It also experiences a subtropical monsoon climate and receives 1,800 mm of rainfall annually.

It is located in the estuary of river Ganges, Brahmaputra and Meghna draining into the Bay of Bengal and shelters many rare and globally threatened wildlife species such as the Estuarine Crocodile (*Crocodilus porosus*), Royal Bengal Tiger (*Panthera tigris*), Water Monitor Lizard (*Varanus salvator*), the Gangetic Dolphin (*Platinista gangetica*), and Olive Ridley Turtle (*Lepidochelys olivacea*) along with associated species (Banerjee et al., 2012; D. Ghosh, 2011; Pant & Singh, 2021). It is the breeding and nursing grounds of 90% of commercial fishes in eastern coast of India (Ajai & Chauhan, 2017; Chandra &

Sagar, 2003). Additionally, its biodiversity constitutes 334 plant species and 693 wildlife species. Aquatic wildlife species constitutes up to 210 fishes, 24 shrimps, 14 crabs and 43 molluscs, etc (UNESCO World Heritage Centre, 1997). Sundarbans also shelters 7.5 million people in the inhabited islands of India and Bangladesh altogether. Almost 40,000 households are involved in fisheries, agriculture, aquaculture, NTFP collection for their sustenance (Chacraverti, 2014; UNESCO World Heritage Centre, 1987, 1997). Additionally, the region is comprised of two major castes of people involved in fisheries – Scheduled Castes and Scheduled Tribes (Chacraverti, 2014).

UNESCO declared Sundarbans National Park in West Bengal, India as a World Heritage Site in 1987 and Sundarbans in Bangladesh as the same in 1999 (UNESCO World Heritage Centre, 1987, 1997). The Sundarbans Reserved Forest in Bangladesh and Sundarban Wetland in India were designated as Ramsar sites in 1992 and 2019 respectively (Ramsar Sites Information Service, 1992, 2019). This area of ecological importance was kept as a reserve forest by Britishers in 1875, under the first Forest Act of British India (Hoq, 2007) . The region is spread over two administrative districts in the Indian side (~ 4000 sq km), namely South 24-Parganas (13 blocks) and North 24-Parganas (6 blocks) and across the Khulna Division of Bangladesh (~6000 sq km). Out of the 102 islands in Sundarbans region, 54 islands in southernmost region are declared as Reserved Forest and are out of bounds for human settlement (Abdullah-Al-Mamun et al., 2017; Chacraverti, 2014). The 3,500 km long embankment protects the densely populated 54 islands in West Bengal, India from incursion of saline water during high tide. The people here are dependent on paddy cultivation, honey collection, wood cutting, aquaculture and fishing (Dubey et al., 2017).

90% of mangrove species (78 species) in the Indian subcontinent are found in Sundarbans makes it one of the dense mangrove forests in the Indian Peninsula contributing to 60% of the total mangrove cover in the country. It is also home to two out of four horseshoe crab species in the world, which makes them one of the most targeted fishing options (Ramsar Sites Information Service, 2019). This has sparked many ecologists and researchers to conserve the targeted and threatened species by prioritizing the Sundarbans mangroves and its political framework. The Indian Sundarbans has several legal policies in action – Indian Forest Act 1927, Forest

Conservation Act 1980, Wildlife Protection Act 1972, Environment Protection Act 1986, etc. (UNESCO World Heritage Centre, 1987).

Sundarbans in Bangladesh consists of three sanctuaries established in 1977 which have been effectively safeguarded by its national laws and policies, including the Bangladesh Wildlife (Preservation) (Amendment) Act, 1974 and Forest Act 1927. The area is well monitored by the forest staff, officers and individual governmental units which successfully checked the illegal movement of poachers, hunters, and fishers at that time. Communities inside the forest had no recognised rights for entry into the forest and collection of NTFPs which was strictly regulated by government-issued permits. This has led to more illegal activities occurring in the region.

In the list of 'extremely risky' countries based on the climate change impacts, by the Climate Change Vulnerability Index, 2011, Bangladesh and India make the top two countries affected immensely (Maplecroft, 2011; Roy & Guha, 2017). The region is highly exposed to tropical storms 3-5 times yearly which makes it difficult for the region to build up resilience for any other externalities.

My research embraces a pragmatic worldview as it is more problem-centered and focuses on real world practice (Creswell & Creswell, 2017). While predominantly pragmatic, this study also has traces of constructivism and transformative. As the study focuses on determining factors to mitigate the consequences of these actions that might lead to a potential disaster as well as examining strategies that would help the SSF communities become viable, makes it more pragmatic. As I must describe the drivers of change first before moving on to analyzing vulnerabilities, it becomes a constructivism approach (Creswell & Creswell, 2017). As a repercussion of this study, the SSF communities could be subjected to any kind of change, would thus make it indirectly transformative (Creswell & Creswell, 2017).

3.3. Methods

This section aims to describe the key methods and tools used for meeting the objectives of the thesis which are systematic literature review (SLR), Assessment based on Description and responses and Appraisal for a Typology (I-ADApt), and Case Studies.

SLR will be the fundamental method to accumulate information and data regarding the research questions which will not only aim at the synthesis of results and discussion but will also execute literature review. Basically, the SLR will be used in two different sectors – broader and global perspective which will aim at describing the concepts and theories that make up Chapter 2, while the other one can be categorized into case studies that are specific to emergent issues creating numerous problems that are concentrated in Chapter 4. Case studies themselves become a tool to analyze the results obtained in Chapter 4 and the discussion can be based on the findings and researcher's interpretation. I-ADApt is going to be the template that considers all the findings and the individual questions in the template will be filled according to the results and discussion from SLR as well as case studies which would provide a brief summarization of the findings according to the research area for further research.

3.3.1. Systematic Literature Review (SLR)

A SLR will be used in this thesis to meet the objectives by assessing the vulnerabilities and analyzing the pathways to viability of SSF and mangroves of Sundarbans. "*A systematic literature review is a method/process/protocol in which a body of literature is aggregated, reviewed and assessed while utilizing pre-specified and standardized techniques*" (Štrukelj, 2018) In this process, the purpose, objectives, methodology and significance of the research work has to be decided beforehand to reduce bias during the review process. It is different from a regular literature review as it focuses on the "*existing evidence concerning a clearly defined problem*" as opposed to starting from a broad overview of the issues that is eventually narrowed down (Štrukelj, 2018). Overall, a SLR helps examine diverse findings and identify concepts and theories that require further research.

Over the Spring term (May – August, 2020), several workshops were conducted in which the students under my supervisor were guided on collecting and organizing papers from databases in Zotero. We learnt and discussed about each of our areas of research and helped each other in the process of SLR through Zotero in a series of 10-12 workshops.

The process of SLR includes the following steps which have been outlines in Figure 4 –

Step 1 – *Defining the Objectives* – At first, the interest area of research is identified and then narrowed down to a specific topic. This topic would then require a certain research area or location to base the entire thesis on. After the traditional literature review or broad-scale research is done for obtaining a focused topic, the next step is to define the purpose and objectives of the research. Along with these, the gaps and significance of the research are to be noted down. In this thesis, I was driven by my interest in studying mangrove ecology as well as its interaction with dependent communities. This interest was picked up during my undergraduate studies and graduate studies in India where I had a chance to go to Bhitarkanika in Odisha, India and Sundarbans in West Bengal, India, as a study tour to conduct primary data collection for assignments. Both the regions are famous for its mangrove ecosystem and fishing communities. I narrowed down the topic to Vulnerability and Viability with the help of my supervisor and set my research area to be Sundarbans guided by my aesthetic encounter with it 4 years ago. The objectives and purpose were then outlined and defined accordingly.

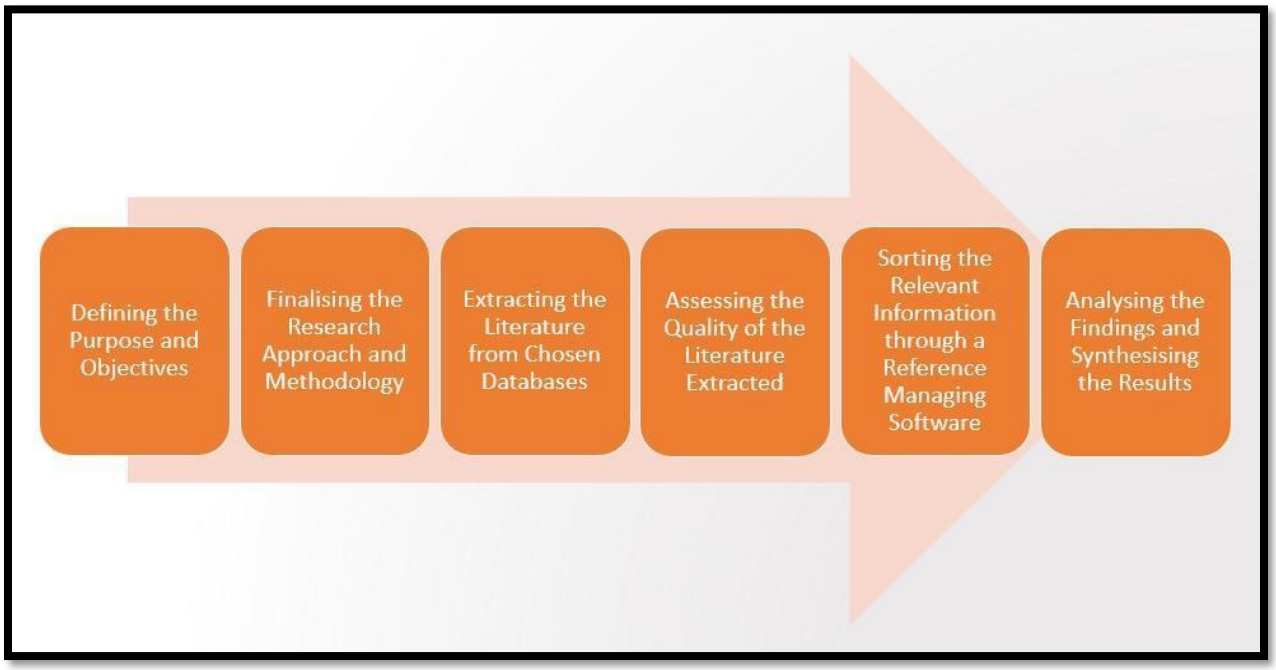

Figure 4 – Steps involved in the SLR method (Štrukelj, 2018).

Step 2 – *Finalizing the Methodology* – Secondly, the methodology of the research is explained, specifying its philosophy. In my research, the methodology was initially mixed methods: collection of primary data from the research area with the help of survey questionnaires, focus group discussions and one-on-one interviews for a

quantitative analysis to follow. Because of the ongoing pandemic, the University issued a research-related travel ban. Accordingly, the methodology of my study changed into a qualitative approach. The method was then chosen keeping safety during the pandemic in mind to SLR for meeting the defined objectives. The philosophy of the research described previously in this chapter then guided the flow of the thesis work.

Step 3 – *Extracting Relevant Literature* – The database for the desired literature is then selected. Depending on the title of the research, objectives and research questions, certain keywords are picked. These keywords are then arranged in a group of two, three or more under different variations and combinations for searching the databases. Under each keyword search, the number of papers found are then added to the reference manager. In my research, the two databases that are used for the extraction of relevant literature are SCOPUS and JSTOR. These two databases were selected on the criteria of diversity of journals and relevancy of papers. Most of the papers, research work that is published by my colleagues, faculty and alumni are found in these databases. Based on the broad-scale research, the following keywords were selected.

1. Mangroves	*4. Drivers*	*7. Well-being*
2. Small-Scale Fisheries	*5. Viability*	*8. Capitals*
3. Vulnerability	*6. Resilience*	*9. Sundarbans*

To limit the total number of journals found through each keyword search, I searched 9 keywords. These were then sorted into different combinations to get the desired papers. The combination of keyword searched are elaborated in the following tables 2 and 3, along with the number of papers found.

Table 4 – List of keyword combinations from SCOPUS

SI.No.	**Combination of Keywords**	**Total no. of papers**
1.	Mangroves+Small-Scale Fisheries	25
2.	Mangroves+Drivers+Keywords	17
3.	Mangroves+Vulnerability+Sundarbans+Abstract	19
4.	Mangroves+Viability+Sundarbans+Abstract	6
5.	Mangroves+Resilience+Sundarbans+Abstract	6
6.	Mangroves+Well-being+Sundarbans+Abstract	5

7.	Mangroves+Capitals+Sundarbans+Abstract	7
8.	Mangroves+Small-Scale Fisheries+Sundarbans	0
9.	Mangroves+Drivers+Sundarbans+Abstract	12
10.	Mangroves+Well-being+Resilience+Capitals+Sundarbans	1
11.	Small-Scale Fisheries+Sundarbans	1
12.	Small-Scale Fisheries+Sundarbans+Abstract	14
13.	Small-Scale Fisheries+Drivers+Sundarbans	6
14.	Small-Scale Fisheries+Vulnerability+Sundarbans	2
15.	Small-Scale Fisheries+Vulnerability+Viability	5
16.	Small-Scale Fisheries+Vulnerability+Viability+Sundarbans	0
17.	Small-Scale Fisheries+Drivers+Sundarbans	0
18.	Small-Scale Fisheries+Well-being+Resilience+Capitals	1
19.	Small-Scale Fisheries+Drivers+Vulnerability	7
20.	Small-Scale Fisheries+Mangroves+Drivers	1

Table 5 – List of keyword combinations from JSTOR

SI.No.	**Combination of Keywords**	**Total no. of papers**
1.	Mangroves+Small-Scale Fisheries	27
2.	Mangroves+Drivers+Keywords	25
3.	Mangroves+Vulnerability+Sundarbans+Abstract	20
4.	Mangroves+Viability+Sundarbans+Abstract	12
5.	Mangroves+Resilience+Sundarbans+Abstract	31
6.	Mangroves+Well-being+Sundarbans+Abstract	22
7.	Mangroves+Capitals+Sundarbans+Abstract	3
8.	Mangroves+Small-Scale Fisheries+Sundarbans	0
9.	Mangroves+Drivers+Sundarbans+Abstract	3
10.	Mangroves+Well-being+Resilience+Capitals+Sundarbans	1
11.	Small-Scale Fisheries+Sundarbans	3
12.	Small-Scale Fisheries+Sundarbans+Abstract	38
13.	Small-Scale Fisheries+Drivers+Sundarbans	52
14.	Small-Scale Fisheries+Vulnerability+Sundarbans	22
15.	Small-Scale Fisheries+Vulnerability+Viability	13
16.	Small-Scale Fisheries+Vulnerability+Viability+Sundarbans	0
17.	Small-Scale Fisheries+Drivers+Sundarbans	3
18.	Small-Scale Fisheries+Well-being+Resilience+Capitals	15
19.	Small-Scale Fisheries+Drivers+Vulnerability	78
20.	Small-Scale Fisheries+Mangroves+Drivers	25

Twenty possible combinations were searched in both databases. JSTOR came up with a greater number of papers when compared to SCOPUS. In the first few searches with single keywords, hundreds of papers in SCOPUS and thousands of papers in JSTOR were found. To limit the number of papers, the criteria were then set in both databases search, to 'abstract' or 'keyword' only where the keywords searched will be present in either abstract or the keywords in the abstract. This reduced the resulting number of papers significantly in SCOPUS but not as much in JSTOR. The criteria in JSTOR were then set to the type of paper - Asian Studies, Economics, Environmental Studies, Environmental Science, Political Science, Public Policy and Administration, Sociology, Anthropology, Ecology and Evolutionary Biology. The total number of papers found from SCOPUS were 135 and from JSTOR were 393. All these papers were saved to the Zotero Reference Management Software under the folders named after the combination of keywords and the date, the search was undertaken as can be seen from Figure 5 below.

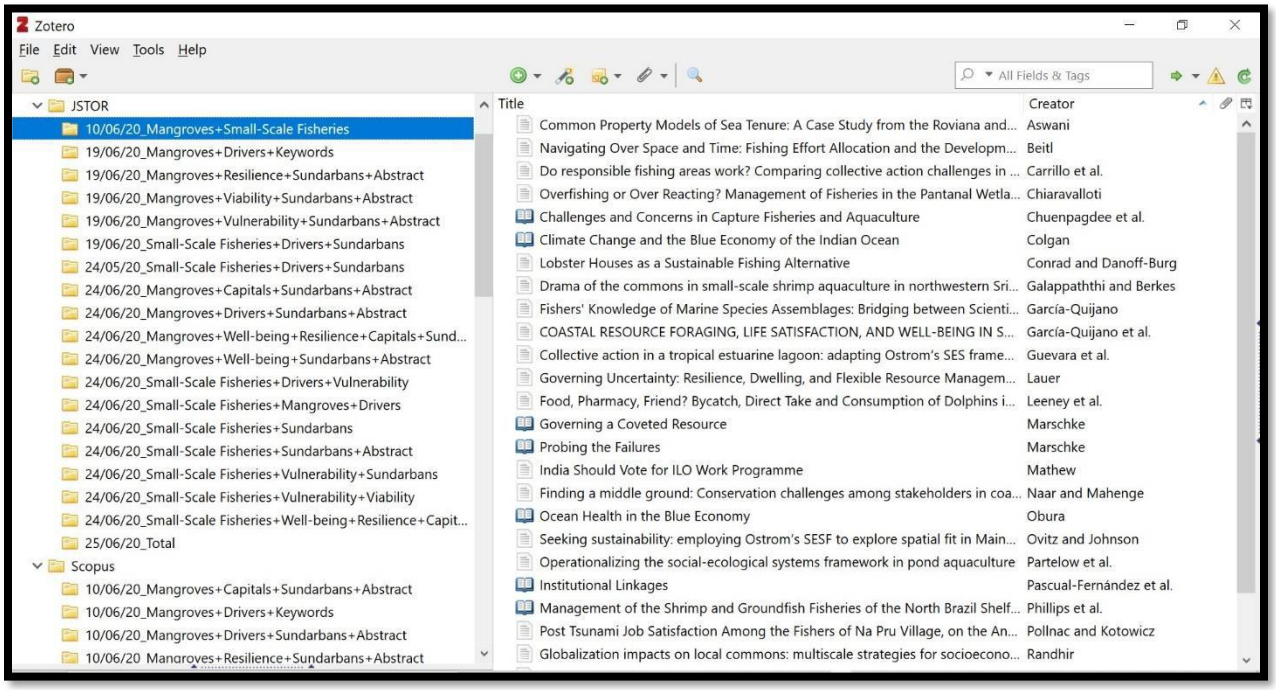

Figure 5 – Screenshot of the Zotero Reference Management Software. It shows the different folders and sub folders in which the papers are organized based on the date of search and the combination of keywords.

Step 4 – *Assessing the Quality of Papers* – After the organization of the papers in the reference management software, the unrelated papers are discarded while the relevant papers are selected for tagging and reviewing. A total of 55 papers from SCOPUS and 15 papers from JSTOR were selected after assessing their relevance to research objectives and questions. The papers that were discarded either had no relation with my objectives or had information that did not answer my research questions. It was seen that the papers found in SCOPUS were more relevant when compared to JSTOR.

Step 5 – *Sorting the Information* – The papers were then sorted into desired folders based on objectives or research questions. The 70 papers were then placed into three folders named according to the respective objectives of my research. The papers that focused on similar objectives or had similar research questions were arranged under the same folder. The papers were then tagged under the 'tag' section of Zotero with important keywords that are used in that paper for better categorization. The papers with similar research were then selected for a detailed review which are then added to the 'notes' section of Zotero.

Step 6 – *Synthesis of Results* – The papers were then analyzed and reviewed. The results are then written based on the findings from the analysis. In my thesis, the notes are synthesized together to yield results where the flow of the case study is maintained throughout in the results chapter using the information collected from both the databases.

Several other papers were also considered depending on recommendation sby supervisor, professor, and colleagues. Relevant papers from google scholar as well as papers found during traditional literature review at the time of selecting the research area, topic and narrowing down the objectives, were saved to Zotero in categorized folders. These papers were also used in combination with SCOPUS and JSTOR for referencing of relevant data and information in the thesis.

3.3.2. Case Studies

Case study approach in addressing specific problems was first used by Sigmund Freud in early 1900s which is still carried on by several researchers working in social sciences

sector (George & Bennett, 2005). The salient features of a case study approach is to generate an in-depth summarization of a problem, issue or an event (drivers of change in my thesis), to understand its complexity in light of the real-life context (Crowe et al., 2011). This approach would be useful in defining the drivers in my research in depth and the significant impacts they have on SSF and mangroves of Sundarbans. They would help understand the multidimensional vulnerabilities induced which parallels the second objective. The base of this approach lies in SLR as it would be used primarily for getting the information in need.

3.3.3. I-ADApt Framework

Several approaches and tools have been initiated through global partnerships to measure, identify, and propose strategies to deal with ecosystem as well as SSF vulnerability, one of which is the conceptual and methodological framework I-ADApt which would be used in this thesis work as already discussed in Chapter 2, Section 2.6.

The questions in the template are categorized under general information, drivers, well-being, capitals, governance etc. which when filled according to the findings would indicate the vulnerability of the target population and research area. After getting the information, measures and strategies would be discussed and proposed for viability. The framework would also help integrate all the knowledge acquired from relevant stakeholders and enable the SSF communities to define their state of vulnerability and pathways to viability.

In my thesis work, the questions in this template will be filled as per the findings through the SLR because primary data collection through surveys and interviews were not possible due to travel ban. This template will then be added to the Annexure-I of the thesis.

3.4. Limitations of the Study

The major limitation to this study was the occurrence of the pandemic which led to indefinite research regarding travel ban throughout the University. As this research was principally based on the collection of primary data from the field and analysing secondary data to yield more accurate findings, all of which was not possible because of

the COVID-19 pandemic. The inability to go to field and absence of participatory observation will be another drawback or limitation to this study. Additionally, working on secondary data has some unavoidable biases in analyzing and discussing about certain contradictory topics. This research is also not strictly limited to SCOPUS and JSTOR database as it also includes articles, journals, newspaper reports, and web pages from government organizations to meet certain dilemmas arising during SLR.

3.5. Reflections

To be able to successfully plan the thesis, complete the secondary data collection and analyzing process deeply overwhelms me. There was a point where I almost gave up on my topic as a major part of its methodology involved participatory observation, surveys, interviews, and focused group discussions. Every step of the way was calculated and organized depending on the time dedicated out on the field. But the COVID-19 pandemic cut down that opportunity of being physically present in the research area and contemplating on the situation of the SSF communities. It changed all the plans of primary data collection, ethics application, and international travel due to research ban implemented by the University of Waterloo. Little did I know about SLR before it was introduced to me by my supervisor in the Spring 2020. This method acted as my fail safe and kept me going till the finish line in the hope that I would be able to produce quality work for V2V Global Partnership and my University. Obviously, it was not the best method compared to field excursion and primary data collection, but it provided me the basic know-how which is quintessential for pioneer research as well as higher studies. This method motivated me to be able to explore the realm of secondary research which plays an important part in scouring the database as well as understanding the research area and its components from inside out.

Chapter 4 - Tragedy of the Sundarbans

A systematic analysis of the drivers and multidimensional vulnerabilities of the mangrove SES

4.1. Introduction

The Sundarbans is a complex and dynamic SES which is regulated by the interactions between its ecological and social sub-systems comprising of the mangroves and the dependent communities respectively (DasGupta & Shaw, 2015). It is characterised by the presence of several components or entities – mangrove forests and associated species, a diversity of crabs, shrimps, fishes, amphibians, reptiles, birds, and animals, and the culture of millions of people (Danda, 2010). These people are mostly SSF communities that are generally affected by disasters, migrating population, expanding industry and other escalating environmental problems (Islam & Chuenpagdee, 2013).

Sensitivity of the Sundarbans mangroves and SSF communities can be assessed by a systematic review and analysis of drivers, vulnerabilities, and strategic responses. Drivers of change can be understood as the natural or anthropogenic stressors on the region that have a massive impact on the functioning of the system (Feka & Ajonina, 2011; Hirales-Cota et al., 2010). The changes due to these drivers affect the ecosystem and its services, the SSF communities, and their survival by eventually causing a chain reaction, leading to several challenges for the system which are identified to be 'impacts' on the system. These impacts create vulnerabilities which are externalities that limit the performance of the entities ultimately leading to a malfunction of the system (Berkes & Nayak, 2018). Vulnerability is a concept which measures multiple parameters – wellbeing, capitals and resilience, to indicate the level of risk while viability is the ability of the community to address these risks, cope and adapt to the changing environment, with or without external help in a sustainable manner (Berkes & Nayak, 2018; Islam & Chuenpagdee, 2013; Nayak et al., 2014).

As defined in Chapter 2, these concepts have been individually explored in different contexts and multiple criteria but have never been linked together with respect to SSF and mangroves. In this chapter, I am aiming to address the key question – "What are the key social-ecological factors influencing vulnerability in SSF communities and

mangroves of Sundarbans?" and how do we address the lack of understanding about the interconnection and interaction between these components of the SES from a vulnerability and viability perspective. This chapter would help bridge this gap between the socio-ecological relationship within these components. The first two objectives of my thesis will be the centre of focus for Chapter 4 which beholds the results obtained through SLR method discussed in Chapter 3 and discussion regarding the findings. The two objectives that the chapter focuses on are –

1. to identify the threats and describe the drivers of change affecting the Sundarbans and its SSF communities.
2. to analyse the multidimensional vulnerabilities experienced by mangroves and SSF communities of Sundarbans

I will achieve the first objective by SLR and a case study approach stating the drivers of change in the Sundarbans. Drivers will be identified and analysed by looking into the data provided in the research papers obtained through SLR. By using that data and with the help of the results from the research articles, I will then analyse the vulnerabilities linked with the drivers identified in the first objective, to meet the second objective.

This chapter will briefly explain the ecological and social conditions of the Sundarbans SES by shedding light on the major vulnerabilities affecting mangroves and SSF communities as well as their responses against these vulnerabilities. Ecological conditions are stated by looking at the mangroves and the associated species; how the environmental problems affect them and their ability to cope to rising threats. Social condition is explored by analysing the wellbeing of the communities and their assets which ultimately impact resilience in the communities.

The rest of the chapter will focus on exploring the status of three-dimensional version of wellbeing & livelihood capitals with respect to induced vulnerabilities. The findings are supported with the help of case studies which investigate the impacts of the cyclones and shrimp aquaculture that affect the SSF and help analyse the vulnerabilities caused by each driver of change. It explores the angles of vulnerabilities affecting wellbeing, capitals, and resilience of SSF communities. The study has potential to further the knowledge of researchers to bridge the gap between the mangroves and SSF on an

ecological and societal point of view. The concept of strategic responses will be explored in the next chapter which will specify the role of SSF communities and their resiliency through coping and adaptive responses and sustainable pathways to viability.

4.2. Drivers of Change

Sundarbans has seen years of degradation through natural disasters and developmental activities that have driven many native people to poverty, unemployment, lack of alternative livelihoods, overexploitation of resources, human-wildlife conflicts, illegal activities, and outmigration (Hossain et al., 2018; Inskip et al., 2013; Islam et al., 2018; Islam & Chuenpagdee, 2013; Kabir et al., 2019; Knowler et al., 2009; Thomas et al., 2017; Thompson et al., 2016). The changes inflicted on these complex ecosystems has disrupted the resiliency of the forests as well as the SSF impacting the ecosystem services (Ghosh et al., 2015). The persistence to survive in extreme conditions, as well as the responses of both forests and SSF have been degrading in the past few decades (Thompson et al., 2016).

Drivers can be classified as natural and anthropogenic, based on source of occurrence (Galatowitsch, 2018). Currently, climatic events or natural drivers including cyclones, salinization, sea-level and temperature rise, along with developmental activities or anthropogenic drivers like in-migration and population explosion, unsustainable aquaculture, agriculture, and tourism practices, industrial activities, construction projects have been creating multidimensional vulnerabilities in Sundarbans (Hossain et al., 2018; Knowler et al., 2009; Thomas et al., 2017; Thompson et al., 2016).

4.2.1. Natural Drivers

Cyclones – The geography of the region has made it susceptible to several cyclones or tropical storms that pose an imminent threat to the ecosystem as well as dependent communities. Loss of infrastructure, livelihoods, and lack of opportunities due to the cyclones have led to unavoidable vulnerabilities among the people living in the region (Islam et al., 2018; Paul, 2009; S. Sen, 2020). Additionally, the biodiversity of Sundarbans is also at stake as there is hardly enough time between two cyclones to rebuild and restore.

Flooding – The steady action of tidal waves makes the region naturally and seasonally inundated with sea water. This phenomenon is helpful in the growth and maturation of mangroves and salt-tolerant paddy cultivation (Blasco et al., 1992). The water from this flooding sometimes does not recede causing increase in salinity towards the inland zone by up to 160 km, which further leads to rotting of certain mangroves as different mangrove species have different range of salt tolerance (Blasco et al., 2001).

Salinization – This process is becoming an impact of climate change events like sea-level rise, flooding, and recurrent cyclonic storms. Sundarbans is the world's second place with rising concerns over salinization (Hossain et al., 2018). Along with ecological impacts, salinization affects the socio-economical state of the Sundarbans communities by increasing salinity in aquifers and the freshwater upstream resulting in scarcity of drinking water (Mehvar et al., 2019). Also, artificial flooding for shrimp aquaculture is accelerating the salinization process in freshwater regions (Hossain et al., 2018).

Erosion and Accretion – It is a natural process and contributes to the sea level rise in the coastal areas. There has been an increase in erosional activity and decrease in accretional activity in the Sundarbans (Rahman et al., 2011). The major attraction of Sundarbans – the Royal Bengal Tiger is endemic to the region and apparently is the worst affected by the sea-level rise. Because of this reason, the tigers move towards safer areas which happen to be densely populated by fisher communities and farmers, eventually creating a human-wildlife conflict of importance (Hazra et al., 2002; Loucks et al., 2009).

4.2.2. Anthropogenic Drivers

Settlements, Agricultural and Aquaculture Expansion – The demand for settlement area increased with the increase in population. Table 6 shows the loss of approximately 4000 sq km of mangrove forests since 1776 to 1968 which points in the direction of agricultural expansion and increasing settlements under the British rule. The British East India Company cleared these lands for new settlements in the name of trade and commerce (Ghosh et al., 2015). The fixed taxes levied on landholders at that time, instigated non-fishers to migrate and settle down for more yield and profits. Because of famines hitting the region periodically, the production of paddy became scarce and non-

fishers started sustaining themselves on fishing eventually creating competition for resources among the SSF communities (Hoque Mozumder et al., 2018). Clearing lands for agricultural expansion is still practiced even though agriculture is not that high yielding when compared to fisheries and NTFP (Singh et al., 2017). In addition to agriculture, wetlands have also been converted into shrimp or fishponds for aquaculture that have been persistent in the region since late 1990s when the demand for shrimps increased in the international market (Knowler et al., 2009). Improper and unsustainable methods and techniques are used by both fishers and non-fishers which is due to lack of knowledge of the skill required for aquaculture or competition for resources in the area. Furthermore, large scale industries getting involved in fisheries pose a threat to the existence of SSF in Sundarbans (Abdullah et al., 2017).

Table 6 – Change in the Mangrove Forest Cover in the Western Part of the Sundarbans since 1776 – 2014. (Ghosh et al., 2015)

Year	Area in sq km	% of Change per Decade
1776	6588	NA
1873	6068	-0.8
1968	2307	-6.5
1989	1983	-6.7
2001	1926	-2.4
2014	1852	-3

Land use change - The nature of settlements in Sundarbans changed from rural to urban in between 2001-2011 due to population explosion (Chacraverti, 2014). This led to an increase in fragmentation as lands became smaller which could not yield sufficient paddy for consumption. Hence, people started shifting to fishing which became the second primary occupation. Overfishing became an emerging issue that resulted because of increase in the number and competition between fisher population. Few of the species started deteriorating and disappearing.

Developmental Projects – These projects hinder the livelihoods of the people by luring them with other job opportunities for which they do not possess the skill. They also fuel

resource degradation which is an impending ecological crisis in terms of releasing greenhouse gases into the atmosphere contributing to global warming. For example, the Sahara India Ecotourism Project in Jambudwip, Sundarbans, India and Coal-Fired Power Plant Project in Rampal, Sundarbans, Bangladesh are multi million-dollar investments that put the ecological and social sub-systems in jeopardy (Chowdhury, 2017; Jalais, 2007). The ecotourism project made the court to pass an order to evict SSF communities from the island and a ban on fishing in the area. Later, the project was called off because of rising conflicts and protests by numerous organisations and institutions.

Table 7 gives a brief about the total number of papers used through SLR to come up with the analysis of potential drivers of change active in the region. The papers considered in the table are strictly related to the specific driver as they have the driver mentioned in their topic, abstract or keywords.

Table 7 – Key Points by papers found in SLR for each driver of change

Drivers	No. of Papers	Key Points
Natural		
Cyclones	13	• Recurrent • High Intensity and Frequency • Livelihood Destruction • Ecological Imbalance • Flooding and Salinization
Flooding	3	• Sea-level rise • Salinization • Constant migration to avoid unfavorable regions • Saltwater inundation twice daily • Waterlogging and rotting of trees

Sea-Level Rise	4	• Habitat loss and fragmentation • Community displacement • Human-wildlife conflict • Loss of fallow land • Flooding in unpredictable areas
Salinization	5	• Soil infertility • Saline drinking water sources • Health issues • Rotting of trees • Loss of native aquatic species
Erosion	1	• Land loss • Community displacement • Species loss • Flooding • Shift in river path
Anthropogenic		
Settlements	2	• In-migration of non-native people • Population explosion • Loss of fallow land • Demand for resources • Competition
Agriculture	4	• Conversion of fallow or wetlands • Deforestation • Agricultural run-off

		• Limited salt-tolerant varieties • Income generated comparatively less
Aquaculture	9	• Conversion of fallow or wetlands • Deforestation • Pollution • Non-fishers, large scale fishing fleets intervention • Loss of SSF livelihoods and native species
Land Use Change	1	• Less yield for sustenance • Smaller shrimp or fishponds • Livelihood Loss • Debts • Biodiversity Loss
Coastal Development	3	• Deforestation • Improper management • Loss of traditional values • Unplanned tourism • Global warming

Table 7 gives a brief summarization of the active drivers of change in the Sundarbans SES. These drivers were selected while doing SLR as the number of papers that pointed to specific threats and identifiable drivers were analysed for the research. As found from the analysis, cyclones and aquaculture were the repetitive drivers that had highest number of papers, hence, were selected for the case study approach.

4.3. Case Studies

This section will be divided into two subsections as it focuses on the two major drivers of change cyclones and unsustainable shrimp aquaculture. Each section would describe the threats, impacts and past experiences of Sundarbans with these drivers of change.

4.3.1. Cyclones in Sundarbans

During the SLR and categorization of journal articles in Zotero, I observed cyclones being mentioned in every article regarding environmental destruction, ecological imbalance, or climate change impacts on the Sundarbans region. About 13 papers directly talked about cyclones as a threat to coastal systems from JSTOR, SCOPUS, Springer, and ScienceDirect. Additionally, many papers hinted cyclones as a disaster, climatic event or a parameter in ecosystem assessment, evaluation, and management studies. For the sake of addressing recent cyclones, blogs, web articles and newspaper reports have also been sited.

Sundarbans receives an average precipitation of 1600-1800 mm per year and is subjected to recurrent cyclones in the months of May-June and October-November formed in the Bay of Bengal (Ghosh et al., 2015; Gopal & Chauhan, 2006). Annually, an average of 12-14 depressions are formed in the Bay of Bengal which have the potential to become cyclonic storms (wind speeds more than 110 kmph) (Paul, 2009). The location of Sundarbans makes it more susceptible to these storms as it lies in the route of most of the cyclones formed in the Bay. Table 8 was adopted from UNDP, 2004 and proves that Bangladesh and India are the top two countries that are most vulnerable to cyclones in the world as the number of casualties in the region was because of these cyclones. The table depicts the situation of these countries before 2003 but since then casualties have been reducing by the pre-disaster management strategy of forecasting, warning, and evacuation (Paul, 2009).

Table 8 - Countries vulnerable to Cyclones and Floods (United Nations Development Programme, 2004)

Tropical Cyclones	Floods

Rank	Country	Death/100,000	Rank	Country	Death/100,000
1	Bangladesh	32.1	1	Venezuela	4.9
2	India	20.2	2	Afghanisthan	4.3
3	Philippines	8.3	3	Pakistan	2.2
4	Honduras	7.3	4	China	1.4
5	Vietnam	5.5	5	India	1.2
6	China	2.8	6	Bangladesh	1.1

Major cyclones that had devastating impacts in Sundarbans in the past 2 decades are SIDR in 2007, Aila in 2008, Amphan in 2020 and Yaas in 2021 (Bhowmik & Cabral, 2013; Chakraborty, 2015; Sen, 2020; Singh, 2021). I was still in the middle of writing this thesis while cyclone Yaas made landfall. The impacts of the other cyclones can still be seen in the regenerating capacity of the Sundarbans and the property loss of the communities. People were still trying to estimate the amount of loss due to Amphan when Yaas hit about a year after it. Their blind faith in the mangroves by avoiding evacuation to cyclone shelters pre-cyclone led them to their deaths during SIDR as strong winds attaining one-minute peak of 260 kmph ripped off the mangrove forests resulting in a 35% loss of vegetation (Bhowmik & Cabral, 2013; Danda, 2020). Aila made landfall in May 2009, affecting 5 million people in total (Chakraborty, 2015). The storm did not have as many casualties as SIDR, but the loss of property was tremendous. The most affected were the farmers awaiting harvest of rice in the season.

Cyclones have an everlasting impact on the components of the ecosystem which might take years to return to its original state which hampers its sustainability (Elsner et al., 2008). SSF communities living here believe that mangroves protect them from the direct destructive impacts of cyclones acting as a buffer against them. They are hit with the gusting wind speeds resulting in loss of plant biodiversity and flooding in the coastal fringe (Blasco et al., 2001). After every cyclone, this flooding caused by the downpour lasts up to 5-12 weeks or more, that poses health risks for local communities (Lara et al., 2009).

Table 8 also shows us that the death rate of the people exposed to floods is not that high compared to cyclones, which is true but the suffering due to loss of property, exposure to variety of diseases and lack of proper health care and sanitation at the time of the event creates vulnerability for these SSF communities. Cyclones and flooding are a recurrent phenomenon in this part of the Bay of Bengal which leads to these kind of losses (Sakib et al., 2015). They negatively impact their subjective and material wellbeing. The fishponds and crop fields are damaged in the storms; saltwater intrusion led to salinization of drinking water sources; boats and other fishing gears along with *kaccha* (mud) houses are blown away and destroyed. They also induce hydrological changes which lower food security and increase health risks (Neogi et al., 2016). Dubey et al., (2017) states that the recurrent cyclones alter the physio-chemical conditions of the artificial ponds created by the SSF communities for aquaculture. They have reported that huge quantities of debris, toxic substances, and pollutants land up in the ponds affecting the ecosystem after the cyclones.

Additionally, I noticed that these cyclones not only have an impact on the SSF communities which make up the social subsystem but also affect the ecological subsystem by affecting the flora and fauna diversity. Large tracts of lands have turned unproductive after post-cyclones, because of salinization (Hossain et al., 2018). Cyclones usually bring about increase in fish catch because of upwelling of nutrient rich water which follows a period of no catch or less catch which affects the ecological balance of the system (Dutta et al., 2015). Post Aila, people had to cut many healthy mangroves which died due to prolonged flooding of saline water (Chakraborty, 2015). The short restoration period between two cyclones is not letting the vegetation, salinity and to come back to normalcy.

Sundarbans has been subjected to more than 200 high-intensity cyclones in the past 100 years that have had a widespread impact (Paul, 2009). Table 9 shows that almost 26 cyclones in the past two decades have passed through Sundarbans even though the landfall area was somewhere else. This table was adopted from Dubey et al., 2017, which clearly states that frequency of the cyclones has been increasing with increase in high category cyclones. One could imagine the type of devastation this many numbers of

cyclones can cause on the species diversity of the region as well as the livelihoods of the communities living in the region.

Table 9 – Types of Cyclones that have passed through Sundarbans in the past two decades. (Bandyopadhyay et al., 2021; Dubey et al., 2017)

S.No.	Cyclones	Year	Wind speed (Km/hr)	Category
1	BOB 04	Oct-2001	65	Cyclonic Storm
2	BOB 03	Nov-2002	100	Severe Cyclonic Storm
3	BOB 04	Nov-2002	85	Cyclonic Storm
4	BOB 01	May-2003	140	Very Severe Cyclonic Storm
5	BOB 01	May-2004	166	Extremely Severe Cyclonic Storm
6	Pyarr	Sep-2005	65	Cyclonic Storm
7	Mala	Jun-2006	185	Extremely Severe Cyclonic Storm
8	Akash	May-2007	85	Cyclonic Storm
9	Sidr	Nov-2007	215	Extremely Severe Cyclonic Storm
10	Nargis	May-2008	165	Very Severe Cyclonic Storm
11	Rashmi	Oct-2008	85	Cyclonic Storm
12	Bijli	Apr-2009	75	Cyclonic Storm
13	Aila	May-2009	110	Severe Cyclonic Storm
14	Laila	May-2010	100	Severe Cyclonic Storm
15	Giri	Oct-2010	195	Extremely Severe Cyclonic Storm
16	Viyaru	May-2013	85	Cyclonic Storm
17	Phailin	Oct-2013	215	Extremely Severe Cyclonic Storm
18	Komen	Jul-2015	75	Cyclonic Storm
19	Roanu	May-2016	85	Cyclonic Storm
20	Mora	May-2017	110	Severe Cyclonic Storm
21	Daye	Sep-2018	65	Cyclonic Storm
22	Titli	Oct-2018	150	Very Severe Cyclonic Storm
23	Phethai	Dec-2018	100	Severe Cyclonic Storm
24	Fani	May-2019	215	Extremely Severe Cyclonic Storm
25	Bulbul	Nov-2019	140	Very Severe Cyclonic Storm
26	Amphan	May-2020	240	Super Cyclonic Storm

Blasco, et al., (1992), stated that the cyclones did not hamper the mangroves in the late 1980s, which is quite contradictory to the impacts that are seen by recent cyclones. It can be inferred from this finding that either the loss of species went unreported in the late 1980s or people did not see high-scale destruction of floristic diversity in the reserve until SIDR in 2007 (Bhowmik & Cabral, 2013). This can indicate that wind speeds have

been spiking lately which is causing devastation. Earlier, there were many human and livestock casualties but because of the Government's disaster management programme of moving the vulnerable communities to cyclone shelters, the casualties have greatly been reduced. Instead, the mangroves have become the first line of defense against these tropical storms and have been lost to them in large numbers (Dutta et al., 2015).

Amphan has been the strongest cyclone to hit the Sundarbans since SIDR (Ghosh, 2020). It made landfall in West Bengal on 20th May 2020. Sen, (2020), reported that 28% of mangrove cover was lost to it and large parts of the state in India as well as division in Bangladesh were out of power and water for a month. 4,000 sq. km of land was waterlogged, thousands of homes were damaged, trees uprooted, electrical poles and communication towers broken, roads, bridges and embankments were left destroyed (Ahmed & Kelman, 2020). The human casualties were around 128 (98 in India and 26 in Bangladesh) which the government was able to reduce in the past years by mobilising huge number of people pre-cyclone, to cyclone shelters in higher elevation areas. Fishermen were asked to refrain from fishing activities in the sea and abide by the cyclone warning. Currently, 12,000 cyclone shelters are functional in this area (Ghosh, 2020). Regardless of the ongoing pandemic of Coronavirus, the lockdown, and quarantines effective since March 22nd in India and Bangladesh, the governments of both countries did greatly in managing the disaster.

The Prime Minister of India announced 136.5 million USD and 68.2 million USD as relief funds for West Bengal and Odisha states respectively after an aerial survey (Ghosh, 2020). Some amount of money was also to be provided to the families who have lost their members to the cyclone or injured during the cyclone. The National Disaster Response Force (NDRF) teams were sent to the respective places to restore electricity and clear the post-cyclone debris from roads and highways. The Ministry of Disaster Management and Relief in Bangladesh announced 35.3 million USD to restore the embankments, 17.6 million USD to the districts affected, and 353 thousand USD to low-income families (Biswas, 2020).

The wrath of these cyclones has been a burden on the fisheries sector as loss of infrastructure and livelihoods of SSF in Sundarbans has been an immense impact in

driving them into vulnerabilities that are uncontrollable. These vulnerabilities would be discussed in detail in Section 4.4.

4.3.2. Unsustainable Shrimp Aquaculture in Sundarbans

Approximately 9 articles in keyword search came up to have shrimp aquaculture in their topics or abstracts. More than 10 papers illustrated the impacts of shrimp aquaculture on the environment as well as communities in the region. More keywords of relevance like SSF, wellbeing, capitals, and resilience were used to pinpoint articles that share similar if not the same objectives.

Shrimp aquaculture has been around mankind since time immemorial. It was considered as a secondary fishing occupation in the South Asian countries, for SSF and other communities until the 1970s (Boyd & Clay, 1998). The term 'blue revolution' came up in the past to reduce the fishing pressure to mainstream shrimp aquaculture as "*10 kilograms of marine life were being caught routinely for each kilogram of shrimp taken from the sea*" (Boyd & Clay, 1998). The juvenile shrimps also called shrimp fry, are collected from coastal areas by fishers or companies who take them and culture them in artificial ponds for the shrimps to mature into a marketable phase. These are then released into the market for sale or are processed and sold as dried fish. *Penaeus monodon* and *Penaeus indicus* are the common species of shrimps used for culture in India and Bangladesh, because of its high market value, profitable returns, and large size (Manoj & Vasudevan, 2009). Aquaculture is an important sector for providing employment to the local people. Fisheries itself along with aquaculture became one of the major reasons for mangrove degradation in the world. Mackenzie, et al., (2016) stated that fisheries in the mangrove shoreline has become a threat to the forests.

While reading through the articles about major drivers, I observed land use changes for aquaculture in Sundarbans as a common issue raised by many authors. Mangrove felling has been recorded since the British Rule where forests were converted into revenue land that yielded commercial crops as well as food that was useful in times of war. Agriculture is the primary occupation of locals in the area even though it is not high yielding when compared to fishing as it contributes 79% to the household income (Chacraverti, 2014; Singh et al., 2017). Roughly about 60% of mangrove swamps in

Asian coastal areas have been converted into shrimp aquaculture farms (Primavera, 2000).

Since the 1980s, mangrove swamps and agricultural lands were being converted into shrimp ponds in the Sundarbans area which were the major source of pollution and other human activities in the area (Kumar, 2012). Furthermore, I found out that many authors of journal articles indicate aquaculture as a solution to the livelihood issues of SSF communities of Sundarbans and as a system that is highly affected by climate (Dubey et al., 2017; Kabir et al., 2019). I agree that aquaculture can be a solution but only if it is practiced in a sustainable fashion. Even though the practice is helpful in economically stabilising these communities, the absence of a proper management system as well as lack of knowledge of techniques and processes for sustainable aquaculture creates substantial damage to the surrounding ecosystem which furthermore affects the marginalised communities (Knowler et al., 2009).

The rate of change of mangrove cover in Sundarbans has not been uniform. Mangrove loss due to land use changes affects the entire system's sustainability (Giri et al., 2015). Usually, these land use changes are specially because of felling of mangroves for developmental projects or commercial use. Agricultural farms are being converted into breeding ponds for shrimps and prawns (Abdullah et al., 2017). These ponds are connected to a source of water nearby – creeks or canals which further connect them to other shrimp ponds, fish farms, agricultural fields, and other major waterways. Unsustainable and extensive shrimp aquaculture in these ponds directly impacts the agriculture, forestry and fisheries sector resulting in externalities. In the Sundarbans, there are many households who are dependent on honey and timber collection, fisheries, and agriculture. The communities solely dependent on agriculture are losing their property to shrimp aquaculture while shifting occupations. Additionally, this kind of shift by non-fishers affects the SSF communities who get indulged in multiple occupations due to seasonal variation of fish populations (Abdullah et al., 2017). If all the households are focused on shrimp farming, this creates an ecological imbalance eventually resulting in extensive aquaculture of shrimps and fishing pressure on the Sundarbans.

The creation of shrimp ponds by felling mangroves and converting wetlands also becomes an environmental issue. This in turn affects the safety of SSF communities who experience the wrath of recurrent cyclones as well as erosion due to loss of soil support (Knowler et al., 2009). It also hampers biodiversity by destroying larvae of other fishes of commercial and ecological importance. The use of pesticides, feeds, chemicals, and disinfectants for its growth pollutes the immediate environment. Knowler, et al., (2009) argues about the potential risks yet to be affecting the Sundarbans soon, as the intensification of shrimp aquaculture is not developed in the Sundarbans. But in recent research by Salunke, et al., (2020), 10 years later, it is seen that West Bengal ranks second by area under shrimp aquaculture as seen in Figure 6. The graph in Figure 6 also shows that there has been a steady increase in the area under shrimp aquaculture in West Bengal other than the years which were hit by cyclones. The paper also stated that the number of shrimp ponds have significantly increased in the Sundarbans of West Bengal that have created a potential issue for the present as well as future.

SSF communities in Sundarbans collect shrimp fry which affects the adult shrimp population. As a result, the capture fisheries industry is negatively impacted (Salunke et al., 2020). Also, the aftermath of cyclone Amphan oversaw a drop in the productivity of shrimps because of a disease outbreak in the farms (Sen, 2020). I observed that cyclones had a grave impact on the farms temporarily, as people started restoring shrimp ponds trying to build up resilience for better opportunities and income strategies.

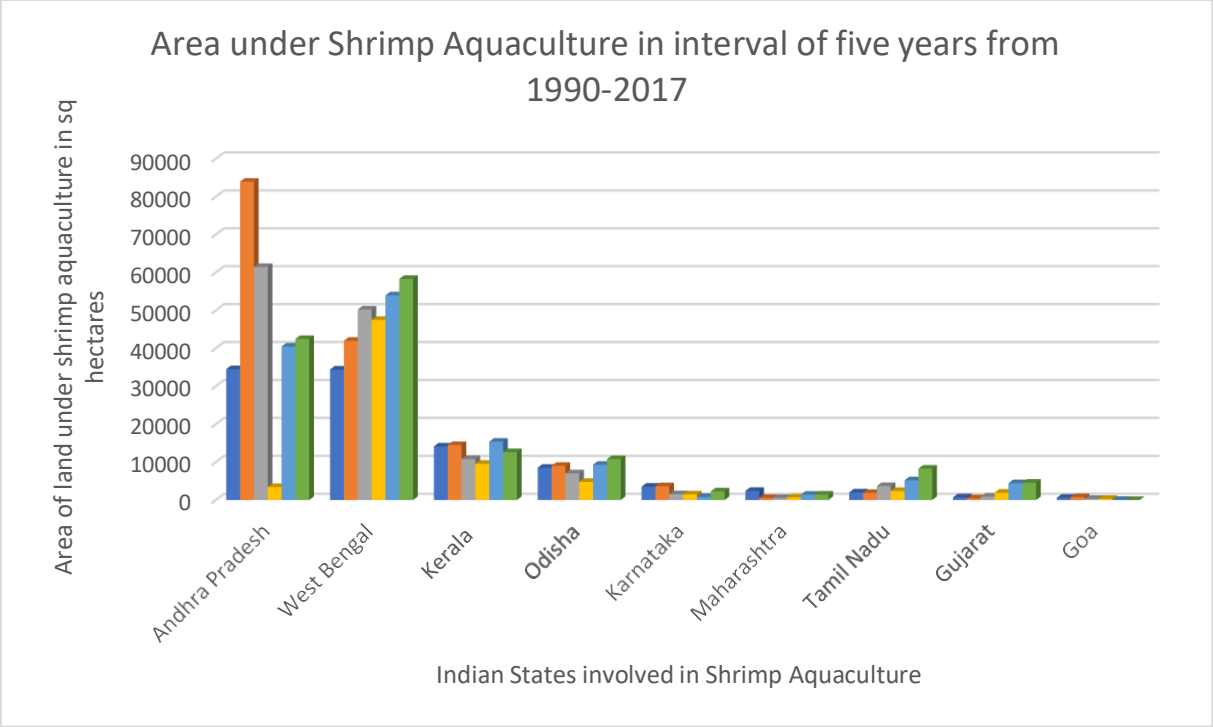

Figure 6 – Area Under Shrimp Cultivation in India (Salunke et al., 2020)

I also found out that large tracts of lands were converted in the blocks near Sundarbans in India, but rarely any aquaculture land was shifted to forests or fallow lands (Kumar, 2012). Table 10 shows the data for the conversion of wetland or fallow land area into aquaculture. This confirms the potential of shrimp aquaculture impacts on the Sundarbans SES in terms of loss of wetlands and improper management of the forest grounds.

Table 10 – Conversion of lands in the Indian Sundarbans until 2004 (Kumar, 2012)

Blocks	**Land Converted to Aquaculture (sq km)**
Sandeshkhali I & II	104.36
Minakhan	124.41
Namkhana	23.72
Basanti	37.37
Canning I & II	54.28
Kakdwip	8.16
Gosaba	31.91
Kultali	32.21

The following land use and land cover change classification by Rahman & Begum, (2013), has shed light on the amount of fallow land being transformed into shrimp aquaculture. It is clearly seen that the "blue areas" which represent water bodies have increased in place of "pink areas" which represent fallow lands in the classification map. This gives satellite confirmation of loss of huge tracts of land to improperly managed, mushrooming shrimp ponds in Sundarbans.

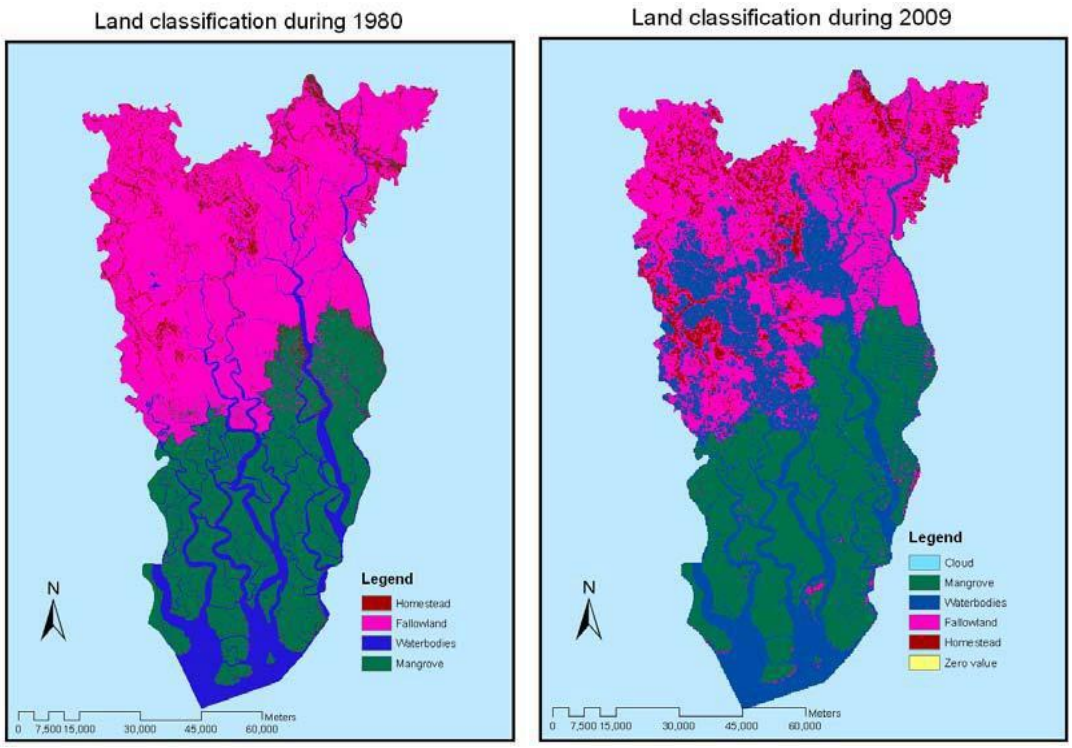

Figure 7 – Land use land cover change classification of Sundarbans in Bangladesh in between 1980-2009 (Rahman & Begum, 2013)

Earlier, aquaculture was done by SSF communities by using traditional and benign methods. After its commercialisation, the productivity increased 5 times in two decades by 2005 (Manoj & Vasudevan, 2009). The brackish water cultivation of shrimps and fishes contributed to the national economy which made India, the fourth largest producer (Knowler et al., 2009). People have been shifting to shrimp aquaculture because of its growing demand in the developing countries and its economic benefits. The 1980s marked the beginning of the advent of commercial shrimp farming which

pushed the traditional system to a corner. There was a boost in the practice of shrimp aquaculture since 1990s without a suitable management and regulatory body (Salunke et al., 2020). Their major goal was to increase the export and the quality of the yield which required high quantities of feed supplements. Over 80% of the shrimp farms are owned by SSF communities in the coastal regions of India (Knowler et al., 2009).

The productivity per household is decreasing because the farms are mostly small (0-2 Ha) in size (Knowler et al., 2009). Additionally, the occurrence of diseases in shrimps has also been on the rise recently. This is caused mostly due to low quality seeds imported from Southeast Asian countries. Farmers are tempted to buy these seeds from these countries to increase the yield in their small ponds. Because of these disease outbreaks in the Sundarbans many people have adopted traditional methods for its cultivation (Vivekananda et al., 2014).

I also observed large-scale multinational companies playing an important role in the commercialisation of shrimp seeds. Hindustan Unilever, Britannia, ITC, Tata, and many large-scale industries operate the hatcheries in India (Dutta, 2015). Hatchery produced shrimp seeds are not sufficient and adequate in this region, hence, the communities collect the seeds from the natural sources – the intricate mesh of roots of mangroves. Furthermore, a significant number of households neglect the traditional techniques and use juvenile shrimp catches extensively in a fear of competition and loss of income to other large-scale industries involved in industrial aquaculture (Dutta, 2015). The seeds are sorted out which makes up to 0.25% of the total catch and are kept aside while the rest of the catch are thrown away in the sand flats and mud flats (Sarkar & Bhattacharya, 2003).

The whole process is rather traditional as the people are not trained in collection, processing, and marketing of the prawns. Sarkar & Bhattacharya, (2003) explored the ecological and occupational consequences of these actions, where they found that the catch that was thrown away, contained varieties of finfish and shellfish which can be used instead of being wasted. They discussed the outcomes of dragging nets along the creeks and coastline which further led to uprooting of mangrove seedlings, soil erosion, destruction of pelagic biota and stock depletion of specific aquatic varieties. Also, these

actions of collection of seeds for aquaculture led to the degradation of the water quality in the catchment areas. Subsequently the fishermen were exposed to these waters for prolonged hours and suffered from water-borne diseases and reproductive tract infections in women (Sarkar & Bhattacharya, 2003).

While there is a lack of data on the shrimp aquaculture outputs from the Indian Sundarbans, the Bangladesh Sundarbans have lost tenfold area to shrimp aquaculture since 1980s (Hoq, 2007). The agricultural lands of Sundarbans which belong to the poorest communities are bought by the higher income communities for culturing shrimps. These poor communities are then forced to work as low paid tenant laborers which makes them financially vulnerable. Furthermore, there are multiple journals stating that shrimp aquaculture is an emerging problem in Sundarbans of both countries but data regarding numbers in specific districts and divisions are not evident. Lack of such data creates a gap in understanding the ground reality of the status of shrimp aquaculture in the region. Impact and management studies have been done in the region while scaling the area of primary data is lacking regarding the amount of land converted to shrimp ponds or fishponds.

There was a significant difference in the number of papers considered for the two case studies as the major driver in the region is cyclones compared to shrimp aquaculture, regardless of its natural or anthropogenic nature. The next section discusses about the vulnerabilities generated from these drivers elaborated in the case studies.

4.4. Multidimensional Vulnerabilities in the Sundarbans SES

Regardless of all these drivers and its potential threats, cyclones, and unsustainable shrimp aquaculture act as key drivers in magnifying the vulnerabilities of the region. Bangladesh and India have been the top two countries impacted by climate change events like cyclones, as per Climate Change Vulnerability Index, 2011 (Maplecroft, 2011; Roy & Guha, 2017). 35% of the mangroves are being devastated every decade due to high-intensity cyclones (Danda, 2020; Sen, 2020). Large tracts of mangrove lands have been removed in the name of shrimp aquaculture which has led to a substantial decrease in the forests and pollution on the Indian side of the Sundarbans (Kumar,

2012). Which is why, I would like to focus on these two drivers inducing vulnerabilities on the ecological and social sub-systems of the Sundarbans SES.

The drivers of change identified and described above create several problems or vulnerabilities in the Sundarbans SES. These vulnerabilities be it caused due to natural or anthropogenic drivers prevail in the system for greater periods of time. To understand these vulnerabilities observed during SLR and case studies mentioned before in Section 4.3, it is important to discuss the multidimensional aspect of it, in the following section. I will be dividing this section into two sub-sections which individually would examine the vulnerabilities induced in ecological sub-system and social sub-system. It was observed that the direct impacts of these drivers can lead to additional impacts on the surroundings which can have further implications as well. Therefore, it is important to look at mangroves and SSF communities specifically as key components of the system to reach a certain outcome.

4.4.1. Vulnerabilities in the Ecological Subsystem

This subsection will solely discuss the vulnerabilities induced in the mangroves and associated species due to the drivers of change mentioned in Section 4.3.

- *Mangrove Degradation* – Regardless of the type of driver of change, I observed that both cyclones and shrimp aquaculture had adverse impacts on the mangrove cover in the region. Cyclones being a natural driver is out of our control and in such a situation, it is difficult to avoid mangrove degradation (Bhowmik & Cabral, 2013). But the mangrove felling due to shrimp aquaculture can be limited under certain policies and laws (Kabir et al., 2019). Even though numerous trees have been taken down in the name of industrial aquaculture practices, it is necessary to look at the chain of events that could strike if mangroves are not properly managed and conserved. It is hard to sink in the irony of natural breeding grounds for crabs and shrimps being lost to artificial shrimp aquaculture ponds. The western part of Sundarbans which lies in India has seen a remarkable decline in the forest cover (Ghosh et al., 2015). Degradation was identified as a vulnerability for the ecosystem as mangroves are the keystone species and are linked to many ecosystem services without which would lead to a system collapse.

- *Waterlogging/Flooding* – This is a common issue noticed as a vulnerability for the mangroves due to cyclones and aquaculture. As pointed out in the case studies before, I bring forward artificial waterlogging due to aquaculture and flooding because of torrential downpour after cyclones as key factors for a series of other implications. Tidal surges because of cyclones damaged the embankments and led to soil erosion (Dubey et al., 2017). These implications are rotting of healthy mangrove species, increase in salinity gradient of the soil and aquifers, eventually affecting the larger waterways, which itself creates further vulnerabilities on social subsystem as well (Blasco et al., 2001). Mangroves are not aquatic plants that can completely survive underwater, instead they require frequent inundation of brackish water, at least twice a day (Hogarth, 1999). Additionally, artificially water logging for aquaculture increases the salinity of nearby paddy crop fields as well as groundwater reserves which in turn creates another vulnerability for social subsystems by reducing the quality of drinking water from wells and hand pumps (Chowdhury et al., 2019). These implications by themselves can also be described as vulnerabilities as they generate a certain response among the components of the SES.
- *Salinization* – It can be a driver as well as a vulnerability to the mangroves. The interconnection between drivers and vulnerabilities will be discussed in the last section of this chapter. Even though the mangroves are salt-tolerant species, they can tolerate a certain level of salinity in the soil (Chowdhury et al., 2019). As discussed in the flooding section, the waterlogged condition causes mangroves to rot as it is not a favourable environment for them to grow in. The waterlogging near the roots, deposit larger amounts of salts than necessary which further affect the biota dependent on the roots for shelter and survival like certain invertebrates (Neogi et al., 2016). This leads to loss of certain species important to the mangroves for its growth. The additional salt used for aquaculture in the ponds move through the channels created to connect them to a common creek or rivulet nearby, gradually raising the salt content in the freshwater source which makes it uninhabitable for certain fishes (Dasgupta et al., 2017).
- *Loss of Species* – As an impact which causes a domino effect connecting both the subsystems, loss of species due to cyclones is a vulnerability that hits on the long

run. There are certain fishes, crabs and shrimps that deposit their faeces near mangrove roots which act as a fertiliser for the saplings as well as adult trees in return for a breeding ground (Hogarth, 1999). Salinization, flooding, and mangrove degradation create vulnerabilities for these dependent species and some species are lost during this process. Many mangrove saplings get uprooted by the gusty winds which tend to disrupt the maturation process of the plant (Dutta et al., 2015). They are vulnerable for the first 4 to 8 years of their lifespan and require care and uninterrupted growth. Figure 8 shows that the frequency of cyclones in the past two decades is so high that these species (both mangroves and associated species) hardly have the time to restore and regenerate eventually get endangered and subsequently extinct in the region.

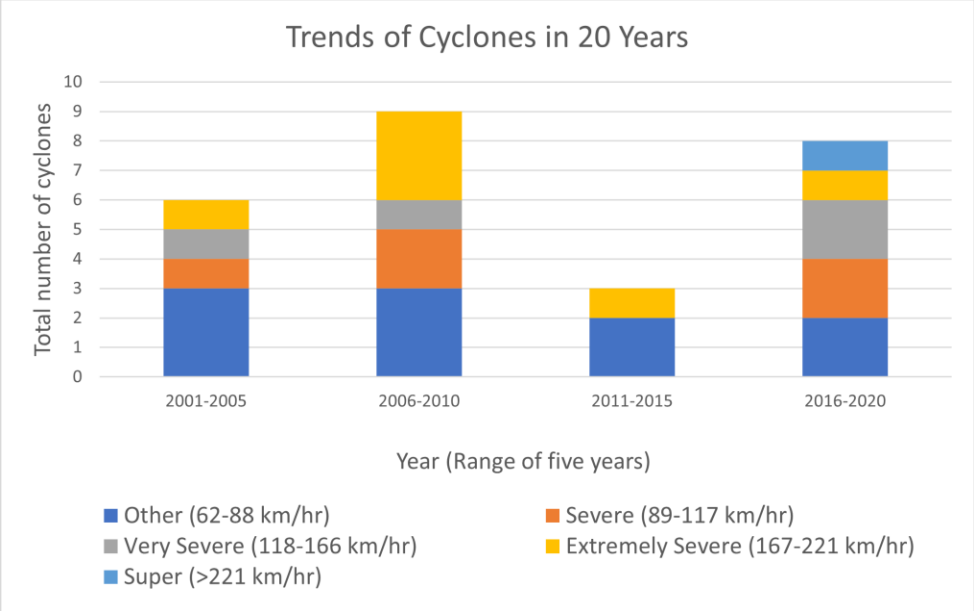

Figure 8 – Trends of cyclones in 20 years (Graph generated from the data provided by Table 9 in Section 4.3.1)

- *Pollution* – This is observed in the case of unsustainable shrimp aquaculture mostly as the use of pesticides, disinfectants result in environmental degradation of common creeks and channels (Salunke et al., 2020). Pollution as a vulnerability for the water sources as well as aquatic species can generate a ripple effect creating a disruption in the habitat of certain fish species on which SSF

communities are directly dependent on. High-speed winds during cyclones also deposit debris, toxic substances, and variety of pollutants in the waterways and ponds which becomes another source of pollution making it a vulnerability for the system.

Table 11 gives a good understanding about the vulnerabilities affecting the Ecological Subsystem in brief.

Table 11 – Key Ecological Vulnerabilities observed in the Case Studies

Drivers	**Vulnerabilities**
Cyclones	• Uprooting of Mangroves due to gusty winds and felling rotten trees due to flooding of saltwater • Flooding because of torrential downpour • Increase in salinity gradient in aquifers and soil • Loss of certain species of flora and fauna
Unsustainable Shrimp Aquaculture	• Mangrove felling for shrimp ponds • Pollution of common waterways due to feeds and chemicals in pesticides • Artificial waterlogging increasing salinity • Ecological imbalance due to focus on shrimp aquaculture extensively • Loss of certain fish species during sorting

The vulnerabilities mentioned above are not limited to the ecological subsystem (like mangroves, fishes, crabs, birds, and animals) but also has an extensive impact on social subsystem (livelihoods of SSF) as well. The direct and indirect impacts driving vulnerabilities among SSF are discussed in the next section.

4.4.2. Vulnerabilities in the Social Subsystem

This subsection will solely discuss the vulnerabilities induced in the SSF communities due to the drivers of change mentioned in Section 4.3. This section will first describe

the major vulnerabilities and then discuss the multidimensional aspect of it by the help of its parameters.

- *Loss of Infrastructure* – Cyclones bring about years of torment for the people exposed to them. It was evident from the case studies in section 4.3 that strong winds destroy the mud houses, fishing boats, nets and other important infrastructure like power lines and telecommunication towers, hampered water supply and sanitation. According to table 9 and figure 8 mentioned above in sections 4.3.1 and 4.4.1 respectively, cyclones be it low or high category generates loss of infrastructure as a vulnerability because of its frequency and intensity. More the number of cyclones, higher the loss of infrastructure and associated vulnerabilities (Ghosh, 2020). I observed that it becomes difficult for the SSF communities to develop resilience with respect to short duration between two cyclones. Cyclones and floods resulting from downpours affect the SSF communities, because of which large population from both India and Bangladesh become homeless as shown in table 12 below, and are totally dependent on relief provided by the government (Vivekananda et al., 2014). As a result of which some members of individual household of SSF communities tend to migrate to safer areas. This vulnerability is not directly associated with shrimp aquaculture but happens to be an indirect vulnerability where fishers tend to drown in debts to restore aquaculture ponds destroyed during cyclones.

Table 12 – Cyclones and Floods in Bangladesh and India from 1993-2013 (Vivekananda et al., 2014)

Country	**Bangladesh**		**India**	
Driver of Change	**Cyclones**	**Floods**	**Cyclones**	**Floods**
Occurrence	84	47	59	146
Deaths	8,676	4,991	17,466	26,445
Injured	133,790	592	13,774	771
Affected	20,131,475	118,605,420	32,999,201	525,793,245
Homeless	1,699,625	676,638	1,967,345	7,643,500
Total damage (in USD)	3,497	7,728	5,856	29,735

- *Lack of Opportunities and Alternatives* – The SSF communities of the region are economically inefficient when compared to large-scale fishing fleets (Kolding et al., 2014). Cyclones have pushed them into poverty traps due to loss of income due to long periods of no catch, compromised basic amenities as well as lack of skills for other sources of income. Danda, (2020) argues that the cyclones not only impact the natural areas but also affect the indigenous people in the area. He explains the island physiology of Sundarbans being saucer shaped in inhabited areas and upturned saucer-like in forested islands leading to flooding for long periods of time. This led to loss of income source as well as the hunt for alternative livelihood opportunities for the next 3 years. People were forced to switch from aquaculture and agricultural activities to other sources of income which they do not possess the skillset for, whilst some people became unemployed (Rahman et al., 2017). Many fishers are left with no alternatives due to non-fishers acquiring the shrimp aquaculture sector and commercialising it into international markets for profitable returns (Abdullah et al., 2017). Hence, resort to migration as a coping response for a hunt for job opportunities. They are also being displaced due to new migrating people and large-scale industries initiating industrial aquaculture projects along with other coastal development projects (Chowdhury, 2017; Dutta, 2015; Jalais, 2007).
- *Loss of livelihoods* – It is a major vulnerability observed in both cases of cyclones and shrimp aquaculture equally. Cyclones result in upwelling of sea water, which brings in high quantities of fish near the shore after landfall (Vivekananda et al., 2014). This instigates community members to also fish for 'tomorrow's catch' which in turn creates competition for fish resources among them. Shrimp aquaculture as mentioned before has multinational companies and non-fishers migrating into the region for more profits tend to pose a risk for the fishers and their livelihoods which forces them to compete for the resources (Dutta, 2015). Additionally, with rising concerns over resource conflicts, the current value of the future returns through shrimp aquaculture or fisheries are gravely affected (Boyd

& Clay, 1998). This leads to a series of responses shown by the community which will be discussed in the next chapter.

The multidimensional nature of these vulnerabilities in addition to the complex, highly dynamic and relational aspect as elaborated by Chuenpagdee & Jentoft (2018), vulnerability of SSF communities in Sundarbans SES is characterized by its parameters which are as follows –

1. ***Compromised Social Wellbeing*** – Wellbeing as discussed before in Chapter 2, is a state where a person, community or society enjoys a quality of life by meaningfully pursuing their goals and where their needs are met (Weeratunge et al., 2014). This state of satisfaction for SSF communities can be viewed under the lens of material, relational and subjective wellbeing (Nayak et al., 2014). It is further discussed how each component of social wellbeing compromises or alleviates the state of SSF communities.
    - Material wellbeing – The drivers have hindered the welfare of these communities economically where their standard of living has declined due to loss of income, livelihood capitals, wealth, physical and environmental health. These are a direct result of the cyclones and extensive unsustainable shrimp aquaculture. Fishing nets, boats, houses, and other investments including basic amenities are lost to cyclones while for most fishers, environment quality and physical health is lost to the unsustainable practice of shrimp fry collection (Elsner et al., 2008; Salunke et al., 2020). Long exposure to the salt waters and contaminated waters by chemicals from aquaculture ponds have increased the rates of health issues in the Sundarbans. The quality of material wellbeing is declining with the effects of these drivers.
    - Relational Wellbeing – The best part about SSF communities is their bonds and partnerships. The connections that they have with other fishers plays a key role in alleviating stress and loneliness. The local governing authorities which are the panchayats are inclined towards the concerns of fishers during any unfortunate period. The neighbouring fisher communities help each other in lending loans for attaining to basic amenities in the aftermath of a cyclone or during clearance of debts for pond repairs (Chuenpagdee et al., 2005; Islam & Chuenpagdee, 2013).

Relief distributed by the government is shared among the community members which rather strengthens their relationship than compromises it. The NGOs and other local institutions also play a key role by partnering with fishers to help them in developing skills for additional sources of income and future opportunities in aquaculture. This is the only type of wellbeing which I found out to be the strength of the community members eventually contributing to community resilience which would be discussed in the next chapter.

- Subjective Wellbeing – The self-notions and norms of the SSF communities about their past and present state of experiences has accumulated sense of fears and aspirations in association with drivers of change inducing vulnerabilities. Their lack of trust on the government for help during times of need is one of the key factors for a compromised subjective wellbeing (Biswas, 2020). As pointed out in the case studies above, the communities undergo a lot of suffering due to cyclones and extensive shrimp aquaculture in the area that their levels of satisfaction have deteriorated. Their moral standing and mental health which is a key component of the subjective wellbeing has been the worst affected by these drivers, hence inducing this vulnerability (Berenji, 2020). If the cyclones just keep on coming twice every year, there will not be any reason to live, as people will lose all hope to rebuild after reaching a point of saturation. Even though there is competition for resources with larger fishing fleets, deep down the level of dissatisfaction just keeps growing along with other rising vulnerabilities (Kolding et al., 2014).

2. ***Decline in quality of Livelihood Capitals*** – The categorisation of the vulnerabilities with the help of livelihood capitals, as discussed in Chapter 2, as an indicator helps broaden our ideas about the economic condition, knowledge and skillsets of the fishers, perception about their environment and resource management, access and benefit sharing, active participation in family decisions, fisher organisations and local institutions (Chen et al., 2013). This part will be divided into five different livelihood capitals and the results found through SLR will be discussed individually.

- Physical Capital – The communities affected by the cyclones lose their durable and fixed assets which include boats, fishing gear, household furniture and roofs (Sen, 2020). As a result of extensive shrimp aquaculture, access to their benefits is now shared with large-scale fishing fleets hungry for profits and non-fishers/farmers shifting to aquaculture for more gains (Dutta, 2015).
- Human Capital – The SSF communities are endorsed with low technology fishing gear and traditional knowledge about fisheries and aquaculture that have been passed on for generations which eventually strengthens their skills around that sector (Berenji, 2020). They have also been living around the coasts for centuries to know about the ecosystem services mangroves and natural resources provide and do not wish to harm them. But given the circumstance where drivers of change come into the picture, the quality of this asset still stands, as the knowledge and skill once learnt always tag along. But if the communities are subjected to lack of alternatives, competition, and resource depletion, some of them compromise with the human capitals to build up resilience.
- Natural Capital – The fishers used to believe that mangroves save them from cyclones completely back in the history which changed with time after SIDR hit in 2007. There was a loss of 35% of mangroves which changed their perception about mangroves being their sacred groves (Bhowmik & Cabral, 2013). But the SSF communities did know that the direct impact of the cyclones could have been greater. The communities believe in the management of the forests by looking after them while going there for fishing and NTFP collection (Hoque Mozumder et al., 2018). This capital stands strong as the communities share the same value to protect and manage the forest while industries and companies do not.
- Social Capital – Sundarbans is a little underdeveloped when considering social networking as there are some villages which have recently got the access to electricity and safe drinking water. The members of the fisher organisation, local panchayats, authorities, and the NGOs have good ties with the SSF communities in the area (Berenji, 2020). After cyclones SIDR and

Amphan, this partnerships and good relationships with them helped them build community resilience during times of dire need. Similarly, the Sahara India Tourism Project was halted because of the actions of all the partnerships and protests to save the livelihoods of SSF and protect the mangroves (Jalais, 2007).

- Financial Capital – Income and expenditures of the SSF communities when viewed through a driver's perspective has been steadily affected by cyclones. It was seen that the loss of income, infrastructure and livelihoods lead to collateral damage which hinders their investment by reducing future returns (Chuenpagdee et al., 2005). As elaborated in Chapter 2, the income of SSF communities is hardly $1/day while they contribute to 79% of the region's demand for fishes mainstreaming them as a key contributor to food security and SDGs.

3. ***Weakening of Resilience*** – Due to all the vulnerabilities mentioned above, the community resilience is weakened by the advent of recurrent cyclones and extensive shrimp aquaculture (Salunke et al., 2020; Sen, 2020). The occurrence of repetitive high intensity cyclones weakens the restoration of mangroves and associated biodiversity along with weakening of rebuilding power of SSF. In an effort against the drivers, the SSF of the region respond in various means which are either sustainable or unsustainable. Resilience by the SSF communities is divided into coping and adaptive responses generated due to the vulnerabilities induced. The next chapter will be briefly addressing the efforts by the communities to attain resiliency.

Table 13 gives a good understanding of the vulnerabilities affecting the social subsystem and their associated parameters.

Table 13 – Key Social Vulnerabilities observed in the Case Studies

Drivers	**Vulnerabilities**	**Parameters**
Cyclones	• Loss of Infrastructure • Lack of Alternatives	• Compromised Material and Subjective Wellbeing

		• Decline in quality of livelihood capitals • Weakening of Community as well as SES resilience
Unsustainable Shrimp Aquaculture	• Loss of Livelihoods • Loss of Opportunities	• Compromised Material and Subjective Wellbeing • Decline in quality of livelihood capitals • Weakening of Community as well as SES resilience

The vulnerabilities mentioned in the table above have impacted both social and ecological subsystems of Sundarbans SES either directly or indirectly. The interconnection between the drivers, vulnerability and viability will be elaborated in the next section.

4.5. Interaction and Interconnection of the Ecological and Social components of the SES

This section will focus on the model derived out of the understanding of results from SLR and some important takeaways while achieving the first and second objectives.

4.5.1. The 'Chain of Events' Model

All the findings from my review of secondary literature are inclined towards the same idea – mangroves (the ecological subsystem) and SSF communities (the social

subsystem) being webbed together into a complex system. In Figure 9, 'Chain of Events' model describes the flow of the events starting from drivers and ending in viability.

The drivers affect both mangroves and SSF communities together under a 'chain of events' regardless of their natural or anthropogenic nature. The flow of these events follows this similar pattern regardless of any drivers replacing the cyclones or aquaculture. The people who are affected the most are the marginalised communities dependent on SSF in addition to the species associated with mangroves. It is easier to understand the perspectives of SSF communities and hear them speak about the challenges they face and sufferings they endure due to these drivers. This is because SSF communities when compared to mangroves can speak loud and clear which works on their advantage while mangroves on the other hand need soldiers to fight their war for conservation.

The model explains the link between the mangroves and SSF as the drivers affecting the ecology of mangroves, physiology of Sundarbans and inducing climate change effects that are directly affecting the wellbeing and assets of SSF communities through multiple vulnerabilities. Cyclones result in upwelling of cold water, change in tidal, water currents, and hydrology of water in the coastal fringes (Dutta et al., 2015). This affects the material wellbeing of the communities along with loss of capitals. With the help of the SSF communities in Sundarbans, the ecological balance has been kept under control. These communities play a key role to keep the fish population in check as well as actively contribute to fisheries, and agro economy.

Large-scale industries operate their hatcheries for shrimp culture by harvesting the juvenile shrimp seeds from the roots of the mangroves using fine nets. The shrimps are then sold for $11/kg in the international market by the traders (Dutta, 2015). Constant treading on these roots can damage the trees and with the use of dragnets, shrimps as well as many other pelagic biota and fish seedlings are harvested and thrown away. This can result in loss of fish species as well as loss of work for the local fishermen for about 10-14 days (Dutta, 2015). Hence the mangroves face similar kinds of vulnerabilities as compared to the communities due to the drivers. This negatively affects the wellbeing of the fisherfolk and makes them financially vulnerable. As the livelihoods of these

communities are endangered by the large-scale industries, the fishermen do not fear the penalty of using illegal fishing methods as a response for resiliency.

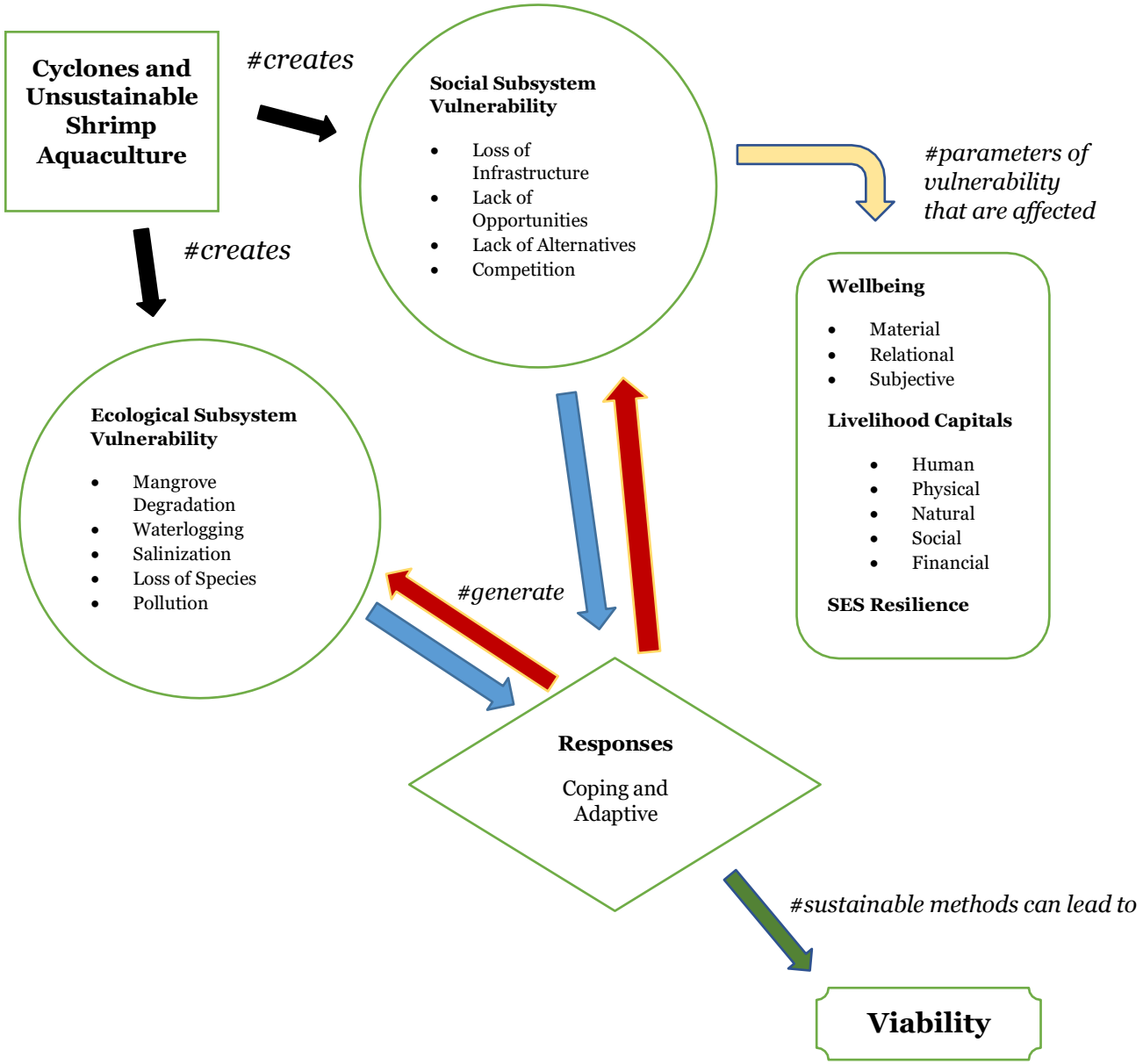

Figure 9 – The 'Chain of Events' Model (Generated after analysing the findings through SLR)

4.5.2. Important Takeaways

Multiple observations were made while doing the SLR and writing the case studies –

- The drivers are themselves interconnected. Cyclones destroy the shrimp ponds hence, affecting its culture. Shrimp Aquaculture leads to salinization of nearby waterways which is again a driver itself. Salinization leads to pollution which as a driver can induce vulnerabilities.
- The drivers can be vulnerabilities themselves which affect the ecological subsystems. It was seen that salinization and pollution were vulnerabilities that drive further vulnerabilities and can be considered a driver of change themselves.
- The vulnerabilities induced due to both drivers mentioned in the case studies are mostly similar and yield same types of responses but eventually degrading the wellbeing and capitals.
- It was seen that vulnerability affects both ecological and social subsystems of Sundarbans equally.
- The model in section 4.5.1 states that the drivers of change create vulnerabilities in the Sundarbans SES which affect the wellbeing, capitals, and resilience of the dependent communities. These vulnerabilities generate a response among the communities that if is unsustainable may lead to a new set of vulnerabilities or if sustainable, might lead to viability.

The potential of Sundarbans as a SES is vast as it not only provisions fisheries, but also provides NTFP products. Many dependent SSF communities have multiple sources of income in different seasons but the major part being from fisheries. The climatic events make the destruction of the mangrove habitats unavoidable, but it has been stated that these local communities help building back by restoring the forests by looking after these trees. The whole system of events is more of a cycle where everything starts from a change, which creates an impact and the resiliency of the affected, help in restoration, until there comes another change. The drivers and the vulnerabilities go hand in hand regardless of the ecosystem and community. The negligence of the vulnerabilities can create a marked difference in conservation and sustainability plans of Sundarbans.

Chapter 5 – Responses and Viability: A Way Forward

Examining the coping and adaptive responses to vulnerabilities and pathways to viability

5.1. Introduction

In the previous chapter, I identified and described the drivers of changes affecting Sundarbans SES with the help of two case studies focusing on one natural driver – cyclones and one anthropogenic driver – unsustainable shrimp aquaculture. In accordance with that, I discussed and analyzed the multidimensional vulnerabilities which were induced in the ecological and social subsystems of Sundarbans SES, because of the occurrence of these drivers. It was found out that these drivers and vulnerabilities affecting the mangroves and the SSF communities have been intensifying over past two decades. In the end of the previous chapter, I put forth the effects of these drivers and vulnerabilities on the wellbeing, livelihood capitals and resilience of the SSF communities to understand the condition of these communities, if they are being positively or negatively affected.

These multidimensional vulnerabilities in SSF communities provide a platform to study the responses to changes in environment along with strategies needed to strengthen the resource base and market (Coulthard, 2008). 'Responses' can be understood as certain actions or strategies developed by communities, government, or stakeholders to protect the social subsystem, a common cause or even the environment, if we look at it holistically. These actions can also reflect on individuals, communities or group of people that are affected by any wicked problem and eventually develop the ability to build up resilience as a reaction to those threats (here, impacts of drivers of change, vulnerabilities induced) (Coulthard, 2008; Johnson, 2013).

Furthermore, Nayak, (2017), identified that these responses can be of two types based on sustainable or unsustainable practices and time scales– coping and adaptive (Nayak, 2017). As elaborated in Chapter 2, coping can be defined as a short-term process of responding to a wicked problem as a reaction to alleviate it (Johnson, 2013; Nayak, 2017). It can be understood as the actions of fisher communities to build up resilience against any externalities (Rashid et al., 2006). Certain coping responses when practiced

for a long period of time becomes a habit for the one practicing it, ultimately leading to adaptation (Nayak, 2017). Adaptation or adaptive responses is the continued practice of a coping response by any system to adjust, cope, or manage according to the changing environment on a long-term basis (Smit & Wandel, 2006). It is an important factor, required in strengthening the community resilience among the fishermen households given that the practices are sustainable. Given the circumstance if no actions or responses are taken against the vulnerabilities then either it would generate more vulnerabilities or lead to a governance failure in the long run.

These responses adopted by the SSF communities have two possible outcomes (Nayak, 2017). Firstly, if the responses are embraced through unsustainable and improper means, would rebound back to pre-described vulnerabilities or a new set of vulnerabilities affecting the system. Secondly, if the responses are taken up by sustainable means, would therefore lead to viability. The 'chain of events' model explained in Chapter 4, suggested that the relationship between the vulnerabilities and responses were circular but not linear. As a result of unsustainable responses, there is a collapse in the system which affects its governability along with decline in interactive governance which is a key component in the pathways to viability of SSF communities and mangrove ecosystems.

The third objective of this thesis will be the primary topic of discussion for this chapter. The objective in focus is –

- To examine key response strategies of SSF communities and pathways to achieve viability.

In this chapter, I would like to discuss and examine the response strategies by the SSF communities perceived in the form of resilience as there hasn't been any emphasis on them which could have been proved essential for the governability of the region (Iwasaki et al., 2009). The effects of these response on the governability of the system will also be elaborated. Moreover, I will be identifying and describing the pathways to viability for these communities which will be a vital component for SES sustainability. Based on the SLR and qualitative analysis of the journals from Scopus, JSTOR and other databases, the response strategies will be identified and discussed herewith. It will try to bridge the

gaps between vulnerabilities, responses, and governance malfunctions in the path to viability from a SES perspective.

5.2. Coping and Adapting Responses

According to the chain of events model in Section 4.5.1 of Chapter 4, one vulnerability gradually generates a chain of vulnerabilities if no actions are taken to reduce them. Vulnerabilities induced can be reduced by key policy actions on variety of temporal and spatial scales (Cinner et al., 2012). Short-term, medium-term, and long-term responses were identified at a local level. Cinner et al., (2012), stated that migration, evacuation, diversification within the fishing lifestyle, improving market terms, and adding and removing fisheries closures contribute to the short-term responses; connection with variety of livelihood activities, strengthening social groups and networks, developing coastal infrastructure and migrating to a safer place nearby contributed to the medium-term responses; enhancing health conditions, alternative livelihoods, poverty reduction, awareness of ecology of coastal environments, investing in robust institutions for governance was set out to be the long term responses.

Responses have also been described in terms of resilience and sensitivity (Allison & Ellis, 2001). Coping and adaptive responses have different levels of resilience and sensitivity (Davies, 1996). In a livelihood approach explained by Allison & Ellis, (2001), SSF livelihoods tend to be more robust if they have higher resilience and low sensitivity. Sensitivity as stated by the paper can be understood as the "magnitude of the system's response to externalities" (Allison & Ellis, 2001). Chapter 4 gave a brief understanding of the SSF in Sundarbans SES where the vulnerabilities were higher due to greater impacts of drivers and hence resulting in low resilience and higher sensitivity of responses. This is going to be discussed in the next sections in terms of key vulnerabilities observed in case studies.

Given that responses come in different types and categories, this section will focus on the responses that were seen in Sundarbans while doing the SLR and case studies. Sometimes, few responses lead to further vulnerabilities that impact well-being and capitals of the SSF communities. Other responses that are sustainable can be considered as an effective tool for pathways to viability. Pathways of viability is rather a new term

used alongside vulnerability. It can be described as the strategies adopted from the variety of responses generated among the SSF be it coping or adaptive. These strategies have the ability to make the communities viable and less susceptible to vulnerability if not completely resistant. Pathways of viability will be discussed in Section 5.3 of this chapter.

5.2.1. Coping and Adaptive Responses to Ecological Subsystem Vulnerability

This section is briefly going to touch base on the responses of SSF communities of Sundarbans toward ecological vulnerabilities. Table 14 condenses all the coping and adaptive responses noticed during the SLR. These responses are described based on the vulnerabilities in ecological subsystem of Sundarbans discussed in Chapter 4. The table also points out the pathways to viability analyzed from each of the journals describing the vulnerabilities.

Table 14 – Coping and Adaptive Responses to Ecological Subsystem Vulnerabilities and Pathways to Viability

Vulnerabilities	Coping Responses	Adaptive Responses	Pathways to Viability	Sources
Mangrove Degradation	No action, protests, rallies against parties responsible	Chopping off rotten trees, utilizing land for settlement or aquaculture, bouldering or cementing to control erosion	Incentives for plantation, implementing conservation strategies, formulating stricter laws and policies	(Abdullah-Al-Mamun et al., 2017; DasGupta & Shaw, 2015; Hoq, 2016; Hoque Mozumder et al., 2018)
Salinization	Rainwater harvesting, no action	Rainwater harvesting, crab fattening,	Integrated farming and fishing,	(Hossain et al., 2018; Rao, 2013)

		saline resistant horticulture, salt-tolerant rice varieties, creation of mud barrages	rainwater harvesting,	
Flooding or Waterlogging	House abandonment, accessing loans	House reinforcement, outmigration, makeshift, or temporary houses	Modifying and maintaining architecture, social innovations, diversification of occupations	(Rao, 2013; Sakib et al., 2015; Vivekananda et al., 2014)
Habitat loss, Loss of Species	Overfishing Poaching	Overfishing, diverting to alternative sources of income	Conservation strategies, strengthening institutions, restoration measures	(Barlow et al., 2010; DasGupta & Shaw, 2015)
Pollution	Cleaning debris out of waterways	Cleaning drives along the coast or no action	Stricter waste management rules, sustainable aquaculture practices, use of organic feed, chemicals, and disinfectants	(Burman et al., 2019; Rahman et al., 2010)

No action or rigorous actions through protests, rallies– Usually, there is not enough time to sink in the situation after a cyclone, which leads to a state of confusion that prevails, and no actions can be seen as a go-to response to many ecological vulnerabilities, especially mangrove degradation. The people chop down dead trees due to rotting of roots which has become an adaptation (Danda, 2010). SSF communities are indulged in prioritizing their basic amenities over ecological conservation during times of crisis (Vivekananda et al., 2014). They also do not mind drinking groundwater with low salt content. No specific actions are taken for waterlogged conditions due to shrimp ponds (Hossain et al., 2018). Hence, the primary coping response is to adjust according to minor changes. Whilst these vulnerabilities due to cyclones and aquaculture hardly generate and immediate response, drivers like coastal development projects by companies are countered by these communities by protests and rallies throughout the area joined by numerous villages, NGOs, fisher organizations and other stakeholders. This type of resilience shown by the fishers to save their livelihoods is their last resort to circumstances that they cannot adjust to. This type of rigorous action is an example of close-knit community resilience of SSF communities.

Rainwater harvesting, diversification within occupation – Harvesting rainwater through modifying their roofs or pipes and use of kitchen vessels is a sustainable coping response which has become an adaptation among the communities against extensive salinization of local water resources due to flooding or waterlogging. As the region receives good amount of precipitation, rainwater harvesting becomes more feasible. Furthermore, use of pond sand filters, pond excavation and managed recharge of aquifer were identified as adaptive responses of the people for better quality drinking water (Hossain et al., 2018). Hossain et al., (2018), also observed that diversification within the fishing occupation is seen in some communities where they use crab fattening procedure for better returns. Fishers with secondary agricultural occupations practice the use of salt-tolerant varieties of rice and horticulture. Additionally, construction of mud barrages was an option for many, to prevent the incursion of saline water. While some fisher villages were responding well to this vulnerability, many fishers were not able to take any action (Vivekananda et al., 2014).

Outmigration, house abandonment or reinforcement, makeshift, or temporary houses – Abandonment was observed to be the immediate response to cyclone warnings. Many fishers who did not wanted to move to cyclone shelter lost their property, livestock, and collateral (Sakib et al., 2015). As mentioned before, the flooding due to aquaculture was more of adjustable situation for these communities. They have adapted to the situation by creating makeshift or temporary houses out of mangrove stumps, which is itself another issue as they have to keep on moving after every disaster (Rao, 2013). Apart from that the fishers who have built up a strong resilience to disasters and other drivers have either responded to it by reinforcement or repairing their properties and influencing younger generations to move out for better opportunities instead of living in unfortunate, unpredictable, and uncertain conditions (Vivekananda et al., 2014).

Overfishing, wildlife poaching – Due to loss of certain fish species as an impact of cyclones and aquaculture pollution, fisherfolk resort to any other target species and tend to exploit their population by overfishing. Overfishing in areas that they are not licensed to as well as using illegal means to achieve their goals has become a response to this vulnerability. This has intense impacts on the fish population of the region as well as creates conflicts in between fisherfolk. Barlow et al., (2010) elaborated that loss of mangroves and associated flora displaced Bengal tigers from their habitat and encounter the fishing villages. This leads to an inevitable response of hunting the tigers attacking cattle or humans which is an act of poaching, by the communities to bar tigers from entering the villages. The poaching is an adaptation as these fishers have been losing their livestock or family members to these tiger attacks since the dawn of time (Loucks et al., 2009). There is a whole village of SSF communities which has 'tiger widows' who have lost their spouses to gruesome tiger attacks (Barlow et al., 2010).

Cleaning Drives – As a direct response to flying debris dispersed everywhere post-cyclone, the communities tend to clean up the coasts or waterways with time. This action is not immediate after cyclones as the government and NDRF teams are deployed to clean up the broken trees and fix up the supply of water and electricity (Danda, 2020). Hence, the primary response is to save and care for themselves with relief provided to them by the government. Gradually with the help of partnerships and volunteers from NGOS enough media attention is gained to fire up cleaning drives.

Moreover, pollution due to chemicals and feed from shrimp ponds has no specific actions taken by the communities resulting in more health issues among the nearby villages.

5.2.2. Coping and Adaptive Responses to Social Subsystem Vulnerability

This section is briefly going to discuss the responses of SSF communities of Sundarbans toward social vulnerabilities. Table 15 condenses all the coping and adaptive responses noticed during the SLR. These responses are described based on the vulnerabilities in social subsystem of Sundarbans discussed in Chapter 4. The table also points out the pathways to viability analyzed from each of the journals describing the vulnerabilities.

Table 15 – Coping and Adaptive Responses to Social Subsystem Vulnerabilities and Pathways to Viability

Vulnerabilities	Coping Responses	Adaptive Responses	Pathways to Viability	Sources
Loss of Infrastructure	Partnerships, sharing responsibility, exchanging information, borrowing money	Mutual support and insurance, consumption adjustment	Habitat improvement, restoration, incentives for children in schools, disaster preparedness, modifying and maintaining coastal infrastructure	(Dubey et al., 2017; Islam & Chuenpagdee, 2013)
Lack of Opportunities or Alternatives	Outmigration, change in food habits, encroachment,	Borrowing money, consumption adjustment,	Stock Enhancement, ranching, diversification	(Hoque Mozumder et al., 2018;

	illegal fishing and collection of NTFP		of livelihoods and fishing occupations, skill development, empowering through institutions, media intervention	Ortolano et al., 2017)
Loss of Livelihoods	Violation of Laws and Regulations, overfishing, illegal fishing and collection of NTFP, adjusting labor supply	Exploitation of resources, child labor, encroachment	Gear and species restrictions, setting aside protected areas, licensing of fishing vessels, seasonal bans of certain fish species	(Hoque Mozumder et al., 2018; Islam & Chuenpagdee, 2013)

Mutual Support and insurance, consumption adjustment – The communities move to higher grounds before cyclones and stay there till it is over. Even after that, the government provides relief and funds for them till the powerlines and roads are fixed. During this time of crisis, the members of the community become each other's mutual support and share responsibilities by exchanging information. As cyclones are a recurrent phenomenon, this has more often become an adaptation which has strengthened there relational well-being. This kind of support is still seen in these communities due to vulnerabilities caused due to extensive shrimp aquaculture by large-scale fishing fleets and non-fisher communities (Dutta, 2015). Apart from that, there is a

change in food habits that has become a cause of concern as the fishers tend to limit their food consumption to respond to any loss of infrastructure or livelihood. This has also turned out to be an adaptive response to secure food in case of a future crisis which in turn affects their material well-being.

Encroachment, violation of Laws, illegal activities, and overfishing - The fisheries department allots specific areas under lease to the SSF communities in the inland areas of Sundarbans (Thompson et al., 2016). The authorities allow only those fishermen who pay the lease for capture fisheries or aquaculture. In addition to that, these areas lack defined boundaries and create overlapping areas which furthermore creates encroachment issues leading to intra-community conflicts (Vivekananda et al., 2014). After cyclones, Dubey, et al., (2017) stated that the fish stocks increase along with catch density. This condition instigates farmers to fish and sell more to balance the loss of livelihoods in the post-cyclone period. In competition with large scale fishing fleets and non-fishers, fisherfolk also show this coping response in return. Even though there are certain amounts levied as 'fine' on the fishers for overfishing, there is no sense of 'fear' as the cost of the fines is overpowered by the profit in sales of the fish catch (Islam & Chuenpagdee, 2013). As the fishers indulge in overfishing and exploitation of other resources i.e., overcollection of NTFP products, it becomes hard to come out of that trap as it favors them with better returns provoking them to get banned fishing nets and equipment for better and broader target catch. Lack of alternatives and opportunities has pushed the communities into this trap of illegal and unsustainable activities that jeopardizes their relational well-being, natural and human capitals, which in turn generates further vulnerabilities.

Outmigration, informal loans, selling of assets – Rise in the frequency of cyclones in the past 2 decades, hampered the physical environment of the SSF communities. Migration of better off people and companies into the Sundarbans have risked the livelihoods of these communities. Some people indulge in illegal activities while others migrate to safer and better places in terms of food security and economic opportunities. For example, tidal surges due to cyclones damaged the embankments and led to soil erosion (Dubey et al., 2017). These incidents forced islanders to migrate due to lack of ecosystem services, loss of income and livelihoods, lack of alternatives to fishing and

farming, and increase in number of disease outbreaks. Local people took loans from some moneylenders on high interest rates as a response to industrial aquaculture interventions to boost up their productivity, which became difficult for them to pay back. Hence, people migrated from the area to cities where it would be hard to track them for the returns (Moniruzzaman et al., 2018). Additionally, they seek help from these moneylenders regarding selling of fixed and durable assets for loans to get better varieties of shrimp seeds. Along with that they tend to reduce their food consumption to the point of starvation which becomes an added vulnerability instead of a sustainable response strategy. Sometimes the children of the households are dragged into the situation to help uplift their livelihood by doing laborious jobs instead of attending school (Thompson et al., 2016).

5.3. Pathways to Viability

I observed that the responses generated by the communities had some sustainable and some unsustainable options that have a great impact on their vulnerability and viability. This not only affects them but also their immediate environment which indicates that there is direct relationship between both the subsystems of Sundarbans. It also bridges the gaps that have framed the purpose of the thesis, along with meeting the objectives of my research.

This section will talk about ways that were identified as sustainable coping and adaptive responses by SSF communities that pave pathways for ecosystem and livelihood viability in details. These viability strategies have been categorized according to the vulnerabilities of the ecological and social subsystems in table 1 and 2 respectively, which have been detailed above.

i. Diversification

Diversification is a necessary pathway where the fishers can widen their horizon of opportunities to alleviate poverty (Thompson et al., 2016). This supports SSF communities to diversify their livelihoods by working differently under the same occupational hood which requires minimum skill development and training as well as

yields better returns than before. But due to lack of finances and necessary skills fishers do not attempt to diversify as they are limited by culture and caste (Nayak, 2017).

a. Skill Development and Training

Many authors discussed the bonding between fisherfolk that strengthens their relational well-being, along with partnerships with local federations and organizations that help in the times of crisis (Berenji, 2020; Islam & Chuenpagdee, 2013; Moniruzzaman et al., 2018; Vivekananda et al., 2014; Weeratunge et al., 2014). The presence of these fisher federation clubs, and women's self-help groups (SHG) can itself be an achievement for the SSF communities in the Sundarbans (Vivekananda et al., 2014). These groups when given the right trainings and skills can attain the strength to make their community resilient. For example, the skills needed to make rugs out tattered clothes, candle making, create jewelry from shells derived from the forest and coasts by household members or women as a group, can get the fishing households additional source of income during vulnerable times (Chacraverti, 2014; Rudra & Chattopadhyay, 2019). The skills required for sustainable fisheries, aquaculture and agriculture can also be learnt from the active local institutions for avoiding any kind of setbacks.

b. Sustainable Agriculture, Aquaculture, Ranching

Some fishers were spotted taking unsustainable responses against many vulnerabilities or no action at all. While others were practicing agriculture, NTFP collection as secondary sources of income as a response to these unpredictable vulnerabilities (Singh et al., 2010). Also, the household members can resort to ranching which is herding of cattle, goats, or chickens. Within the agriculture sector, people can try varieties of rice and other crops that are salt-tolerant along with growing of horticultural crops like marigold, sunflower, etc. (Rudra & Chattopadhyay, 2019). Within the aquaculture and fishing sector, people can depend on varieties of fishes, crabs along with shrimp instead of focusing on a single species and depleting its population. They can also use sustainable techniques like crab fattening – which is a process of fattening the crab by feeding bivalves to juvenile ones that causes the crabs to grow faster into a marketable size (Hossain et al., 2018). Integrated fish farming can also be done by mixing agriculture and fisheries together, where rice and certain fish-varieties can grow in a

waterlogged condition (Hossain et al., 2018). This lessens the impact on the declining livelihood capitals by creating opportunities for financial upliftment in the time of unexpected market or livelihood failures and other uncertainties.

ii. Incentivization

Researchers, scholars, scientists interested in research and development in Sundarbans have the potential to bring funding for the development of the region. This can be done by including incentives into the types of ongoing research in the area. Incentivization can be done by giving benefits to the communities in return for a specific task that can aide viability of the system. The benefits can be in terms of money, partnerships or opportunities related to fisheries or forestry. Market-based interventions are also used for conservation or management practices (Gelcich & Donlan, 2015).

a. Conservation Practices

The drivers have led to the destruction of Sundarbans mangroves and other associated fauna species which are conflict species that intervene between the successful functioning of the social subsystem. SSF communities can be given incentives to plant mangroves and take care of them till they mature to help restore the mangrove population lost to the drivers (Rao, 2013). This can also help build steppingstones for these tigers to pass through forest patches with creating conflict (Loucks et al., 2009). This can also be done in the case of cobras and crocodiles by creating special protected areas that the fishers have access to. Defining more protected area borders can only help if the laws allow the fisherfolk to fully operate there (Hoque Mozumder et al., 2018). They can act as a connecting link between the maintaining ecosystem balance and sustainability.

b. Social Innovations

Salinization and flooding in the area have grave impacts on the SES as mentioned in Chapter 4 and previous section. But social innovations are the key to adapt to these situations as they are pieces of creativity that addresses the needs of the people in a better and cost-effective way which are usually put together by members within the community itself (Rudra & Chattopadhyay, 2019). For example – creating specific types

of water containers from waste that can help store rainwater or constructing mud barrages that have the power to stop the incursion of water into crop fields or fishponds (Hossain et al., 2018). This would help increase livelihood capitals and becomes an incentive itself for new inventions and attention from external sources. Children within the community given proper education and food in school as an incentive can help develop their knowledge about these social innovations (Islam & Chuenpagdee, 2013; Vivekananda et al., 2014a).

c. Sustainable Management Practices

Practices like proper waste management and resource management can be achieved through incentivization (Ortolano et al., 2017). Pollution is a vulnerability but cleaning up and managing the waste post-clean up can be difficult (Danda, 2020). NGOs, volunteers, students from universities can help communities with management of waste in return for better research and focus on their livelihoods. Media and international organizations can push fundraisers for the incentives to work in their favor (Rahman et al., 2010). Fishers can be paid a certain amount as incentives to not fish illegally or exploit resources which would check the depletion of resources (Thompson et al., 2016). The need for sustainable management practices is crucial and can lead to viability of the SES.

iii. Strengthening Community Groups

If the social groups of local fishermen, or women from the SSF households form groups that are strong enough to manage the resources in the Sundarbans – fisheries, mangroves, NTFP and honey collection – instead of jeopardizing them, there is a chance of looking at how a sustainable complex ecosystem would function. Strengthening the existing SHGs or fisher federations can help move vulnerable lives a step towards viability (DasGupta & Shaw, 2015).

a. Co-Management and Power Sharing

To strengthen these groups, there is a requirement of interventions from NGOs, Forest Department of both the countries and media (Abdullah-Al-Mamun et al., 2017). The government should be adopting the idea of participatory forest management or co-

management which would include the SSF communities instead of the individual rule and management of the Forest Department. The idea of power-sharing can eradicate the prevailing management crisis in the Sundarbans if given full support from the right authorities (Roy & Alam, 2012).

b. Mainstreaming SSF communities into Developmental Policies

Interaction between the fishers and mangroves must be brought into the developmental policies of both countries to avoid further unsustainability. The strengthening of human and natural capitals, along with the three versions of wellbeing is essential to support the viability strategies of the SSF communities. Doing this, would also help in conservation strategies, modifying infrastructure and reinforcement of laws and policies in local areas (Aguilera et al., 2015).

iv. Stricter Policies and Rules

These policies and strategies that help in the governance of the system has been a burgeoning problem in the fisheries sector from the beginning. Sustainable community-based adaptation strategies should be integrated not only in the political sector but also in the cultural, economic, and institutional setting (Aguilera et al., 2015).

a. Gear Restrictions and Licensing of Vessels

In order to avoid illegal fishing, exploitation of resources by fishers, non-fishers and large-scale companies, certain restrictions regarding fishing gear and fishing vessels have to be considered (Dutta, 2015; Thompson et al., 2016). The environmentally unsustainable net types should be banned or replaced from the market source so as to avoid such vulnerabilities. Additionally, licensing fishing vessels can help rid the unwanted population of illegal fishers off the territory of the mangrove reserve.

b. Coastal Infrastructure and Habitats

The need for better infrastructure in the region as a bill or law passed through the government as a viability option to both drivers of change becomes a requirement for better response strategies (Rao, 2013; Sakib et al., 2015). Repair and maintenance of roadways, embankments, pond dikes after any cyclones in the area as a part of post-

disaster response strategies becomes an essential part of adaptive responses (Sakib et al., 2015). All these actions can be done altogether with the help of an interdisciplinary team simultaneously working for the development of the coastal infrastructure to help the fisheries sector in the long run.

5.4. Takeaways

This chapter helped understand the underlying pathways of viability within the responses of SSF communities towards drivers of change. There are several things that surfaced while examining the responses –

i. *There is an intra-connection between the responses observed in table 14 as well as table 15* which individually discussed about the responses of SSF communities towards ecological and social systems of Sundarbans. For example, in table 14, SSF communities responded similarly to salinization and loss of habitat and species with looking for additional source of income from different occupations or diversifying whatever was available to them. While in table 15, exploitation of resources was a response observed in the communities against competition and lack of opportunities and alternatives.

ii. *There is an interconnection between the responses in table 14 with responses in table 15.* For example, flooding and loss of habitat and species lead the communities to outmigration and overfishing observed in table 14 while in table 15, lack of opportunities or alternatives and competition lead to outmigration and overfishing as a response from these communities.

iii. *Responses lead to other vulnerabilities depending on its sustainability*. Judging from the different journals and scholars discussing about the coping and adaptive responses adopted by the SSF communities, it was observed that, these responses in table 14 and 15 themselves give rise to other vulnerabilities affecting not only SSF but also the mangroves of Sundarbans. For example, in response to the vulnerabilities caused by cyclones in Sundarbans, which is the lack of alternatives or opportunities, the SSF communities tend to migrate to a different place looking for occupation other than fishing. Migration itself is a type of vulnerability because it deviates the SSF communities from their primary

occupation. Moreover, there is a rise in the varieties of fishes and the fish catch increases after a cyclone, making it the most suitable time for the fishers to exploit the resources and deplete them which is a vulnerability affecting the ecological subsystem causing loss of species.

This explains the multidimensional nature of the vulnerabilities leading to interconnecting responses. Also, all the vulnerabilities give rise to similar kind of responses at the end regardless of their ecological or social nature. Some of these responses can be a direct disadvantage to the environment and the fisheries sector. As it is seen that the responses of SSF communities to cyclones and extensive shrimp aquaculture gave rise to more vulnerabilities, the need for working the pathways to viability for the long-term stabilization and ecosystem sustainability becomes crucial. Instead of looking at the situation from a reductionist point of view, we should rather be thinking about a holistic perspective in dealing with the case.

Sometimes, it becomes a challenge for these viability options to work out because of its complexity and involvement of multiple stakeholders working individually. But the formation of a group or team of interdisciplinary stakeholders can help develop an effective plan or a framework for the success of the strategies proposed.

Chapter 6 – Summary

Synopsis of all chapters, key insights, and recommendations

6.1. General Inferences

Mangroves and dependent SSF communities of the Sundarbans are seriously threatened (Banerjee et al., 2012; M. M. Islam & Chuenpagdee, 2013). The ecosystem services of the mangroves make them ecologically significant whereas the association of SSF communities with mangroves help manage the forests and keep destruction in control (Huntington et al., 2017; Lele et al., 2013). They are world's largest carbon sinks and their potential to store carbon is in jeopardy because of constant interference of drivers of change (Feka & Ajonina, 2011; Ray et al., 2011). The rising concerns due to natural disasters like cyclones and flooding and developmental activities like agriculture, aquaculture and tourism have threatened SSF communities and mangrove associated flora and fauna (Abdullah et al., 2017; DasGupta & Shaw, 2015; Hoque Mozumder et al., 2018). These disasters and developmental activities were identified as active drivers of change that affected Sundarbans SES. The ability of the SSF communities to rebuild has also diminished as the drivers affect their wellbeing, capitals, and resilience immensely (DasGupta & Shaw, 2015; Eriksson et al., 2016).

These drivers of change were identified to be natural and anthropogenic in Chapter 4 which indicated cyclones and shrimp aquaculture to be the most destructive ones in terms of level of vulnerability among mangroves and SSF of Sundarbans. Cyclones SIDR and Aila had already wiped out 35% of the mangroves in 2007 and 2009 respectively, but an additional 35% of the vegetation cover was depleted after Cyclone Amphan in 2020 (Bhowmik & Cabral, 2013; S. Chakraborty, 2015; Sen, 2020). They have been constantly rampaging the livelihoods of SSF to an extent that has led to many of them migrating out of the region due to lack of opportunities and alternatives because of loss of infrastructure and property. Rising demand of shrimps have attracted companies around the world to the region's biodiversity and richness of shrimp species. This has led non-fishers from neighbouring areas to invest in the shrimp aquaculture industry through unsustainable means for ready cash and profits (Abdullah et al., 2017; K. Dutta, 2015; Salunke et al., 2020). Migration into the region from higher potential and self

contempt people has created a rift among the SSF communities, furthermore, creating competition for resources, illegal fishing and exploitation (Guha & Roy, 2016).

6.2. Objectives and Conceptual Position

The purpose of this research was to analyse the vulnerabilities induced due to these drivers of change affecting mangroves and dependent SSF communities and assess the pathways to viability through three main objectives –

a) To describe the drivers of change affecting mangroves and dependent SSF communities in the Sundarbans
b) To analyse the multidimensional vulnerabilities experienced by mangroves and SSF communities of Sundarbans, and
c) To examine key response strategies of SSF communities of Sundarbans and pathways to achieve viability.

Objective 1 was formulated to identify the threats of Sundarbans which have a significant impact on the environment creating disruptions in SSF livelihoods and ecological imbalance. Chapter 4 gave a brief idea about the active drivers, be it natural or anthropogenic, and elaborated two case studies that gave an in-depth description of cyclones and shrimp aquaculture. These two drivers were the most impactful ones out of all others as they were affecting larger populations and had a long-term effect on the region. Literature review stated that these drivers were the most common drivers in Sundarbans.

Objective 2 was developed to analyse the impacts of the drivers on SSF communities and mangrove ecosystem. This was discussed in the same chapter as objective 1. The flow of the case studies led to the identification of impacts generated which eventually were discussed as multidimensional vulnerabilities in the later sections of chapter 4. They briefed about the vulnerabilities affecting mangroves and SSF and the nature of these vulnerabilities being able to affect both components at the same time.

Objective 3 was framed to examine the strategies or responses of SSF in terms of their attempts to build resilience and efforts to attain a stage of viability. It also aimed at describing the pathways to viability which when understood according to its actual

definition are responses which are sustainable and do not create more vulnerabilities in return. This was briefly discussed in chapter 5 explaining the responses to specific vulnerabilities of the Sundarbans SES.

Chapter 2 described all the concepts and theories relevant to further understanding the three objectives that focus on mangroves, SSF and wellbeing, capitals, and resilience which were also used as keywords for SLR. Additionally, it elaborated the theory behind I-ADApt and its components. The SLR technique was also used to describe site specific details in chapter 2 in addition to the traditional literature review technique. To base the foundation of the intended objectives of the research and results, this chapter described the mangroves and SSF general information and their status and details worldwide. Furthermore, it mapped the theories of wellbeing, capitals, resilience, and coping & adaptive responses in the context of V2V which linked the concepts of SSF and mangroves together.

6.3. Methods

At first the method of this thesis was supposed to include primary data collection but because of research ban in the University of Waterloo due to the COVID-19 pandemic, the method was converted to secondary literature research that was conducted using two databases – Scopus and JSTOR and were managed in Zotero. The papers and articles were not limited to only these two databases as most of the papers found in the keyword search were discarded due to lack of any relation with my research objectives and questions. Google Scholar, Science Direct, and SAGE was also used in minor searches to backup the data found in the major keyword search in SCOPUS and JSTOR.

The key words used for the search were the words that were emphasized the most in the objectives and research questions. The literature review was based on these key words that were used as the area of literature under different subsections of Chapter 2. The methods used to achieve the objectives were a SLR and case study approach which were discussed in detail in chapter 3. The first objective was achieved by using a case study approach to address one natural and one anthropogenic driver of change while the second and third objectives were achieved by SLR focusing on the two case studies described in chapters 4 and 5. An in-depth explanation of the drivers of change,

vulnerabilities affecting wellbeing, livelihood capitals and resilience were detailed in chapter 4 while the coping and adaptive responses of SSF communities and pathways to viability was examined in chapter 5.

6.4. Key Insights

There were many inferences and insights that were deemed important after results and discussions in chapters 4 & 5. Most of the insights are put together below based on each objective.

- *Objective 1 – Threats and Impacts of Cyclones and Shrimp Aquaculture as drivers of change in Sundarbans*

Because of the intensity of the cyclones and the range of impact on Sundarbans it was selected as one of the case study areas. It was found out from the case studies that more than 10 high-intensity cyclones have passed through Sundarbans since the year 2000 till now. The cyclones not only impacted the livelihoods of SSF but also highly created an ecological imbalance due to loss of habitats and species. It was found out that most people subjected to the aftermath of the cyclones are quite remarkably the least responsible for the problem caused (Sen, 2020). Aquaculture is also expanding in the Sundarbans because mangroves act as breeding grounds for fishes, shrimps, and crabs. The backbone of Sundarbans' economy and food security is contributed by shrimp aquaculture in India and Bangladesh which happens to support the livelihoods of millions of people in the respective countries. Much of the catch is exported to Southeast Asian and East Asian countries. Majority (87%) of the fish and crab traps were set along the mangrove shorelines (Mackenzie et al., 2016). Sustainable practices of aquaculture and fisheries should be adopted as the demand for fish is constantly on the rise along with its growing per capita income. If not planned in a proper way for development, then it might affect the environmental conditions.

Findings from objective 1 –

- Active natural drivers in Sundarbans – cyclones, floods, salinization, erosion, sea-level rise.

- Active anthropogenic drivers in Sundarbans – shrimp aquaculture, mangrove degradation for coastal development projects like multimillion dollar tourism projects, thermal coal-fired power plant projects.
- Major impacts on the region from high intensity recurrent cyclones and improper practice and management of shrimp aquaculture ponds.
- Impacts of the drivers of change have a prolonged recovery period for both mangroves and SSF livelihoods.

- *Objective 2 – Multidimensional vulnerabilities in Mangroves and SSF*

This high-scale destruction brought many vulnerabilities for the poor and marginalised SSF communities in Sundarbans (Biswas, 2020). People lost their agricultural fields and are subjected to debts. The fishponds for aquaculture were also damaged eventually pointing to a long-term loss of income and livelihood. This directly affects the material well-being of the fishers as there is substantial impacts on the financial, social, physical, and natural capitals. However, the proper use of their human capitals – by applying the skills and knowledge regarding fisheries and mangroves, they can build resilience. The relational well-being on the other hand, is enhanced as the community comes together and makes decisions regarding relief funds and food for the people. The financial help from government does help in a short-term scale but questions the long-term sustenance of the fisher families. People have started to restore the drinking water supply, houses, and toilets usually with the help of the local population and self-help groups. Ahmed & Kelman, (2020), argue that there is no external assistance for restoration of livelihoods apart from the little amount of money sent by the government as relief. Many families disconnected from the mainland did not get that relief up till now. People started migrating from the islands to other places looking for employment opportunities (Dubey et al., 2017). This makes the fishers vulnerable to unemployment for long periods and financially unstable.

Findings from objective 2 –

- The drivers impact both mangroves and SSF livelihoods similarly, regardless of them being different components of SES.

- The impacts are linked to vulnerabilities of mangroves ecosystem through parameters like ecological function, vegetation cover, and species richness.
- The impacts are linked to vulnerabilities of SSF through parameters like wellbeing, capitals, and resilience.
- Observed ecological vulnerabilities due to cyclones and shrimp aquaculture are – mangrove death, flooding, salinization, loss of native species and pollution.
- Observed social vulnerabilities due to cyclones and shrimp aquaculture are – loss of livelihoods & infrastructure, lack of opportunities & alternatives, and competition & resource exploitation.
- The ecological vulnerabilities acted as drivers by themselves as they have their own set of vulnerabilities.

- *Objective 3 – Pathways to viability through sustainable coping and adaptive responses*

Chapter 5 detailed about the coping and adaptive responses of SSF which lead to vulnerability in most cases and viability in some. The major reason of studying social responses was because SSF act as a key component of the Sundarbans in understanding how the system functions while mangroves or the ecological components do not possess the ability to understand social components. Sundarbans region has been trapped in the vicious loop of vulnerability as the responses generated to the existing vulnerabilities create addition threats and impacts on the environment and society. This was understood as the negative feedback loop. This loop only forms if the responses are improperly planned without keeping sustainability and long-term stability in the bigger picture. But some SSF do practice healthy response strategies worldwide and in Sundarbans itself which can act as pathways to viability for the whole SSF community.

When aquaculture and agriculture are done together along with mangroves, it aims at a long-term sustainability of the mangrove ecosystems (Kabir et al., 2019). Hilsa grows well in the area and the demand for the fish is high. But the shrimps are mostly cultivated because it gets the maximum cash because of the exportable quality produced in the region. The Sundarbans acts as a refuge to numerous marine aquatic species and provides a friendly environment for the growth of tiger prawns. For a steady income,

many SSF communities have adopted extensive shrimp aquaculture as their round the year occupation (Dubey et al., 2017). It can be both a driver of change as well as a strategy for community resilience. The unsustainable practice of shrimp culture can affect the environment as it has been documented in many studies that the water quality is degraded with the constant use of feed, chemicals, and pesticides in these farms. While the shift to shrimp aquaculture can help the SSF communities to improve their livelihoods financially as the demand of shrimp is increasing globally. There is a visible paradox in this situation where it can be both advantageous and disadvantageous to the community and environment. As to which practice is sustainable, makes an actual difference.

Findings of objective 3 –

- Vulnerabilities in the social subsystem generated responses – coping and adaptive amongst SSF.
- Some responses were deemed unsustainable which created their own chain of vulnerabilities while some responses were environmentally sustainable and led to viability.
- Negative feedback loop was seen while analysing the chain of events occurring due to unsustainable responses.
- Defying fishing regulations, illegal fishing, exploitation of resources, migration, consumption adjustment, encroachment, selling of assets and informal loans were observed to be some responses that generated its own set of vulnerabilities.
- Mutual support & insurance, diversification of livelihoods & occupation, modifying infrastructure, skill development & training, and sustainable management practices were observed to be some responses that led to pathways of viability.

6.5. Recommendations

While examining the coping and adaptive responses of SSF communities it was found out that diversification of livelihoods, occupations can help curb the effects of these vulnerabilities if not eradicate them. Integrated fish farming can be used for boosting up

the potential of the Sundarbans. This concept of combined culture of vegetables, crops, and aquaculture can be utilized to avoid the excessive use of chemicals and fertilizers (Chakravartty et al., 2017). This process not only helps the environment but also reduces the financial pressure on the SSF communities by providing them with locally grown food and reduced crop maintenance costs. Also, there is a need for a regulatory body to oversee the introduction of the types of species being imported from foreign countries to restrict the inflow of diseased shrimp varieties. SSF communities being mainstreamed into developmental decisions can also act as a better strategy in conservation of mangroves (Berkes & Turner, 2006; DasGupta & Shaw, 2015).

Additionally, the SSF communities are affected in the long run by these drivers of change. The well-being of the individuals is in jeopardy when the natural processes are affected by climate change and other uncertainties. Due to the unpredictability of climate change, loss of assets, be it human, financial, or social, is evident. It was also found out that the natural resources continued to decline despite major advances in existing scientific understanding of how ecosystems and human populations interact, and the application of considerable conservation and management efforts at different scales. This was because of the extent of the drivers of change in Sundarbans that had taken a toll on the communities and mangroves. Greater effort will be required to avert increasing damage from over-exploitation, pollution, and global climate change in the future. The need for a holistic perspective over a reductionist one will provide ample opportunities for the communities as well as alleviate mangrove degradation.

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APPENDICES

APPENDIX-I – CASE STUDY TEMPLATE FOR I-ADApT

Integrated Marine Biogeochemistry and Ecosystem Research

www.imber.info

The development of such a framework necessarily requires an interdisciplinary approach. The case study template is comprised of six sections (A-F in "Contents" below) with a total of 30 questions, which will probably require input from several people. The case study template is designed around an "Issue" affecting fisheries that links the natural properties of the marine ecosystem with the natural, social and governance systems. **As the research is based on social-ecological systems, the governance aspect of questions would not be answered as that was not part of the research questions and objectives**.

This case study template is downloadable from our website (http://www.imber.info/index.php/Science/Working-Groups/Human-Dimensions/IMBER-ADApT).

(Bundy et al., 2016; Hardy et al., 2016)

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A. BACKGROUND INFORMATION

In this section, please provide background information about yourself and your case study, as well as a clear description of the Main Issue affecting fishing or aquaculture in your case study. Please provide as much information as necessary to understand the Main Issue. If required, use an extra page and feel free to provide references where relevant.

INFORMATION	**DETAILS**	
CASE STUDY CONTRIBUTORS **(please include all contributors)**	**NAME: Aishwarya Pattanaik** **AFFILIATION: University of Waterloo, Canada** **Email: apattana@uwaterloo.ca**	**NAME: Prateep Nayak** **AFFILIATION: University of Waterloo, Canada** **Email: pnayak@uwaterloo.ca**
NAME OF STUDY AREA	**Sundarbans**	
COUNTRY/COUNTRIES WITH JURSIDICTION	India and Bangladesh	
GEOGRAPHIC LOCATION	Tropical	
ECOSYSTEM TYPE	Coastal, Mangrove, Delta	
MAIN ISSUE (a) Provide a concise, detailed description of the Main Issue affecting the case study. Include the following	**Description of Main Issue** The rivers Ganga, Brahmaputra and Meghna form a delta which harbors one of the largest mangrove forests in the Asian continent. Sundarbans Delta is located in the transboundary region of India and Bangladesh. It comprises of a coastal wetland and mangrove ecosystem that provide storm protection, biogeochemical cycle	

information to show the extent of the effect of the Main Issue:	regulation, erosion control, fisheries, and forestry products etc. The area is spread over 10,000 sq km (60% in Bangladesh and 40% in India) which supports the livelihoods of 7.5 million people involved in agriculture, fisheries, aquaculture, and NTFP collection. It has a diverse species background – 30 true mangroves, 20 mangrove associates, 753 insects, 350 fishes, 356 birds and 50 mammals. These ecosystems are on the verge of destruction because of drivers of change affecting the region as well as associated human population. A major part of which are Small-Scale Fishers (SSF) that actively access benefits from the region and share among themselves. Drivers of change like extreme weather events (cyclones, flooding) and coastal development (agriculture, aquaculture, tourism projects) have driven these communities of mangroves and SSF into vulnerability which jeopardizes the conservation strategies of forests and weakens wellbeing, capitals and resilience of fishers and their livelihoods. Cyclones and shrimp aquaculture have turned out to be the most destructive compared to other drivers. Hence the case studies are based on their in-depth details. SSF, ministry of forests, local and regional government, community federations, people residing in the area are key stakeholders.
(b) When did the Main Issue occur?	Cyclones have been a regular phenomenon and are recurrent in the region. The destructive nature of cyclones has been recorded since 1980s. The casualties have been reduced to a huge extent but the impact on the livelihoods due to property loss as well as loss of mangroves have been severe. While shrimp aquaculture gained demand since mid-1990s, and non-fishers & large-scale companies have been interested in the region's biodiversity for ready cash and unlimited profits. They have been moving into the area to settle in the name of business and market interventions which have been creating more population pressure on Sundarbans as well as competition for already settled natives which happened to be SSF.
(c) Are there other geographical areas that are also affected by this issue, but not included in this case study?	Most coastal communities face similar issue regarding unsustainable shrimp aquaculture. But cyclones in the Bay of Bengal always tend to move towards Sundarbans or neighboring states like Odisha, India which harbors the second largest mangrove forest of India. Aquaculture is also a rising concern in the Indian peninsula as well as other coastal countries.

B. DESCRIPTION OF THE STRESSORS AND THEIR IMPACTS

This section aims to gather information about the scale of the affected natural and social systems, and the governing systems, the main stressors affecting these systems, the consequent changes that this cause, and their impacts. Please provide as much information as necessary, but in no more than 200-300 words for each question. Please provide references where relevant.

Questions	Natural system	Social system	Governing system
1. What are the boundaries of the natural, social and governing systems?	The natural system can be defined as the ecological subsystem of the Sundarbans social-ecological system. This comprises of the mangrove wetlands, associated flora and fauna, the biogeochemical cycles, the tidal systems, hydrological phenomenon, and climatic events.	The social system can be defined as the social subsystem of the Sundarbans social-ecological system. This comprises of the depended human population seeking shelter, food, and work in the region and which interact among themselves. For example – SSF	NA
2. Which of the following levels is the Main Issue related to? Please describe for each system and level, where appropriate.	The destruction of mangroves and loss of species is more localized, but the impacts are local, regional, national, and global. A. LOCAL	The SSFs in the social system are being affected more locally and regionally. A. LOCAL The SSFs are affected by the drivers of change locally due to the impacts of cyclones. The local fishers also face complications due to non-fishers practicing shrimp	NA

	The loss of mangroves disturbs the ecosystem services of the local areas which in turn creates vulnerabilities for the social subsystem of the specific area. B. REGIONAL (within country) The loss of species reduces the economy of the region as well as the state. C. NATIONAL The economic evaluation and GDP are also affected which is part of a national concern. Additionally, the importance of the Sundarbans in terms of tourism, and ecological importance is of national concern as well. D. INTERNATIONAL/GLOBAL The region has the potential to store carbon, which is comparable to any rainforests, hence the carbon reserves are lost which will	aquaculture and exploiting the resources. B. REGIONAL The same drivers affect the SSFs communities around the Sundarbans and the state by putting them in a state of vulnerability which involves loss of livelihoods, opportunities, migration, and competition. This in turn reduces the potential of food security and GDP in Fisheries sector affecting the economy of the state.	

	affect the global environmental state.		
3. What are the main natural, social and/or governance stressors that affect this system?	Cyclones, Shrimp Aquaculture, Salinization, Flooding, Pollution, Coastal Development, Deforestation, Exploitation, Encroachment	Cyclones, Shrimp Aquaculture, Salinization, Flooding, Pollution, Coastal Development, Deforestation, Exploitation, Encroachment, Competition, Selling of Assets	NA
4. What changes in the natural, social and governing systems do these stressors cause and where?	Cyclones – Loss of Species, Flooding, Salinization, Erosion, Habitat Destruction Shrimp Aquaculture – Salinization, Pollution, Loss of Species, Waterlogging	Cyclones – Loss of livelihoods and infrastructure, lack of alternatives and opportunities, migration Shrimp Aquaculture – Competition, Encroachment, Exploitation, Illegal fishing, Migration	NA
5. What are the impacts or consequences of this change on the natural, social and governing systems?	Salinization reduces the aquatic diversity by making the region uninhabitable for some fishes. Flooding for prolonged periods results in rotting of mangrove roots due to increase in salt content eventually leading to mangrove death.	Loss of livelihoods and infrastructure have affected the material and subjective wellbeing negatively. Migration of SSFs to other areas has made them suffer more in labor jobs as well as created a disconnect between them and fisheries.	NA

C. VULNERABILITY (6 questions)

Please provide as much information as necessary in no more than 200-300 words for each question and provide references where relevant.

NB: These questions refer to the period PRIOR to the Main Issue

QUESTION	Details
6. What was the ecological status of the ecosystem (e.g., eutrophication, changes in size and/or trophic level, loss of key species, habitat quality, invasive species structure, dead zones) prior to the main issue?	Dense mangrove forests that provided favorable habitats for Royal Bengal Tigers, Crocodiles, King Cobra, and many other native species. Additionally, Sundarbans harbors a diversity of species including 753 insects, 350 fish, 356 bird, and 50 mammals. *Casuarina, Prosopis juliflora,* Eucalyptus, and water hyacinth were the major invasive plant species.
7. What was the productivity of the system (low, medium or high) prior to the main issue?	High productivity due to the presence of mangroves as well as aquatic species.
8. What were the main livelihood activities (e.g., fishing, tourism, etc.) directly affected by the Main Issue?	Agriculture, Aquaculture, NTFP Collection, Fisheries.
9. What other livelihood opportunities (e.g., farming, manufacturing, forestry, etc.) were there in the affected area prior to the main issue?	Tourism, Landless laborers, Animal rearing, etc
10. What % of the total catch/production from fisheries and or aquaculture was used for own household	NA

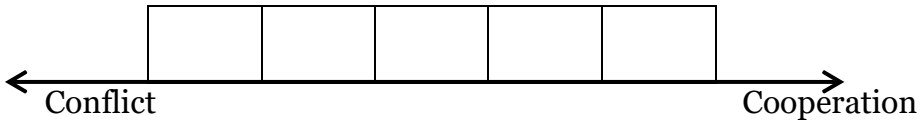
consumption (not sold) prior to the main issue?	
11. What proportion of household income came from fish caught or produced locally (including post-harvesting activities) prior to the main issue?	Around 89% of households participate in agriculture which is not high yielding due to high soil salinity, whereas fisheries and NTFP sector contribute approximately 79% to the household income despite fewer people being involved in the sector.

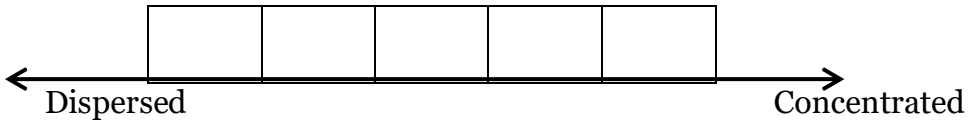
D. GOVERNANCE AND GOVERNABILITY (8 questions) – THIS SECTION IS LEFT BLANK BECAUSE THE GOVERNANCE ASPECT WAS NOT EXPLORED IN THE THESIS OBJECTIVES.

Please provide as much information as necessary, but in no more than 200-300 words for each question, and provide references where relevant.

NB: These questions refer to the period PRIOR to the Main Issue

QUESTION	Details
12. What were the relevant organisation(s) or individual(s) (including state, market and civil society) responsible for governance of fisheries and aquaculture at local, regional and national levels in this area prior to the main issue?	LOCAL: REGIONAL: NATIONAL:
13. What was the mode of governance (e.g., self-, co-, hierarchical (local), hierarchical (larger scale), mixture) prior to the main issue. Please describe.	
14. What were the long-term management objectives prior to the main issue?	

15. What were the key rules, regulations, instruments and measures employed to achieve the management objectives prior to the main issue?	
16. Were there any informal rules, regulations, instruments and measures that play an important role in the governance of fisheries and aquaculture prior to the main issue? Please describe.	
17. What was the nature of the relationship between the different sectors or livelihood occupations in this system prior to the main issue? (i.e., was there conflict or cooperation) Were there any special circumstances in their relationships that should be noted?	Please tick the box corresponding to the most appropriate situation 
18. Who dominated or wielded the most social power in the area prior to the main issue? (e.g., fishers' associations, unions, corporations, governments, business owners, etc.)	

19. How concentrated was social power in the area prior to the main issue? (ie., was power held by a few people/1 organisation (concentrated) or was it dispersed over several organisations)	Please tick the box corresponding to the most appropriate situation of the social system 
20.Were there any structural changes in the governing system or individuals prior to the main issue? Please describe the changes and why they occurred?	
21. Were there any changes to the key rules, regulations, instruments and measures, or have any new ones been introduced prior to the main issue? Please describe the changes and why they were introduced	

E. RESPONSE (2 questions)

The objective of this section is to evaluate the response of the natural, social and governing systems to the Main Issue. We ask for information about Short Term (within 2-5 years) and Long Term responses for the natural, social and governing systems. Please provide as much information as necessary, but in no more than 200-300 words for each question. Please provide references where relevant.

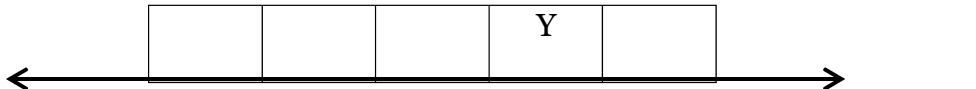
	Natural	**Social**	**Governing**
22. a. What were the **short term** responses of the social and governing systems to the main issue? (Include structural changes in the governing system(s) or individuals, or the changes in key rules, regulations, instruments and measures etc.)	NA	TYPE OF RESPONSE Borrowing Money, selling of assets, sharing responsibilities, exchanging information, change of food habits, violation of laws and regulation, house abandonment, overfishing. LEVEL OF RESPONSE Local and regional	NA
b. What were the **long term** responses of the social and governing systems to the main issue? (Include structural changes in the governing	NA	TYPE OF RESPONSE Mutual support & insurance, child labor, encroachment, exploitation of resources, illegal fishing, modifying household infrastructure, borrowing	NA

system(s) or individuals, or the changes in key rules, regulations, instruments and measures etc.)		money, and consumption adjustment. LEVEL OF RESPONSE Local and regional	
23. a. What were the objectives of the **short term** social and governing responses for the natural, social and governing systems?		To be able to survive the vulnerabilities and move to viability. To be able to make use of amenities available. To be able to provide for the families.	
b. What were the objectives of the **long term** social and governing responses for the natural, social and governing systems?		To be more resilient. To be able to compete with the non-fishers. To be able to earn more money.	

F. APPRAISAL (7 questions)

The objective of this section is to evaluate the response of the natural, social and governing systems to the Main Issue. We ask for information about Short Term (within 2-5 years) and Long Term responses for the natural, social and governing systems. Please provide as much information as necessary, but in no more than 200-300 words for each question. Please provide references where relevant.

	Natural	Social	Governing
24. a. What were the results of the s**hort term** response for the natural, social and governing systems (ie were the objectives in Q.23.a achieved)?	There was a significant depletion of fish resources which in turn became a vulnerability by itself. Additionally, the mangrove species were lost to converted farmlands or shrimp ponds for more income sources.	The objectives were achieved at the moment but in turn created more vulnerabilities like uncertainty of stability and generation of debts. This created more financial problems for the fisher families.	NA
b. What were the results of the **long term** response for the natural, social and governing systems (ie were the objectives in Q. 23.b achieved)?	The responses on the natural ecosystem also led to degradation of mangrove and aquatic species habitat. Overfishing depleted few target native fish species, and encroachment degraded the mangrove trees.	Some adaptive responses tend to be sustainable and served the purpose of viability like rainwater harvesting, cleaning drives, modifying coastal infrastructure, adopting technology, mutual support and partnerships helped move SSFs from V2V.	NA

25. Was the Main Issue addressed (Section A)? Please describe			
Please describe	The immediate issue gets addressed. But cyclones are natural drivers that are recurrent with increasing intensity and frequency. Shrimp aquaculture is a rising concern for the region as well. So, eradicating the problem would not be the solution. Instead, increased resilience and sustainable practices would help in viability of SSFs.	The immediate issue gets addressed. But cyclones are natural drivers that are recurrent with increasing intensity and frequency. Shrimp aquaculture is a rising concern for the region as well. So, eradicating the problem would not be the solution. Instead, increased resilience and sustainable practices would help in viability of SSFs.	NA
26. a. What factors contributed to the successful **short term** results described in Q 24.a (e.g., enabling policy, government funding)	Most of the short term or coping responses were unsustainable and created additional vulnerabilities but some responses like protests, rallies, cleaning drives, rainwater harvesting, house reinforcement were sustainable and contributed to the stability of SSF livelihoods.	Most of the short term or coping responses were unsustainable and created additional vulnerabilities but some responses like gear restrictions, partnerships along with strong relational wellbeing helped in successful responses for viability.	NA

b. What factors contributed to the successful **long term** results described in Q 24.b (e.g., enabling policy, government funding)	Policy implementation, gear restriction, mainstreaming SSF into developmental policies, NGO and institutional intervention in skill development.	Diversification of livelihoods, modifying infrastructure, Policy implementation, gear restriction, mainstreaming SSF into developmental policies, NGO and institutional intervention in skill development.	NA
27. a. What factors (if any) prevented the **short term** objectives from being fully achieved? (e.g., regulatory barrier, lack of social cohesion, costs too high, climate variability, judicial decisions).	Lack of rights of SSFs, improper management of mangroves and aquatic species, lack of implementation regulatory laws.	Lack of rights of SSFs, improper management of mangroves and aquatic species, lack of implementation regulatory laws.	NA
b. What factors (if any) prevented the **long term** objectives from being fully achieved? (e.g., regulatory barrier, lack of social cohesion, costs too high, climate variability, judicial decisions).	Lack of rights of SSFs, improper management of mangroves and aquatic species, lack of implementation regulatory laws.	Lack of rights of SSFs, improper management of mangroves and aquatic species, lack of implementation regulatory laws.	NA
28.Has there been a formal evaluation of the responses? If so, how was this done and when?	No formal evaluation. Just qualitative analysis through SLR and case studies.	No formal evaluation. Just qualitative analysis through SLR and case studies.	NA

29. a. What were the benefits related to costs of the **short term** response?	NA	NA	NA
b. What were the benefits related to costs of the **long term** response?	NA	NA	NA
30. Were other options considered for the short and/or long-term responses? Why were these not selected?	NA	NA	NA

G. GLOSSARY

Driver

Any natural or human-induced factor that directly or indirectly causes a change.
(http://www.greenfacts.org/glossary/def/driver.htm)

Ecosystem

A discrete unit that consists of living (e.g. assemblage of plant and animal species) and non-living parts (e.g. the physical environment), interacting to form a stable system.[1,2]

Eutrophication (Q#6)

The process of nutrient enrichment (usually by nitrates and phosphates) in aquatic ecosystems, such that the productivity of the system ceases to be limited by the availability of nutrients. The increased growth of plants and algae depletes the dissolved oxygen content of the water and often causes a die-off of other organisms. It occurs naturally over geological time, but may be accelerated by human activities (e.g. sewage disposal or land drainage); such activities are sometimes termed 'cultural eutrophication'.[1]

Governance

Governance refers to groups of people coming together to achieve a particular outcome. It involves all interactions among government, private firms, civil society, citizens as well as any other relevant stakeholder groups to solve societal or environmental problems and to create opportunities. In addition to the day-to-day management tasks, the boundary of governance includes the formulation and application of principles and visions guiding those interactions and care for institutions that enable and structure them.[4,6]

Governance refers to mechanisms, processes and institutions through which public and private sectors articulate their interests, exercise their rights, meet their obligations and mediate their differences in order to make decisions affecting society (Rosenau, 1999).

Habitat (Main Issue)

The natural environment, characterized by its physical features (e.g., temperature range, availability of light, food availability or dominant plant types) in which an organism or population normally lives. Marine habitats include, for example, mangroves, intertidal zones, coral reefs, deep sea.

Household (Q#10, 11)

A household is a domestic unit consisting of the members of a family, as well as any non-relatives who live together in the same dwelling.

Instruments (or measures) (Q#15, 16, 21, 22)

Instruments are tools used in governance to overcome problems or obtain a desired effect. They are usually of a regulatory or economic nature. There is a large variety of instruments including 'soft' ones, like information and advice, and 'hard' ones such as taxes and regulations. Laws, treaties and appointments are formal instruments, while oral agreements, visits, or making a speech are more informal.[4]

Invasive species (Q# 6)

A species that is not native to an area that it colonizes and that is capable of causing harm to native species or the natural environment, and incur economic damage, or injury to human health.[1]

Mode of governance (Q#13)

There are three forms of governance: hierarchical, co-governance or self-governance. Hierarchical governance is a top-down 'steering and control 'style of intervention, that uses policies and in law. Co-governance requires involvement from various parties with a common purpose (e.g. fisheries co-management). In self-governance (e.g., community- or market-based) the actors take care of themselves, outside the purview of government. While self-governance may be initiated by governments through deregulation or devolution, it can also come about of its own accord.[5,6]

Power (relations) (Q#18)

Power is the ability to influence the behaviour of others and in social relationships is determined by the actors' access to power resources. Besides obvious power resources such as wealth and control over jobs, many others exist, for example, organizational capacity, expert knowledge, control of information, being in certain social positions, and even having a reputation of being powerful. Power has a reciprocal nature: A acts, B reacts, A reacts to B's reaction, and so on.[7]. This can manifest as power to exclude, power to influence markets or power to influence decision-making

Primary Productivity (Q#7)

The photosynthetic fixation of carbon by chlorophyll containing organisms, such as phytoplankton, macroalgae, mangroves, sea grasses and other sea plants. It is measured as the weight of carbon fixed per unit area per time, usually as $g.C.^{m-2}.yr^{-1}$

Rules (formal and informal) (Q# 15, 16, 21, 22)

Formal rules (e.g., constitutions, laws and regulations) are consciously designed and often codified in written form. They are often enforced by an external authority such as the police and the courts. Informal rules evolve spontaneously and unintentionally over time through human interaction, and take the form of unwritten conventions, routines, customs, and behavioural norms. Informal rules are often self-enforced, because all (or most) actors find it beneficial to adhere to them

(as long as others do too). Those who do not abide by the informal rules of society can expect the other actors to show their disapproval even to the extent of expelling them from the group.[3]

Social system

Organisation of individuals into groups or structures that have different functions, characteristics, origin or status. http://www.businessdictionary.com/definition/social-system.html. Characteristic pattern of interrelationships between individuals, groups, and institutions to form a coherent whole http://www.merriam-webster.com/dictionary/social system

Stressor (Section B, Q# 3, 4)

An event, condition, individual, or other stimulus that causes stress to a system.[9]

Structural changes (Q#20, 22)

Changes to the structure of an organization to achieve its goals. These can be either a partial adjustment or a total overhaul of the duties, tasks, and responsibilities of individuals and departments, as well as reporting relationships and the number of levels in the organization's hierarchy.[8]

Trophic level (Q#6)

The position that an organism occupies in a food chain. For example, green plants (which obtain their energy directly from sunlight) are the primary producers, and herbivores are primary consumers (and secondary producers). A carnivore that eats only herbivores is a secondary consumer and a tertiary producer. Many animals feed at several different trophic levels.[2]

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I. NON-CONSENT FORM

Purpose

The Human Dimensions Working Group of the Integrated Marine Biogeochemistry and Ecosystem Research project (IMBER) is developing a decision support tool known as IMBER-ADApT (Assessment based on Description, Responses and Appraisal for a Typology). It will be built from lessons learned from case studies collected from around the world, dealing with issues relating to global change impacts on marine fisheries and aquaculture, and the people who depend on them. Its aim is to provide managers, decision makers and other stakeholders faced with difficult decisions with considered options on how to respond effectively.

Information and data

Once developed, the IMBER-ADApT will be made available as an open-access web application available to all stakeholders. This means that some or all of the information that you provide in the ADApT Case study template will be available on-line. By signing this form, you have indicated that you do not agree to having the information that you have provided made available on-line.

If you have questions regarding this study, contact:
Dr. Alida Bundy, Chair Human Dimensions Working Group

Alida.Bundy@dfo-mpo.gc.ca

Statement:

The nature and purpose of this project have been adequately explained to me but I do not agree to the use of my data and research as indicated above.

Signature:_____Aishwarya Pattanaik_____Date:_____August 10, 2021_____

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