The Economic Impact of Tropical Storms on the Sundarban's Mangrove Ecosystem Services and Local Communities

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The thesis titled "**The Economic Impact of Tropical Storms on the Sundarban's Mangrove Ecosystem Services and Local Communities**" submitted by **Md. Ashiqur Rahman, Md. Shahriar Ahmed**, session 2017-18, has been accepted as satisfactory in partial fulfillment of the requirement for the degree of **BACHELOR OF URBAN & REGIONAL PLANNING (BURP)** on **October 04, 2023.**

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ABSTRACT

Mangrove ecosystem services are a blessing and play a big role in the overall national economy. Sundarbans provides valuable ecosystem services every year, among which provisional services include fish, crab, timber, thatching materials, honey, wax and so on, on which the local community of Sundarbans is directly or indirectly dependent. But tropical storms such as floods, tidal surges, and cyclones affect the system every year socially, environmentally and economically. So, this study aims to determine the economic value of the provisional ecosystem services, quantify the effect of the tropical storm on ecosystem services and local communities and provide management strategies to ensure sustainable management of the common pool resources. The market price approach is used for estimating the value of ecosystem services and to identify the effects of tropical storms on the management of common pool resources. A questionnaire survey and various PRA tools are also used. It was found that the average economic value of the provisional services in the Sundarbans was almost 65.86 million taka between the financial years 2010-2022. The tropical storm had a direct effect as the collection remained off for almost 12 to 15 days and there was also a significant difference in income from the services just before and after the storm. Although some positive effects occur because of the less extraction during those times, SLR and land cover change are the long-term issues that will affect biodiversity. As year by year these impacts cannot get over even after taking management policies, so improved common pool resource management is proposed using the Gordon and Scott model. Localized common pool resource management opportunities are assessed using Ostrom's rules by involving the local community, among whom 54% are WTP in policy making and giving sanctions, which include shared quotas, moderate MSY, annual allowable cut, alternative income opportunities, and financial support by local, national and international enterprises. This study provides a way to improve the management of common pool resources to ensure sustainability of the resources as well as better security of tenure for the local communities.

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Acronyms and Abbreviations

AAC	: Annual Allowable Cut
ADB	: Asian Development Bank
ADP	: Annual Development Plan
BBS	: Bangladesh Bureau of Statistics
BCDP	: Biodiversity Conservation Development Project
BCIC	: Bangladesh Chemical Industries Corporation
BGD	: Bangladesh
BLC	: Boat License Certificate
cc	: cubic centimeter
CEGIS	: Centre for Environmental and Geographic Information Services
CF	: Conservator of Forests
cft	: Cubic Feet
cm	: centimeter
CMP	: Conservation Management Plan
CO2	: Carbon dioxide
CPR	: Common Pool Recourse
DOE	: Department of Environment
DOF	: Department of Fisheries
ECA	: Ecologically Critical Area
e.g.	: for example
et al.	: and others
etc.	: etcetera
FAO	: Food and Agricultural Organization
FD	: Forest Department
FG	: Forest Guard
FGD	: Focus Group Discussions
GDP	: Gross Domestic Product
GIS	: Geographical Information System

ha	: hectare
i.e.	: that is
IFMP	: Integrated Forests Management Plan
IPAC	: Integrated Protected Area Co-Management Project
IRMP	: Integrated Resource Management Plan
IUCN	: International Union for the Conservation of Nature
KFD	: Khulna Forest Division
km	: kilometer
km^2	: square kilometer
LULC	: Land cover/ Land use change
m	: meter
m^2	: square meter
MOEF	: Ministry of Environment and Forest
MSc	: Master of Science
MSY	: Maximum Sustainable Yield
NGO	: Non-Governmental Organization
RF	: Reserve Forest
SMP	: Strategic Management Plan
SRF	: Sundarbans Reserved Forest
Tk	: Taka
UNDP	: United Nations development Program
UNESCO	: United Nation Education, Scientific and Culture Organization
USAID	: United States Agency for International Development
VGD	: Vulnerable Group Development
VGF	: Vulnerable Group Feeding
WB	: World Bank

Chapter 1: Introduction

1.1 Background of the Study

Mangrove forests are essential coastal resources that have an important function in the socioeconomic growth. The mangroves serve as a source of highly desirable commercial goods, fisheries resources, and locations for expanding ecotourism (Kathiresan & Bingham, 2001). More than 70 direct human activities, including fishing and the collecting of fuel wood, have been shown to be supported by mangrove forests (Hamilton et al., 1989). The mangroves provide fishing resources (fish, prawn, crab, mollusk, etc.) as well as forestry products (firewood, charcoal, lumber, honey, etc.). Since it contains a lot of calories, mangrove sticks are used to make charcoal and firewood (Kathiresan, 2012). Honey bees are attracted to mangroves, which in some places makes apiculture easier. (Siddiqi, 1997).

In Bangladesh, the Ganges, Brahmaputra, and Meghna (GBM) river delta on the Bay of Bengal is home to the Sundarbans mangrove. It occupies a 580,000-hectare area in the southwest of Bangladesh, between 21 and 22 degrees north and 89 degrees east (Islam, 2010). The biological resources of this forest are very important on a regional and global scale. This forest has been recognized by UNESCO, which designated it as "The World Heritage Site" in 1997 (Islam, 2003). The Sundarbans is indeed essential for ecosystem functions like sediment trapping and land acclamation, safeguarding people and their homes from common cyclones, serving as a nursery for fish and other aquatic life, producing oxygen, recycling waste, producing wood, providing food and building materials, and carbon cycling (Biswas & Choudhury, 2007). The Sundarbans provide vital ecological functions and have potential economic value. Also, it is a component of indigenous culture (Islam & Noor, 2009).

Functions of ecosystems are described as "the capacity of natural processes and components to supply goods and services that either directly or indirectly meet human needs" and are categorized into regulatory function, production function, habitat function, and information function (De Groot, 1992). The Sundarbans ecosystem services support many livelihoods, and economic evaluation of the services can be used to fund programs in the areas to enhance livelihoods (Md,

2011). More than 3.5 million people who live near to the Sundarbans rely on these services either directly or tangentially (Giri et al., 2007) Traditionally, the coastal livelihoods rely on the natural resources that can be found in the Sundarbans. The main Sundarbans provisioning services that the respondents were involved in were fishing, followed by gathering fuel wood, crab, honey, and Golpata (Walters et al., 2008). The provisioning services offered by Sundarbans is fuel wood, fish, timber, crab, honey, thatching materials and so on. Hantal and Goran are the two most famous fuel wood species. Sundarbans' overall revenue includes fuel wood sales, and locals rely on it for a portion of their lives (Rahman MA ,1995).

Mangroves are at risk of being damaged by climate change's catastrophic effects on coastal environments and livelihoods (Dasgupta et al. 2017). However, both manmade and natural forces pose a danger to the Sundarbans. The Sundarbans is susceptible to sea level rise brought on by climate change among other natural processes (Gilman et al., 2008). The coastline of Bangladesh is directly influenced by storm surges, congested drainage systems, and rising sea levels, which places it on the front lines of combating the effects of climate change. (Alley et al., 2007). Nearly every year, cyclones hit Bangladesh's coastal districts. Between 1877 and 1995, Bangladesh was struck by 154 cyclones, including 68 tropical depressions and 43 cyclones, five of which were severe (Md, 2011). The biodiversity of the Sundarbans is also under pressure from stronger cyclones like Sidr in 2007, which destroyed 25-40% of the forest (Sultana & Luetz, 2022). As well, Bangladesh's coastal regions and residences are in danger of being flooded because of storm surges brought on by powerful storms. Future increases in the intensity of tropical cyclones are predicted to cause in more catastrophic storm surges and associated floods (Alley et al., 2007). With an 88 centimeter sea level increase, the Sundarbans' most biodiverse regions will decrease from 60% to 30% in the year 2100 (CEGIS, 2005). In the worst case situation, 84% of the Sundarbans may be flooded by sea level rise of 32 cm by 2050, and the entire Sundarbans may be destroyed by sea level rise of 88 cm by 2100 (Nasreen Mohal et al., 2006). In recent years, Sundari and Gewa have been recorded, which may be related to climate change or to other factors. Due to salt and pest infestations, Sunduri (Heritiera fomes) is also at risk of having its tops die (Rahman MA ,1995).

Up to 30 million Bangladeshis might become refugees from the effects of climate change if sea levels rise by one meter this century. These regions will have an impact on a number of productive sectors, including agriculture, industry, infrastructure, marine resources, forestry, and biodiversity,

human health, and utility services (Agrawala et al., 2003). Along with this the resources of the Sundarban are at serious risk because of the over extraction and illegal operations. If the local population cannot support itself, either via the sustainable and controlled exploitation of resources or through other ways, then it is likely that illegal logging and overexploitation of resources will occur, hastening the destruction of forest resources (Sarker et al., 2021). During the past few years, excessive resource extraction in Bangladesh's coastal regions has caused forest users to lose their traditional means of subsistence (Miah et al., 2010).

The tragedy of the commons is the idea that when several actors use an effective common-pool resource at the same time, the consequent externality will lead to misuse or excessive use of the resource in comparison to the ideal condition (P. K. Dutta & Sundaram, 1993). The term "the tragedy of the commons" has been used to describe issues including the abuse and deterioration of natural resources, such as the destruction of fisheries and the overharvesting of forests. (Ostrom, 1999). But communities can collaborate to manage CPR responsibly but they may need aid from higher tiers of authority for more understanding of resource management because they may not always have the specific expertise needed. To solve the CPR issues and implement sustainable natural resource management, collective action is required (Pretty, 2003).Without including the local population, comprehending their needs and habits, and figuring out how to collaborate with them, it is already understood that protected forest areas cannot be preserved (Gillingham & Lee, 1999). In many situations, developing self-governing structures can assist individuals in managing excessive usage of the commons. They also highlight a number of guiding design concepts that support the development of robust and resilient systems. In addition, they emphasize that for self-governance to work, governments must assume a large amount of responsibility. (Ostrom,1999).

This study aimed to assess the economic value of the provisional services of the Sundarbans such as timber, firewood, thatching materials, fish, crab, honey and so on and quantify the economic impact of tropical storms on these provisional services and local communities. This study tried to point out some possible improved methods for sustainable management of common pool resources with the involvement of local communities. As the general growth of the Sundarban is necessary for various important reasons, the sustainable management of common pool resources should be insured by achieving certain goals.

1.2 Problem Statement

Now a days it is a great concern for the world that the mangrove is decreasing day by day. Mangrove region has experienced a significant decrease in recent years. In Asia, the Philippines receive 60% of this, Thailand receives 55%, Vietnam receives 37%, and Malaysia receives 12%. (Siddiqi, 2001). During the 1990s, a global average of nearly 15 million hectares of woodland per year were destroyed, mostly in the tropics (FAO., 2001). Additionally, it is stated that between the 1980s and 1990s, mangrove woodlands lost 35% of their area (Valiela et al., 2001).

The mangrove habitats are anticipated to be directly and tangentially threatened by climate change. Approximately 20% of shoreline habitats will be lost to sea level rise by the year 2080, according to IPCC estimates, with some regional variation (Gitay et al., 2002). There are various reasons of the depletion of mangroves. The main causes are the tropical storms which includes cyclone, flood, tidal surge and other climate change events. Along with this inefficient management by responsible authority, over extraction by the extractors, change in hydrogeology, sea level rise, land use change are the reasons of the depletion. The most important but most neglected cause is lack of economic evaluation of ecosystem services.

There is always negligence in the economic evaluation of the ecosystem services which results in a lack of consciousness and insincerity about the ecosystem services. Which follows mismanagement of the services. When any tropical storms occur, the ultimate focus is on the damage to the ecosystem or its impact on the environment but the economic damage is always underestimated. And as the people who are directly dependent on the Sundarbans ecosystem services are not aware of the extraction limit which causes over extraction and results depletion of the ecosystem services. As there are a huge number of people in the local community who are living in poverty always seek to earn more from the services as so they attempt irregular activities illegally and unethically. So naturally the growth rate became null as the population of the services is decreasing day by day. Actually, the problem related to the depletion is actually the problems related to common pool resources and the mismanagement of these resources. So, this study has a scope to focus on these things and help in reducing the depletion of mangrove through sustainable common pool resource management with involving the stakeholders from all levels.

1.3 Research Gap

Actually, there are several research on various things about Sundarbans. Several studies are already conducted about the ecosystem of Sundarbans, about the environment, fisheries, carbon sequestration, and climate change impacts on local community and so on. There are also studies about the linkage with the local community or the dependency of the local people on Sundarbans. But the economic evaluation of Sundarban was always neglected and never got that importance to go through. That's why the economic importance is very much unknown to the people and which result mismanagement of common pool resources.

Researchers always focus on the local community and the impact of tropical storms on these local communities. The tropical storms impact on the ecosystem and the environment of Sundarbans is studied in various studies. But the economic impact of the tropical storms on the ecosystem services in neglected and underestimated. Research on the management of the common pool resource with the local community is not focused much. So, in this point there is enough scope to conduct a study about the economic evaluation and to assess the economic damage caused by the tropical storms and ways of effective management of the common pool resources of the Sundarban.

1.4 Rational of the Study

This study will help to address the issue and management problems of the ecosystem of Sundarban as information on economic values are important to evaluate the ongoing issues on management of the ecosystem services. Ecosystem valuation is needed to separate the complexities of socio-ecological relationships. It will help to express these value changes in units monetary that allow for their incorporation in public decision-making processes. It can assess the economic effect of Tropical Storms on ecosystem services and the local community which will help to address the core problems help in managing the common pool resources in an efficient way that can reduce the depletion of the mangrove. The ecosystem valuation helps convincing decision makers to take proper actions for conserving mangrove ecosystems by proper initiative to sustainable management of common pool resources. After completion of the study a rough calculation of the provisional ecosystem services will generate and that will establish a framework for further

valuation of all ecosystem services. It will also help in managing the common pool resources by generating policy of sustainable extraction of the services by the local community.

1.5 Research Question, Research Hypothesis and Research Objectives :

Research Question	Research Hypothesis	Research Objectives
1. What are the ecosystem services of Sundarbans. 2. What is the economic value of ecosystem services of Sundarban.	1.The economic value of ecosystem services of Sundarbans is so much.	1. To assess the economic value of provisional ecosystem services of Sundarbans.
1. Which tropical storms have significant effect on Sundarbans. 2. What are the economic losses of ecosystem services occurs due to tropical Storms. 3. What are the losses incurred to the local communities.	1. The economic loss due the tropical storm is so much and the local communities also face significant loss.	2. To quantify the economic losses of ecosystem services and losses incurred to the local communities due to tropical storms.
1.What is the condition of existing measures. 2.What can be the improved measures to reduce the open access problem.	1. The improved and new strategies will help in reducing the open access problem.	3. To evaluate the effectiveness of existing measures and to propose new strategies to manage the common pool resources in a sustainable way by local community.

1.6 Way Forward

- Economic valuation of the Sundarban in respect of every provisional, cultural, regulatory, supportive services.
- Assess the effects of tropical storms on all Sundarbans ecological functions.
- Initiative in order to provide adequate supportive services to the local people during ban time and other problems.
- Involving the local people in generating alternative income opportunities other than the Sundarban ecosystem services.
- Making policy by involving the local community to manage the common pool resources in a sustainable way.
- Incorporating management principles with an operational economic value.
- Analysis of livelihoods opportunities linking to the ecosystem services.
- Various improvement schemes by coordination of different local, national and international organizations including private NGOs.

1.7 Limitations of the study

During the study period the study team have come constrains in different steps. As the study is related to economic evaluation of the ecosystem services the data related to ecosystem services may not accurate absolutely as there are a significant number of irregular and illegal activity regarding ecosystem services. And the economic impact of tropical storms on the services and local communities are estimated based on the assumptions from various resources, articles and reports. Due to lack of resources and limited time, limited FGD and Kew informant interview is done in two villages of Sundarbans. And as there is no perfect method of common pool resources the methods used in this study may have several constraints.

Chapter 2: Literature Review

A literature review is an exploration of a collection of information on a particular topic. It is a guided tour of the concepts, hypotheses, and conclusions made by earlier researchers. Understanding the present status of knowledge on a chosen topic, identifying any research gaps, and establishing one's own work within a larger area of study are all aided by a well-written literature review. The review of literature will utilize a number of sources, including official publications, research books, scientific papers and journal articles. The literature review concludes by summarizing the key findings and pointing out any gaps in the existing research. It also discusses the main results and recommendations of various studies that have been conducted on the Sundarbans

2.1 Ecosystem Service of Sundarban:

Mangrove forests are located along the coastlines of tropical and subtropical regions (Krauss & Ball, 2013). Additionally, ecosystem services have been subdivided into several providing, regulating, sustaining, and cultural categories (De Groot et al., 2002). According to (Iftekhar & Islam, 2004) the Sundarbans mangrove forest is recognized as one of Bangladesh's most biodiverse and ecologically significant areas. (Glaser et al., 2003) highlighted the Sundarbans provide an extensive variety of ecosystem, economic, and cultural services. The Sundarban ecosystem is one of the Indian Subcontinent's most biologically protected and economically diversified ecosystems (Mahadevia Ghimire & Vikas, 2012)

The Sundarbans are the biggest continuous single block of mangrove forest across the entire world. (S Das, 1985). According to (MEA, 2005) the simplest straightforward way to define ecosystem services is the advantages people acquire from ecosystems. The Sundarbans Forest ecosystem provides a source of livelihood for local people, as well as a variety of species and ecological services. It also directly contributes to well-being, cultural and life support functions (IPAC, 2010). It supports the livelihoods of local communities, protects biodiversity, and provides essential

ecological services. The forest also plays an important role in the cultural and spiritual lives of local people (IPAC, 2010).

According to (M. Rahman & Begum, 2013) the Sundarbans mangrove forest is one of the world's greatest biodiversity hotspots, home to multiple unique biomes. The biome has 1186 recognized living species (flora and animals) demonstrating the ecosystem's richness. Study of ecosystem services provided by Bangladesh's Sundarbans mangrove forest are essential for local human life, the country's economy, and the environment worldwide. Their aim was to investigate the effects that climate change has on all of the ecosystem services and to look into the potential for loss as well as opportunities in the future (IPAC, 2010).

(P. Dasgupta & McKenzie, 2020) studied the mangrove forest ecosystem provides several advantages, including food, fuel (wood, leaves), fiber (grasses), biochemical and pharmaceuticals (medicines and food additives), socio-cultural function (spiritual fulfilment and leisure activities), and biological variety.

The Sundarbans Reserved Forests (SRF) generate a wide range of non-timber forest products including as honey, medicinal plants, wax, golpata, grass and a significant quantity of fish, shrimp and crabs (BFD, 2010). Results from the study showed The Sundarbans Reserved Forests provide a great supply of food and other resources that people can collect and use. Good management is also needed because the mangrove forest is a significant ecosystem that delivers several benefits to the local community and the environment as a whole (BFD, 2010). The Sundarbans ecosystem services (combined contributions of biological variety and natural services) provide livelihood possibilities and life support functions to the inhabitants of this forest region through fishing, honey gathering, and fuelwood, timber harvesting (Ekka & Pandit, 2012). Almost 1 million tons of crabs, prawns, mollusks and finfish, or 1.1% of the total fish caught worldwide, are produced every year by small-scale fisheries in the waterways surrounding mangroves (Kathiresan & Rajendran, 2005).

(Uddin, 2013) studied the ecosystem services provided by the Sundarbans benefit both the economy and the well-being of people. (Uddin, 2013) also looked at the economic value of the ecosystem services provided by the Sundarbans is evaluated in this research, with a focus on

provisioning (timber, thatching materials, fish, fuel wood, crab, and honey), cultural (tourist), regulatory (protection function), and anticipated implications of climate change. Additionally, this study attempts to examine the dependence of livelihoods on the Sundarbans. Currently, the Sundarbans' forest-dependent communities are mostly involved in gathering fish, fuel wood, Golpata honey, (Nypa sp.), crabs and waxes. The Sundarbans directly support the livelihoods of 0.74 million people (IPAC, 2010).

The Sundarbans, the longest continuous mangrove ecosystem in the world, are located in the coastal zone (CEGIS, 2009) . The study was carried out in 16 districts along Bangladesh's coastline that are vulnerable to cyclone and tsunami hazards. Measuring the distance from the borders of India and Myanmar around the Bay of Bengal yields an estimate of Bangladesh's coastline's length of 710 km. Maximum land in the coastal zone is low-lying; 86% of it is below five meters in height, and 62% is less than three meters (CEGIS, 2009).

The Sundarbans is a valuable ecosystem that provides important resources and benefits to people in the region (WWF, 2017). It is home to a variety of fish and other aquatic species, which are essential for the livelihoods of many people and helps to protect the coast from storms and other natural disasters.

The mangrove ecosystems on the tropical and subtropical coast are highly significant ecologically. They provide substantial quantities of fishing resources and numerous essential forestry products, shield the coast from severe storms, tidal waves, coastal erosion, and seawater intrusion.(R. M. Rahman, Asaduzzaman, M., 2010).

2.2 Valuation of ecosystem services:

Understanding economic values is crucial in order to deal with the issue and management difficulties. It is commonly said that the benefits provided by the natural environment are widely recognized and poorly understood. (Daily, 1997). Raising society's awareness about the economic value of ecosystem services and biodiversity becomes important (Mooney et al., 2005). The overall economic valuation of the mangroves was done according to the classification by (Barbier, 1993).

(Barbier, 2008) refers an asset's economic worth is determined by how it contributes to the satisfaction of human needs, such as spiritual awakening, aesthetic enjoyment, or the creation of a marketable good. (Engel et al., 2008) stated that valuation is essential in developing markets for biodiversity and ecosystem services.

Ecosystem valuation assists in encouraging decision-makers to implement appropriate conservation measures for mangrove ecosystems (Walton et al., 2006). Economic information is important for planning and performing efficient and sustainable use of mangroves, because it helps us to understand the value of mangrove ecosystems and the costs and benefits of different management options (Uddin, 2013).

(Pearce & Pretty, 1993) refers economic agents evaluate the value of natural resources by determining their readiness to pay for the services, and this willingness to pay is largely influenced by the socioeconomic environment in which the valuation is being conducted.

According to (De Groot et al., 2002) there are four different types of economic valuation techniques. There are four different approaches: group valuation, contingency valuation, direct market valuation, and indirect market valuation. (Uddin, 2013) stated that the economic assessment of the Sundarbans' provisioning services has been calculated based on the yearly forest product harvest.

According to (Kabir, 2012) the market pricing technique, direct use resources are valued using the present market transaction prices. (Pender, 2010) stated ecosystems are the source of vast environmental, economic, and cultural value, and climate change affects them. The multiple goods and services that mangrove ecosystems give may be more thoroughly valued using methods for valuing environmental goods and services, which helps with decision-making (Spaninks & Van Beukering, 1997). Likewise, to the manner in which salt, shrimp and fish are priced, timber is valued at local prices after discounting input and extraction costs. The market value of traded wood and the collection costs of non-traded timber are used to value fuelwood. Utilizing labor for the purpose of collecting fuelwood has no opportunity costs (Gammage, 1994).

(DebRoy & Jayaraman, 2012) refers that the economic assessment of these specific mangroves assigned a representative value to the significant wealth associated with mangrove resources.

(Barbier et al., 2013) stated increasingly, researchers have been using economic valuation techniques to measure the delivery of ecosystem services, serving as a valuable resource for decision-makers and advocates of conservation. (DebRoy & Jayaraman, 2012) also stated that economic valuation studies also encompass the role of mangroves in serving as coastal defense mechanisms.

Considering the fact that the vast majority of research stated in the valuation literature concentrates on particular ecosystems and geography (Costanza et al., 2014). Ecosystem service valuation can serve as an essential instrument for emphasizing geographical and socioeconomic patterns of ecosystem service consumption across the coastal zone and for offering justifications for coastal conservation programs (Lele et al., 2013).

Assessing the economic value of ecosystem services is an essential tool for making informed decisions about how to protect and manage our natural resources (Vo et al., 2012). The establishment of protected areas is an essential tool for conserving mangrove forests, their purposes and benefits, as well as for preventing further mangrove decrease. Mangrove preservation is more economical than mangrove restoration (Webber et al., 2014). Ecosystem services are the benefits that people get for free from naturally growing ecosystems (Sarhan & Tawfik, 2018). To evaluate the value mangroves, provide to commercial fisheries, the production function method is commonly utilized (Barbier, 2003).

The valuation helps in determining the best course of action for a given situation, finding more cost-effective alternatives, and establishing the proper institutional and market (and non-market) instruments, such as compensation for ecosystem services (ICIMOD, 2011).

2.3 Tropical storm on Sundarban ecosystem

Nearly every year, the cyclonic storm has an impact on 10% of the Sundarbans. On the south side of the Sundarbans, the rivers' accumulations of sediment assist in recharging the soil (Mandal & Hosaka, 2020). Since 1995, Bangladesh's coast has been hit by 5 major cyclones: in May 1997, September 1997, May 1998, November 2007 and May 2009. Bangladesh experiences strong cyclones on average every three years (MoEF, 2009). Huge impacts occurred during the severe

storm events of 2007 and 2009, what caused this damage to forest land, as shown in the interpretation of later satellite images (Mondal & Debnath, 2017).

(Uddin, 2013) stated for countries in the Indian Ocean, tropical cyclones bring an enormous amount of risk. The most recent cyclone to do so was Cyclone Sidr, which hit Bangladesh in 2007 and caused over 6 million people impacted and over 3,000 dead. There were over 0.9 million dwellings damaged and about 0.3 million destroyed. The destruction of crops also included 0.35 million hectares (Uddin, 2013). According to (Awty-Carroll et al., 2019) in 2009, storm Sidr caused damage around 11% areas of the Sundarbans mangrove. (Awty-Carroll et al., 2019) also reported that the time it took for these wounded mangroves to regenerate was between six months and seven years.

According to (BFD, 2010) recent storms Sidr and Aila in the Sundarbans show that man-made climate change is already having an effect on the region and that additional climate change would make matters worse. Cyclone Amphan, which directly struck the Sundarbans on May 20, 2020 causes a significant reduction in the area covered by forest in 2020 (Chowdhury & Hafsa, 2022) .

The strong cyclonic storms and storm surges are regularly damaging Sundarbans which is constraining the typical seaward migration of Sundarbans by adversely eroding the shoreline (Thakur et al., 2021). Saline water infiltration, in addition to cyclonic storms, may be to blame for the recent decline in mangrove density (Quader et al., 2017). During dry seasons, the Sundarbans' present transformation of distributaries into waterways threatens a major freshwater shortage (S. Dasgupta et al., 2017).

More than 3.5 million people in the Sundarbans area depend on ecosystem services in either a direct or indirect way (Biswas et al., 2007; Giri et al., 2007). Also, Bangladesh's coastal communities and homes are in danger of being inundated due to storm surges brought on by severe storms. Future increases in the intensity of tropical cyclones are projected to result in more catastrophic storm surges and associated floods (Alley et al., 2007). Large numbers of people have been forced to relocate as environmental refugees due to the persistent flooding of farmland and the prevalence of cyclonic storms (Mahadevia Ghimire & Vikas, 2012)

2.4 Economic impact on ecosystem service & local people

According to (M. R. Islam et al., 2021) Sundarbans protect coastal regions, resources, and people from typical natural catastrophes in along with providing a wide range of ecological services. Bangladesh's coastal regions are likely to see the adverse impacts of climate change. (Chowdhury & Hafsa, 2022) reported that fragile islands observed in this study around the Bay of Bengal are proof of how sea level rise affects coastal erosion.

Ecosystem services are presented to have additional adverse impacts from climate change. Extreme storms and increasing weather variability are expected to make ecosystem services more vulnerable and have a greater impact on reliant, underprivileged communities (Iqbal, 2020). The Sundarbans ecosystem is important for its natural resources and ecological value, but it also provides 1.7 million people in the border villages of the Sundarbans with a likelihood for direct and indirect income and employment (Inskip et al., 2013). The kind, nature, and number of income-generating activities that are available to residents are progressively constrained the closer the village is to the Sundarbans (Murtaza, 2001).

According to (IPAC, 2010) the provisioning services (main forest products) and livelihoods that depend on the forest will be directly impacted by climate change in terms of employment, income level, and seasonality.

(Iqbal, 2020) stated that the probability that respondents choose an ecosystem services strategy for Bangladesh's Sundarbans is significantly impacted by the ecosystem services' composition. (Sardar & Samadder, 2021) refers the global mangroves are currently under continuous threat of deforestation with an annual loss of 1-2% caused by natural catastrophes, climate change, and human action. This is despite the fact that mangroves naturally shift downward or seaward to respond to changing conditions (Sardar & Samadder, 2021).

Changes in appropriate habitat for plant and animal species, changes in hydrological patterns, changes in salinity, and changes in sedimentation patterns are the principal effects of climate change on the Sundarbans mangrove ecosystem services (CEGIS, 2005).

(M. Rahman & Begum, 2013) also studied that it is a habitat for multiple globally vulnerable species, including the rare Ganges River dolphin, the water bird, the Bengal tiger, and several

animals. It helps with land reclamation, protects coastal habitats from storms and tidal surges, and improves the socioeconomic status of coastal residents.

2.5 Adaptation strategies

About 93% of respondents agreed that mangroves are important in mitigating storm damage, and they also agreed that the mangrove forest should be preserved (Akber et al., 2018). The mangrove forest's storm protection function has been highly recognized in Bangladesh's National Disaster Management Policy, and the policy has underlined the need of conservation efforts to lessen the impact of cyclones (Akber et al., 2018)

To maintain ecological and social system fluctuations, livelihoods should conform to the conservation and management of natural resources (Allison & Horemans, 2006). Lack of capable and qualified authorities and poor planning and knowledge of coastal land use; failure of institutions to effectively manage coastal mangrove resources and conflicting activities; implementation of a development plan that does not include environmental protection principles are the three main management failure reasons contributing to the extinction of the mangrove forest (M. M. Rahman et al., 2010).

According to (IPCC, 2012) the adverse impacts on sustainable growth can be mitigated via the use of mitigation and adaptation strategies, which together have the potential to maintain these risks at a moderate instead of a high level.

(Akhtaruzzaman, 2004) stated the management failure is exacerbated by local political leaders' collusion with encroachers and the carelessness and corruption of government forest department officials.

Providing disaster-resistant housing to the people of Sundarbans, to the degree practicable, and building additional catastrophe shelters would be a beneficial long-term mitigation strategy. (Mahadevia Ghimire & Vikas, 2012). Also stated that once this delineation is complete, residents of the Sundarbans' high-risk zones can be moved to safer inland places (Mahadevia Ghimire & Vikas, 2012).

There have been several publications and studies highlighting the need to manage this species, but no formal management plans have been implemented (Berkowitz, 2014; Ernst & Ketner, 2007).

2.6 Common Pool Resources

The bulk of the world's land, water, forests, and fisheries (CPR) are considered to be "common pool resources" (CPR). Invasion and theft of these resources are common because to the inequitable distribution of CPR benefits, which in turn drives an opportunistic and exploitative approach to resource management. Overuse of the commons is a problem that may be mitigated in many situations, according to Ostrom and other experts, by establishing self-governing institutions. They also provide some design ideas that may be used to build robust and resilient systems. They also note that governments have to take on substantial roles for self-governance to work. (Pretty, 2003) makes a similar point, noting that communities can work together to manage a CPR sustainably; however, they may need assistance from a higher level of authority in order to acquire the specialized skills necessary to manage the resources. To solve the issues of CPR and develop sustainable natural resource management, we need group effort. Collective action occurs when a large number of individuals work together to achieve a common objective. The overall objective would be to ensure the sustainability of the resources by limiting their consumption.

2.7 Tragedy of common

The tragedy of the commons is the idea that when numerous actors use a productive common-pool resource at once, the ensuing externality would cause the resource to be used beyond its optimal condition. This idea was first proposed by (P. K. Dutta & Sundaram, 1993). The tragedy of the commons is now generally acknowledged in many academic fields, including resource science and policy, economics, ecology, and politics. as reported by (McCay, 1990).

Since Hardin's seminal work in 1968 (Ostrom, 1999), the term "the tragedy of the commons" has been used to describe issues related to the overuse and deterioration of natural resources including

the destruction of fisheries, the overexploitation of forests, and the pollution of water supplies. Hardin's "The Tragedy of the Commons" concept predicts that public resources will be overused or degrade over time. Given the reliability of this prediction, it's not surprising that users have successfully negotiated restrictions on their access to the resource and agreed upon standards for its sustainable administration among themselves in many cases (Hardin, 1968).

When it comes to maintaining high levels of trust while also keeping tabs on activities and punishing those who break the rules, effective governance systems do better than their less efficient counterparts. Instead of trying to fix the "tragic" problems that plague the commons, we should focus on preventing them (Ostrom, 1999). In his ruling from 1977, Hardin argued that the commons might be converted into private property or preserved as public property while maintaining the rights of access and usage (Hardin, 1968) in order to avert the disaster.

2.8 Common Pool Resource Management

In order to test the empirical universality of the accepted theory, a number of baseline laboratory experiments have been developed using the framework of Gordon's time-independent model (1954). In these control experiments, participants allocate investments to the common pool resource that are much above optimal. As anticipated, there is a significant rent dissipation. Cooperative CPR management teams might use techniques from cooperative game theory as its foundation. The most stable and likely methods for forcing cooperation among CPR receivers may be found using a number of techniques, such as the Nash cooperative solution, Shapley solution and nucleolus approach, and social planner solution. As opposed to the basic concept of homogenous appropriators obtaining one type of resource unit from an ecosystem system that creates a consistent flow of units, many common-pool resources in practice exhibit far greater levels of complexity and illustrate a wide variety of settings where appropriators dependent on common-pool resources have organized one another to achieve much higher outcomes than are predicted by the theory described above (Cordell, 1989; Sengupta, 1991; Wade et al., 1994).

2.9 Localized Common Pool Resource Management

According to Elinor Ostrom, farmers with enduring ownership claims are able to grow greater quantities of rice, share water more fairly, and maintain their systems in better condition than those who rely on government systems. They are also more likely to be able to communicate, develop their own agreements, designate positions for monitors, and sanction people who do not follow their own rules. There isn't yet a completely developed, reformed theory that includes conventional theory as a particular instance. On the other hand, academics acquainted with the findings of field research mostly concur on a set of factors that increase the possibility of resource appropriators arranging themselves to avoid the social costs associated with open-access, common-pool resources (Ostrom, 1990; Schlager, 1990). Given the complexity of socio-ecological systems, the multisite controlled trial design for this study on community monitoring offers a novel way to examine the consequences of CPR governance frameworks. As an outcome of community monitoring, resource usage is reduced somewhat but considerably (Slough et al., 2021).

Chapter 3: Study Area Profile

3.1 Study Area Location

The Sundarbans is located in the huge delta on the Bay of Bengal which resulted from the meeting of the three major rivers of the subcontinent which are the Ganges, Brahmaputra, and Meghna. It is located in Bangladesh's southwest, between longitudes 89002'00 and 90000'00 East and latitudes 21027'30" and 22030'00 North. It falls within Khulna Circle and encompasses slivers of the districts of Bagerhat, Satkhira, and Khulna. The Indian Sundarbans are next to the western boundary, which follows the Hariabhanga, Raimangal, Kalindi rivers. The Sundarbans meet the Bay of Bengal and two border lines in the south. The Baleswar River borders it to the east, while to the north, there is a pronounced boundary with heavily populated and farmed terrain.

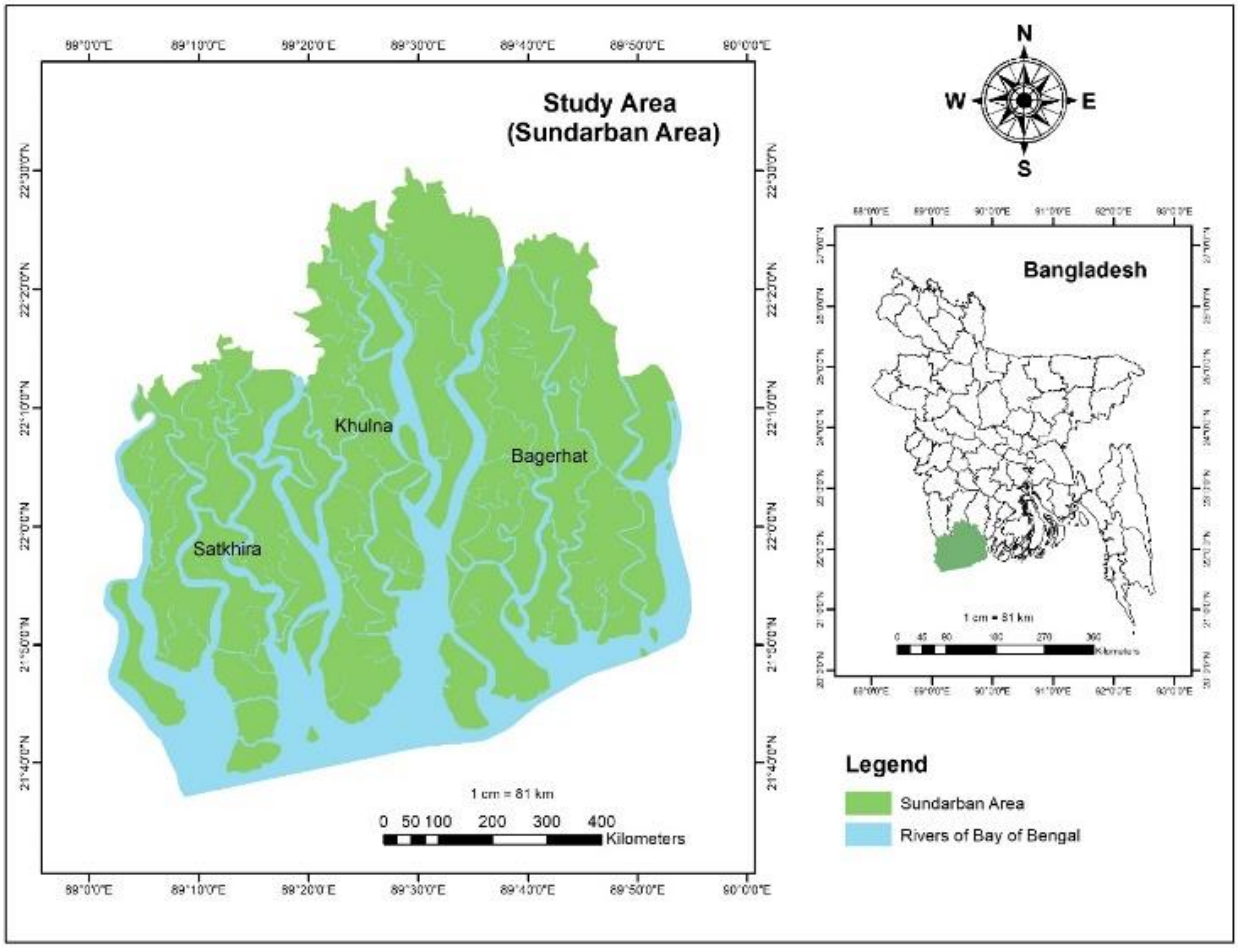


Figure 3.1: Sundarban mangrove forest

Source: Author's preparation (2023)

3.2 Validation for Selecting Study Area

The Sundarbans serve essential ecological services and could potentially be economically valuable. It is a part of indigenous culture as well. (M. S. N. Islam, 2009). Traditional coastal livelihoods rely on Sundarbans' natural resources. The major source of food that the residents obtained from the Sundarbans was fishing, which was followed by the collection of fuel wood, crab, honey, and Golpata (Walters et al., 2008). Climate change is expected to directly and indirectly endanger the mangrove ecosystems. According to IPCC predictions, with some regional variance, 20% of coastline habitats will be lost to sea level rise by the year 2080 (Gitay et al., 2002). Tropical storms, which include cyclones, floods, tidal surges, ineffective management, excessive exploitation, and changes in hydrogeology, are the major causes.

However, the Sundarbans are under peril from both human and natural causes. The Sundarbans region is particularly vulnerable to the rise in sea level caused by climate change and other natural phenomena (Gilman et al., 2008). The most biodiverse areas of the Sundarbans would decline from 60% to 30% in the year 2100 with an increase in sea level of 88 centimeters. (CEGIS, 2005). In the worst case scenario, 84% of the Sundarbans may be submerged by 2050 due to a rise in sea level of 32 cm, and the whole region might be devastated by an increase in sea level of 88 cm by 2100 (Nur Mohal et al., 2006).

The most significant but most ignored factor is the absence of an economic assessment of ecosystem services. The economic evaluation of ecosystem services receives consistently less attention, which leads to a lack of awareness and sincerity regarding ecosystem services. Which accompanies poor service management. When a tropical cyclone strikes, the ecological damage or environmental effects receive the majority of attention, but the economic damage is consistently understated. So, in order to assess the economic impact of tropical storms on the mangrove and managing the common pool resources through community management Sundarban is taken as the study area.

3.3 Study Area Description

The central region of Bangladesh's Sundarban was designated as Sundarban Reserve Forest (SRF) under the British era in 1875. It has an area of around 6,017 sq. km, including about 4,143 sq. km of land and 1,874 sq. km of water, and is administered by the Forest Department. The buffer zone, which is 10 km wide and covers an area of around 175,000 hectares along the northern and eastern edges of the SRF, was designated an Ecologically Critical Area (ECA) by the Bangladeshi Ministry of Environment and Forest in 1999.

Geography

10,000 square kilometer (3,900 sq mile) of the Sundarban forest are covered, of which 6,517 square kilometer (2,516 sq mile) are in Bangladesh. The SRF's soils are a combination of tidal marine deposits and deposits from deltaic floodplains. A silty clay loam makes up the top soil layer, which is overlaid by alternating clay and sand layers. According to IFMP (1998), soil fertility generally declines from east to west and from north to south. The Sundarbans' north and east regions retain a relatively high fertility through yearly silting. The subsoil of these soils is composed of alternating layers of clay and sand, and they are silty clay loam that has a mild saltiness. The most prevalent textural class appears to be silt, and grain size is higher in eastern than western woodlands.

Flora & Fauna

334 plant species and 245 genera in all were identified. The sheer number of sundari (Heritiera fomes), gewa (Excoecaria agallocha), goran (Ceriops decandra), and keora (Sonneratia apetala) that are all widely distributed throughout the region define the Sundarbans flora. The sundari (Heritiera littoralis), which is the forest's emblematic tree, is likely where the name of the forest came from. Dhundul or passur (Xylocarpus granatum) and kankra (Bruguiera gymnorhiza) are both in great supply, but distribution is uneven.

At least 150 kinds of economically significant fish, 270 bird species, 42 mammal species, 35 reptile species, and 8 amphibian species are supported by the Sundarbans, while new species are constantly being discovered. This contains a number of species that are now extinct in other parts of the nation and constitutes a sizeable fraction of the species that are found in Bangladesh (about

30% of the reptiles, 37% of the birds, and 34% of the mammals). Five mammals, two amphibians, 14 reptiles, 25 birds, and two reptiles are all in danger.

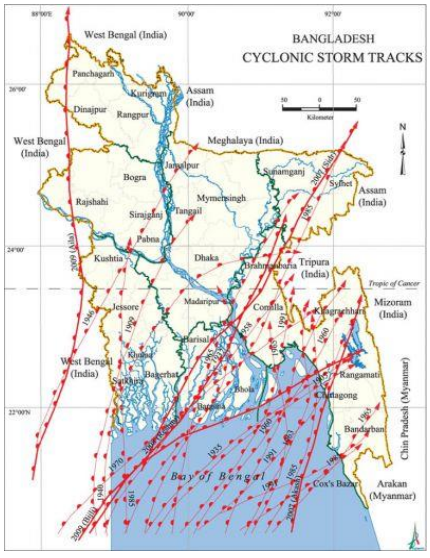
Climate

The Sundarbans' annual mean maximum and lowest temperatures were 12.75°C and 28.44°C, respectively, for a ten-year period from 2000 to 2009. The two hottest and coldest monthly temperatures were 36.6 °C in April 2009 and 11.9 °C in January 2010, respectively. Rainfall is very heavy, especially in Sundarban where the average annual rainfall is 1920 mm during the monsoon season. The area has a comparatively high humidity level. The yearly average humidity was measured as 81%, with the greatest and lowest humidity readings of 90% in April 2000 and 65% in January 2005, respectively.

3.4 Tropical storm

Bangladesh is on the front lines of the climate change problem because storm surges, congested drainage systems, and sea level rise all have a direct impact on its coastline. (Alley et al., 2007). In addition to saline intrusion, increasing sea level, river erosion, water logging, and high tides, the Sundarbans Region of Bangladesh is vulnerable to cyclones, storm surges, floods and other climate change effects. Here is a map representing the tracks of cyclones in Bangladesh. From where it is seen than maximum of those cyclones first hit Sundarbans.

According to (Saudamini Das & Vincent, 2009), one crucial ecosystem function provided by the mangrove ecosystem is its capacity to lessen storm damage. Wide mangroves may significantly reduce storm



Source: Banglapedia

Figure 3.2: Cyclonic storm tracks of Bangladesh

surges and wind speed, according to (Krauss et al.,2009), and mangroves operate as a buffer to protect coasts from waves and storms (Granek & Ruttenberg, 2007) Due to its typical geophysical configuration, Bangladesh's whole coastline region is especially susceptible to tropical cyclones (Murty & Neralla, 1992). Over 70 significant cyclones struck coastal Bangladesh in the previous 200 years (Mallick & Vogt, 2009). Several sources have noted the devastation caused by recent storms Sidr, Reshmi, and Aila on the Sundarbans (Islam 2013) (Deb & Ferreira, 2017; D. Dutta et al., 2015)

Chapter 4: Methodology of the study

4.1 Research Methodology

The research methodology is like the main basement of conducting research. The probability of reaching the exact research goal is highly dependent on the whole approach. In order to reach to the certain goal, first need to attain the research objectives which can be obtain be following some steps. This methodology chapter introduces from the steps for concept building to reach the certain goal of the research.

4.2 Objective Base Analytical Approach

In order to attain certain goals through completing each objectives this chapter includes approaches and particular data collection method and sources. Formulation of this is necessary to obtain particular objective more effectively and efficiently.

Table 4.1: Objective base analytical approach

Objectives	Data	Data Collection Method and Sources	Approach
1. To assess the economic value of provisional ecosystem services of Sundarban.	• Provisional Ecosystem Services • Economic Valuation	• Official Record of Forrest data • IUCN, IPAC, BIPS, CEGIS, BWBD	• Direct Valuation Method Market Price Method
2. To quantify the economic losses of ecosystem services and losses incurred to the local communities due to tropical storms.	• Tropical Storms • Impact on ecosystem services • Impact on Community	• Official Record of Forrest data • Article, Journals • QS, FGD, KII	• Direct Valuation Method • Indirect Valuation Method

3. To evaluate the effectiveness of existing measures and to propose strategies in managing the common pool resources in a sustainable way.	• Existing Initiative • Scope of improving Measures • CPR	• QS, FGD, KII • Articles, Journals	• Group Evaluation • CPR management • Localized CPR management

4.3 Objective base framework

4.3.1 Pre field work

This is the preliminary stage of the research and indeed an important phase which includes preliminary literature review to building concept of the study, study topic selection and more works related to selection of objectives and collection of necessary secondary data.

4.3.1.1 Primary literature review

Primary literature review is done in order to review various researches and articles from various field. Articles and papers from different sectors and different aspects from different countries have been reviewed.

4.3.1.2 Concept building

By reviewing several articles on different perceptions several problems are visible to authors. Within these problems related to Sundarban get more vision for different aspect like climate change impacts on the biodiversity and local people, less importance to the ecosystem and less focus on the valuation on the ecosystem services. As so, economic impact of tropical storms on Sundarbans ecosystem services is taken as the study topic.

4.3.1.3 Identification of the study area

Generally, the whole Sundarban of the Bangladesh portion is the study area. But for communication with the local people who directly connected with the ecosystem services of Sundarban and lead their livelihood two villages just near the Sundarban has been taken. Before finalize the villages as study area general review of the study area is done to make sure the local

people are really impacted by the tropical storms by disturbance in extraction of provisional services from Sundarbans.

4.3.1.4 Formulation of the research objectives

As the study topic and area is selected to obtain particular research goal so some research objective is formulated to lead step by step to reach the certain goal. The objectives are to valuation of the provisional ecosystem services of Sundarban, quantify the economic impact of tropical storms on the ecosystem services and the local people and assess the existing mitigation measures and propose some effective management policy.

4.3.1.5 Literature review

In literature review stage more detailed literature review is done in order to go through the steps to reach each objective and attain certain goal. Actually, more detailed literature review is done in order to go deep through the study topic and explore more techniques, models and framework to complete each objective to reach the selected goal of the study.

4.3.1.6 Collection of Secondary data

Secondary data are collected from various research articles, policy plans like IRMP, Bangladesh Bureau of Statistics (BBS), Forest Department (FD), CEGIS and other organizations.

4.3.2 Field work

Primary data

4.3.2.1 Reconnaissance survey

A reconnaissance survey is done in order to understand the study area. It actually helps in selecting the approaches following which the data collection process will be more effective and efficient. And this preliminary reconnaissance survey makes sure that the collected data are precise and usable.

4.3.2.2 Questionnaire survey

A questionnaire survey is done to get information about the livelihood information about the different ecosystem products collectors. The questionnaire includes the questions related to the income information before, during and after the tropical storms or difficult situation. Randomly selected 40 households is taken who are directly associated with collection of ecosystem services of Sundarban to collect livelihood data.

4.3.2.3 Focus group discussion

Two Focus group discussions is done in two villages in order to understand the perception of the local people about the ecosystem services. Along with this FGD is done to list out the prices of different ecosystem services and to assess the resource collection methods, disturbance and difficulties arises during the extraction due to tropical storms and other reasons. The existing adaptation measures and their effectiveness and the possible management practices related data are collected through FGD. And the respondent's perception and advises about the common pool resources and localized common pool resource management is also assessed.

4.3.2.4 Key informant's interview

An officer from Forest Department helped in providing importance information and facts related to the ecosystem services and their collection and people related to their collection. Information from the FGD about the prices and other things are also cross checked with the information of the officer from FD. Another person worked several years for counting Royal Bengal Tiger and presently worked in the tourist spot as guide provide various information from various perspective about the conflicts of common pool resources and important observation.

Secondary data

4.3.2.5 Ecosystem services data

From Forest Department various data including yearly extraction and revenue generated from the ecosystem services range in between 2011 to 2021 is collected. From CEGIS the information related to SLR condition and other situation is collected.

4.3.2.6 Ancillary data

For representing the impacts and other data more effectively, important maps, diagrams related to the ecosystem services and tropical storms are collected from CEGIS and Forest Department.

4.3.3 Post field work

4.3.3.1 Compilation of the data

Data collected from the various primary and secondary sources are compiled. In order to analyze these data and interpret it more understandably statistics tools are used. SPSS, Microsoft Excel is used to analyze these data and formulate graph, charts, table to represent the data in more effective way. Land cover map and other study related map is processed by using ArcGIS 10.5.

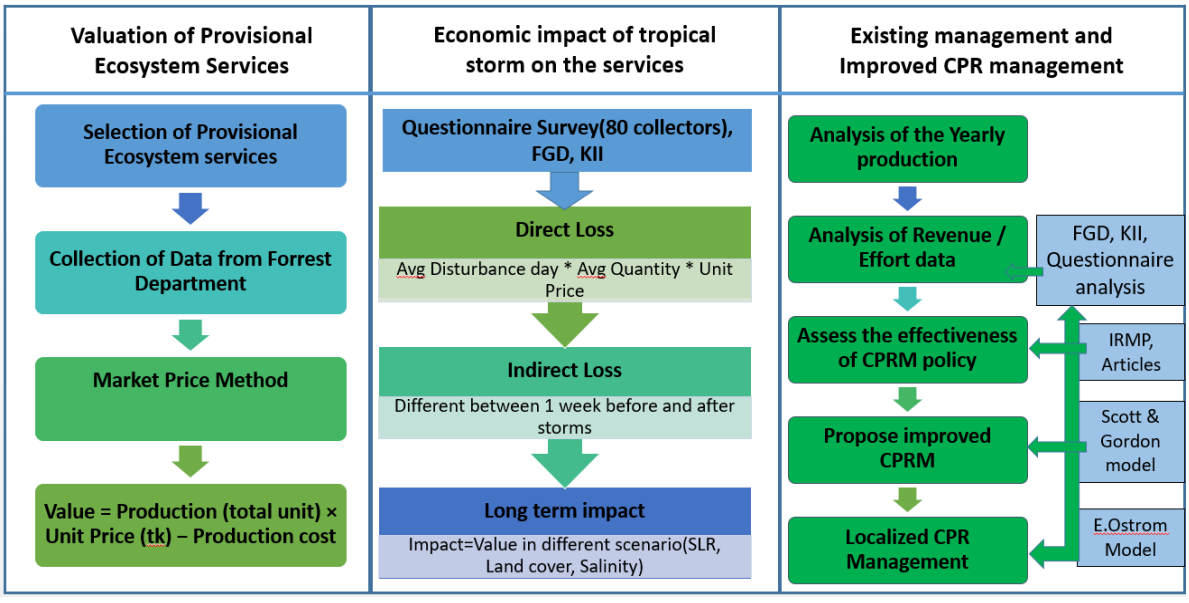
4.3.3.2 Findings from the data

After data analysis and interpretation, the findings from the analysis are list out. And assess the effectiveness of these data in various aspect related to tropical storm management, common pool resource management by local people by following Gordon and Ostrom rule of resource economics.

4.3.3.3 Recommendation

By interrelating the data, effectiveness in several condition in present days is assessed. In Environmental resource economics there are many models and rules to apply effective management policies to common pool resource management with community people who are directly involved.

Table 4.2: Methodology of the study



4.4 Ecosystem Services Valuation

4.4.1 Ecosystem Services Identification

Sundarban contains various ecosystem processes in its biodiversity. But within these only those which are directly or indirectly connected to human benefit and approved by the Forest Department and local people who lives their livelihood by these can be called ecosystem services. Fisheries, crabs, shrimp, timber species, honey and wax, thatching materials etc. are considered as provisional ecosystem services. And with approval from the forest department and local people the ecosystem services which are considered in this research is listed.

4.4.2 Valuation of Provisional Ecosystem services

All the provisional services including fish, timber, crab, honey, thatching materials are valuable and easily tradable in the market which means all have market prices. As the first objective is to valuation of the provisional ecosystem services it is important to fix a method to evaluate the provisional ecosystem services. Market price method is one of the direct valuation methods which is appropriate for valuation of the provisional services. The exchange rate in the market is assessed and conduct the valuation of the goods related to provisional ecosystem services. Records from Forest Department about the extraction of the ecosystem services are available and using these data the yearly valuation can done easily. As so the yearly data of extraction and revenue from the ecosystem services are used in between 2011 to 2021.

So Total Economic Value (TEV) of fish, crab can be evaluated by:

FV, CV = Production (kg/year) × Price (USD/kg) − Production cost (USD)

Total Economic Value (TEV) of Timber, Firewood can be evaluated by:

FwV = Wood collection (bundle/year) × Price (USD/bundle) − Production cost

(USD) (1 bundle = 100 stems with a length of 1 m and a diameter of 4 to 8 cm)

Total Economic Value (TEV) of Honey and wax can be evaluated by:

HV, WV = Production (kg/year) × Price (USD/kg) − Production cost (USD)

4.4.3 Quantify the economic impact due to tropical storms

Impact of the tropical storms on the Sundarbans biodiversity is clear to all. And the tropical storms also impact by the direct damage to the services as well as creating disturbance and obstacles in extracting the services. By comparing reduce in extraction of provisional services from different temporal situation during tropical storm days the economic impact can be assessed from the collector's perspective. The direct impact, and aftermath of the storms and long-term effects can be assessed. Long term impact can be assessed by analyzing the land cover change data as well as the yearly SLR data which causes the change in production of the ecosystem services.

4.4.4 Adaptation Measures

By evaluating the management plans regarding the adaptation measures to cope up with the tropical storms effect as well as sustainable common pool resource management, the effectiveness of the plans and policies can be assessed. Various policy integrated by local government or forest department are there. By following the impact scale, the production rate, revenue rate in several temporal variation the effectiveness of the measures is assessed. The comments from the local people about the efficiency and effectiveness of the adaptation and management measures to tropical storms impact are assessed.

4.4.5 Common Pool Resource Management

4.4.5.1 Fish and aquaculture

For common pool resource management, firstly the existing management strategies is evaluated. The effectiveness of the policies, rules, regulation and programs are assessed by comparing the production and revenue rate in several temporal variation. By increasing effort and advance technology the production should be increase in day by day if common pool resource management is good enough. If the production and revenue rate is not increasing as it should be then economic model of Gordon and Scott should be used. In their model all the assumption is done based on the estimated maximum sustainable yield.

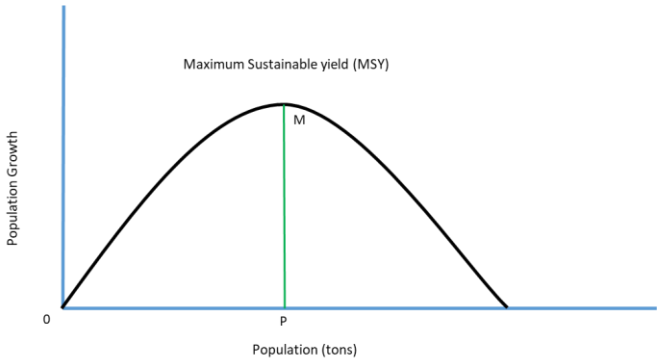


Figure 4.1: Maximum sustainable yield

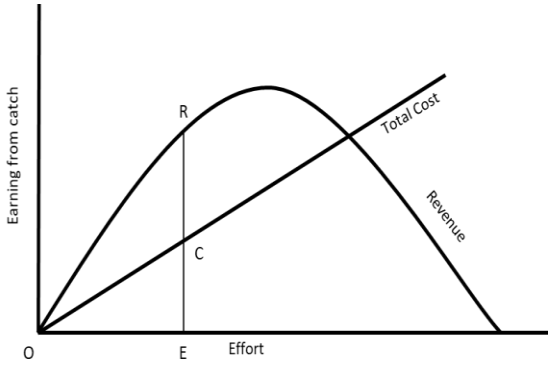


Figure 4.2: Maximum sustainable revenue

Source: Author's preparation (2023)

4.4.5.2 Trees

The Sundarban Reserved Forest's Annual Allowable Cuts (AAC) for several species were calculated using the following formulas:

- AAC = (Present standing mature volume + half increase throughout the period)/Cutting Cycle Period.
- According to the Austrian formula: AAC = I + (Ga - Gr)/A

Where I = Annual growth,

Ga = current growing stock, and Gr = desired growing stock.

A = Adjustment period, which might be a whole cycle or a particular time frame.

In this case, just the increment may be gathered if Ga = Gr.

4.4.5.3 Localized Common Pool Resource Management

Elinor Ostrom set some principles and focused on some major points which should be follow to manage the common pool resources in an efficient way by involving the local people. According to Ostrom without local community people's involvement the best possible policy making regarding sustainable management of common pool resources is not possible. So, the local people related directly to the Sundarbans ecosystem to live their life are involved and their suggestion and recommendations are followed in this study. Principles of Ostrom's theory which should be followed;

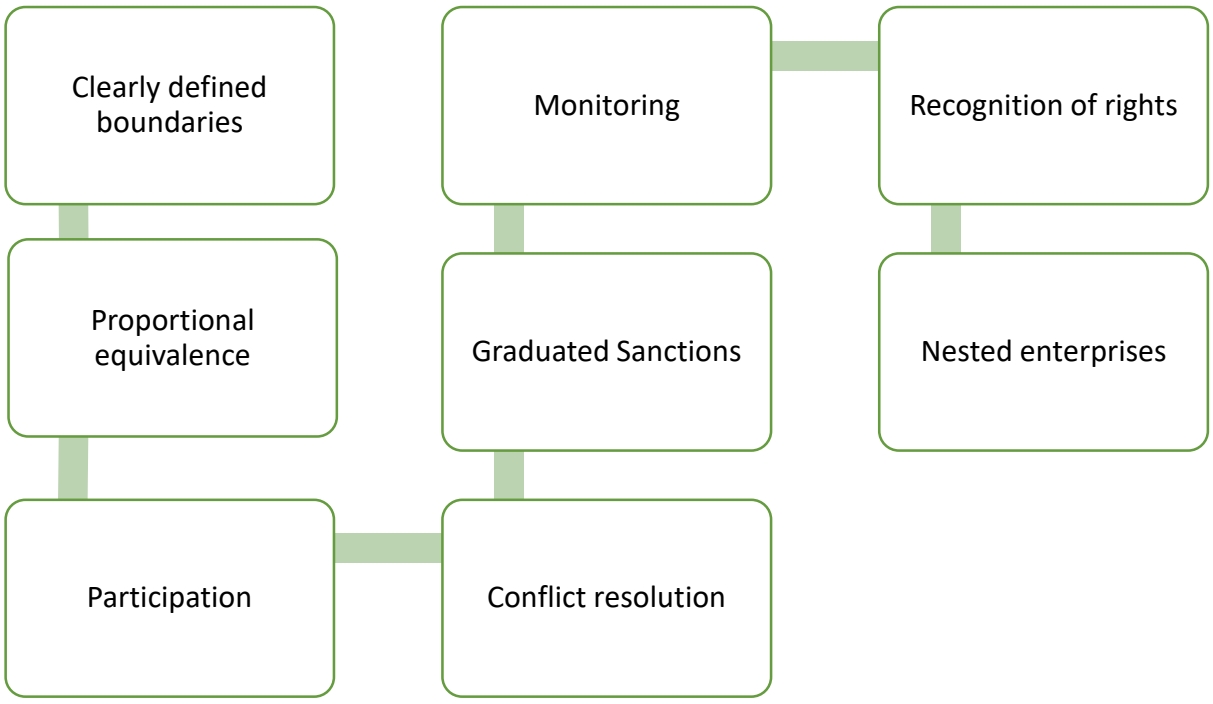


Figure 4.3: Ostrom's principles for CPRM

Chapter 5: Result and Discussion

5.1 Valuation of provisional ecosystem services

5.1.1 Timber

The graph and charts give information on the timber extraction and income from the Sundarbans during a 12-year period, classifying the timber into "Round timber (Sunduri, Bine, Keora)" and "Gewa." This information provides insights into the trends in the harvest of timber from this critically important ecological area.

First of all, the majority of the timber extracted in the Sundarbans is "Round timber," which includes timber species including Sunduri, Bine, and Keora. The extraction volume was significant in 2010-11 at 4,088.03 cubic units, but it gradually decreased over time, reaching its lowest level in 2021-22 at 156.44 cubic units. This loss could be the result of careful timber harvesting practices meant to preserve these priceless species and guarantee long-term viability. The fact that "round timber" profits predominate the overall revenue from wood extraction underlines the importance of species like Sunduri, Bine, and Keora. Even though it fluctuated over the years and reached a sizeable Tk. 2.07 million in 2010-11, it continued to be the main source of the overall revenue.

The harvest of "Gewa" timber, in contrast, showed irregular trends and changing levels of exploitation from year to year. There were times when the extraction was rather substantial, such in 2016-17 when the Gewa timber extraction totaled 7,435.31 cubic units and made a significant contribution to the overall timber extraction for that year. Although it is less significant in contrast, "Gewa" wood revenue demonstrates its significance, especially in years where significant contributions are made. For instance, Gewa timber income in 2016-17 was Tk. 0.24 million, which made it a significant contributor to overall revenue.

The data shows that the amount of timber taken and the money generated have an approximate correlation value (r) of 0.68, indicating a significantly favorable connection among these two variables. There has been a noticeable pattern over time where the amount of timber extracted tends to match the money produced. The income is proportionally larger in years with higher extraction levels, such as 2010-11 and 2016-17. The money earned is also lower in years with lesser extraction, such as 2012-13 and 2021-22. This alignment emphasizes the anticipated relationship between the volume of timber extracted and financial results.

Source: Google, Afrin Naz

Figure 5.1: Timber extraction

It's crucial to keep in mind that while the correlation shows a positive correlation, it isn't perfect. The amount of money made from wood extraction can be influenced by a number of other variables, including market circumstances, timber quality, and price swings. Government laws and sustainable harvesting methods may also have an influence on the extraction rates.

The following graph illustrates, in summary, a moderately favorable correlation between the quantity of timber extracted and the money made in the Sundarbans. It emphasizes the value of timber as a resource for the local economy while highlighting the relevance of sustainable management techniques to preserve the Sundarbans' long-term sustainability and ecological preservation.

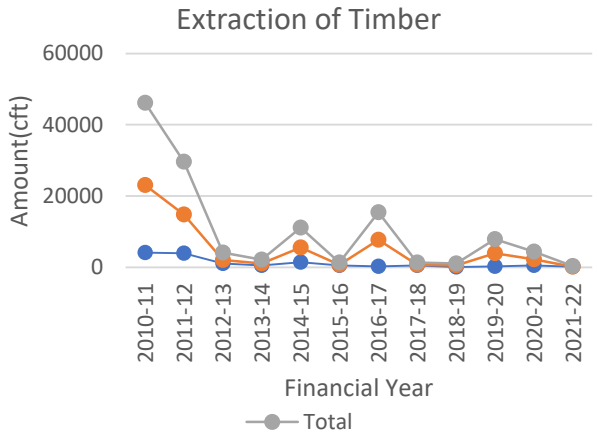


Figure 5.2: Amount of timber

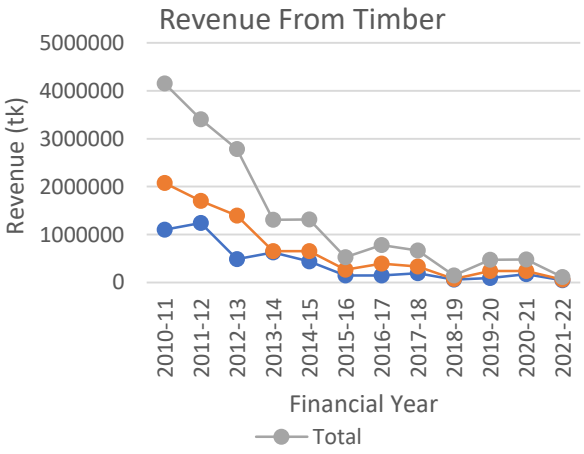


Figure 5.3: Revenue from timber

Source: Author's preparation (2023)

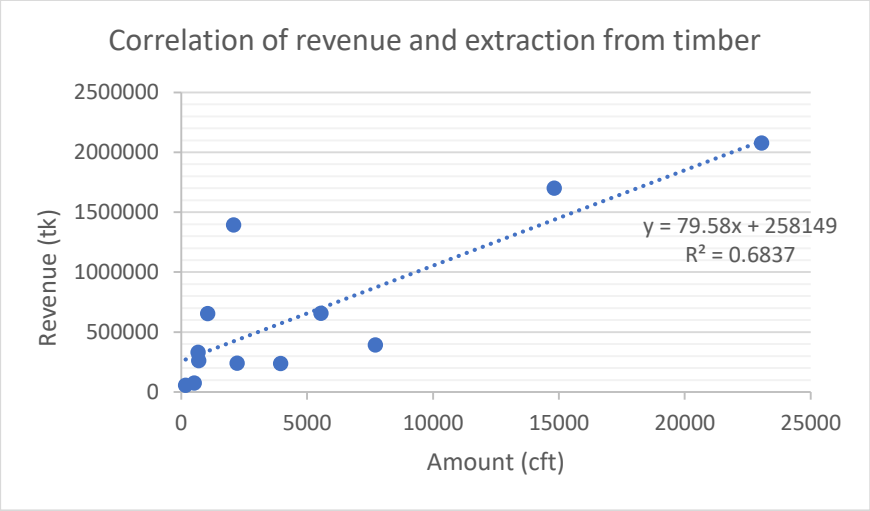


Figure 5.4: Correlation of revenue and extraction from timber

Source: Author's preparation (2023)

5.1.2 Fish

The graph gives information on the number of fish harvested in the Sundarbans over a 12-year period and the money that was made from it. A significant rise in the number was seen in the first two years, from 2010 to 2011, with a major increase from 152,309.7 maunds to 186,471.38 maunds. However, this increased trend was only short-term, as the amount significantly decreased to 146,259.33 maunds in 2012-13. There was a discontinuous trend with variations in the quantity from 2013-14 to 2015-16. The highest according to amount during this time period was 179,731.7 maunds in 2013-14, while the lowest was 126,426.2 maunds in 2014-15. The number significantly decreased in 2017-18, reaching 108,048.80 maunds, one of the lowest figures during this time period. However, the volume increased somewhat in 2018-19, reaching 112,041.76 maunds. In 2019-20, while the recovery was still going strong, the quantity increased to 114,163.13 maunds. Despite small changes, the most current data, from 2020-2021-2022, shows a resumed increase trend, with the quantity rising from 131,890.52 maunds to 127,868.81 maunds.

Source: Field survey (2023)

Figure 5.5: Catching of fish

The revenue has shown various trends over the last twelve financial years, showing changes in its financial performance. Beginning in 2010-11 and continuing through 2012-13, there was a generally upward trend in revenues, which peaked in 2010-11 at Tk. 62.14 million. However, when the revenue started to fall off starting in 2013-2014, a new trend started to develop. The revenue didn't recover until 2015-16, when it fell to its lowest level of Tk. 37.91 million. It's interesting to consider that this trend reversed in the following years, with income increasing to Tk. 41.38 million in 2016-17. Unfortunately, this upward trend was only short-term, as revenue declined again in 2019-20, to Tk. 35.54, maybe expressing some economic difficulties at the time. However, the most current data shows a notable rebound, with the revenue significantly growing in 2020-21 to Tk. 60.07 million and then further rising to Tk. 63.17 million in 2021-22. These two years of increase may indicate improved economic conditions or carried out strategic improvements.

So, the revenue data shows an early phase of expansion, followed by a decrease, stability, and a later rebound. Positive revenue patterns during the past few years can be a result of efforts or adjustments that were successful in improving financial performance. Making wise financial decisions and future planning needs an understanding of these patterns. The number of fish removed and the income have a correlation value (r) of about 0.05, which points to a very slender positive association between these two variables. When looking at the statistics, it is clear that there are annual variations in the quantity of fish extracted, and that these variations are not always accompanied by changes in revenue. For instance, the number of fish removed in 2020-21 increased significantly, while the amount of money was made far more than in prior years. In contrast, the quantity of fish removed in 2017-18 and 2018-19 stayed largely stable, although the

income varied significantly. Market circumstances, fish quality, price swings, and outside economic influences are just a few of the causes of the sluggish association between the quantity of fish extracted and income. The fishing sector in the Sundarbans may also be impacted by factors that are not taken into consideration in this correlation, including as changes in fishing techniques, governmental regulations, and environmental concerns.

In the Sundarbans, the statistics indicate a very weak positive association between fish extraction and income, showing that there are other complicated elements besides merely the amount of fish taken that have an impact on the money gained from fish harvesting. To better comprehend the dynamics of, it would be required to do a more thorough study that takes into account these external variables.

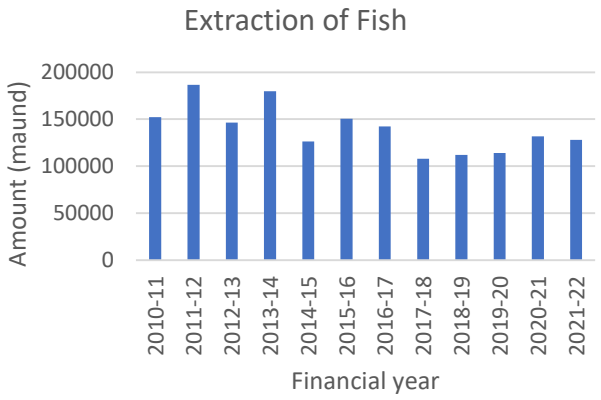


Figure 5.6: Amount of Fish

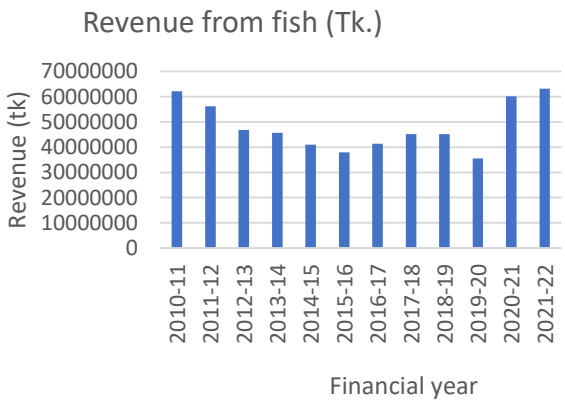


Figure 5.7: Revenue from fish

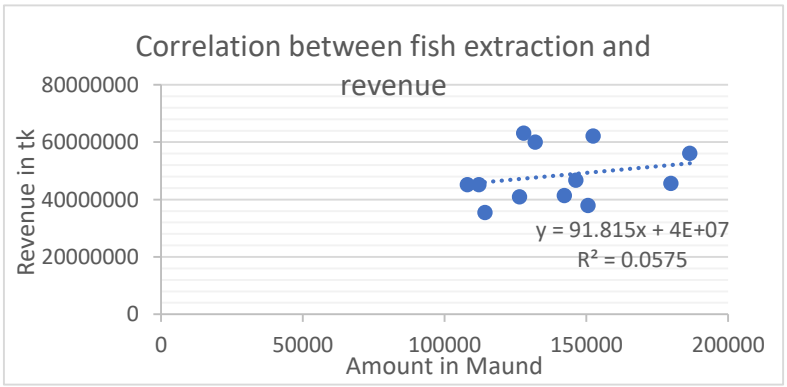


Figure 5.8: Correlation between fish extraction and revenue

Source: Author's preparation (2023)

5.1.3 Thatching Materials

The following chart gives a thorough description of the quantity of thatching materials collected from the Sundarbans during a 12-year period, notably Malia Grass/Shan and Golpata, as well as the revenue that they earned.

First off, both the revenue and the volume of extraction have changed noticeably and significantly over time. The extraction volume reached its peak in 2010-11 at 732,157 maunds, generating a large profit of Tk. 6.83 million. The following years saw a severe fall in this abundance, which reached its lowest level in 2015-16 with just 34,055.572 maunds harvested and Tk. 1.86 million in income. This declining trend can be a sign of problems with overharvesting or environmental variables that impact the availability of these resources.

It's interesting to see that from 2015-16 onward, both extraction volumes and income have gradually increased. By 2021-2022, extraction totaled 41,539.72 maunds, with income of Tk. 1.5 million to go along with it, indicating better resource management techniques or probable replenishment of natural resources.

Figure 5.9: Collection of golpata

Source: Field survey 2023, Google

The quantity of thatching material collected and the money generated are positively correlated, with an estimated correlation value (r) of 0.71 showing a reasonably strong positive link. Looking at the statistics, it is clear that there is a general tendency toward growing income with more extraction, highlighting the significance of these resources from an economic standpoint. The high in both extraction volume (291,398 maund) and income (Tk. 2.71 million) in 2013-14 reflects a

particularly prosperous time, maybe fueled by increased demand or advantageous market circumstances. In contrast, there is a considerable decline in both extraction (32,150.4 maund) and income (Tk. 1.43 million) in 2020-21, suggesting that the industry may be experiencing a slump or difficulties during that fiscal year. Overall, the findings highlight the significant economic contributions that Golpata, Malia Grass, and Shan make to the community and highlight the demand for sustainable harvesting methods to strike a balance between economic gain and ecological preservation in the special Sundarbans habitat.

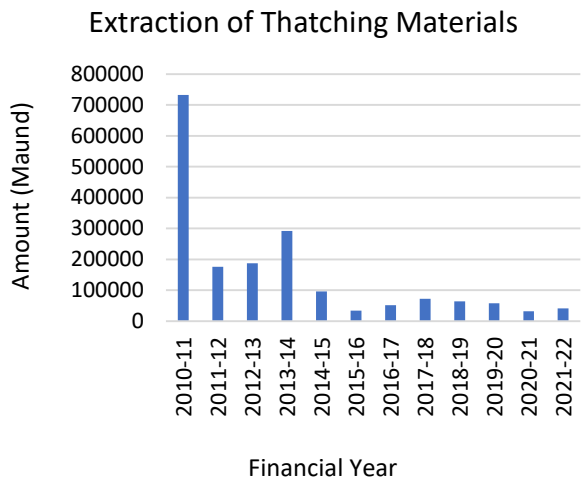


Figure 5.10: Extraction of Thatching Materials

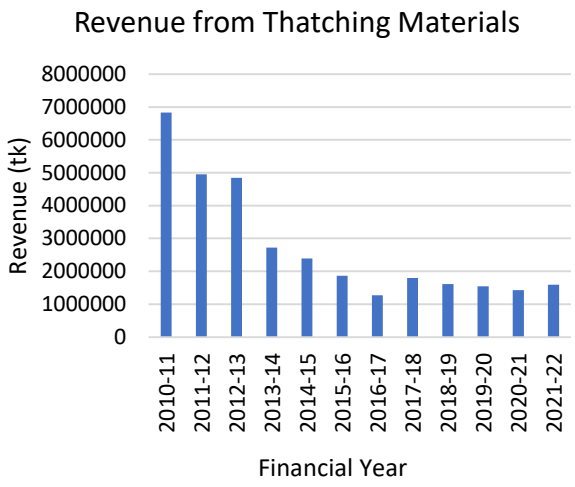


Figure 5.11: Revenue from Thatching Materials

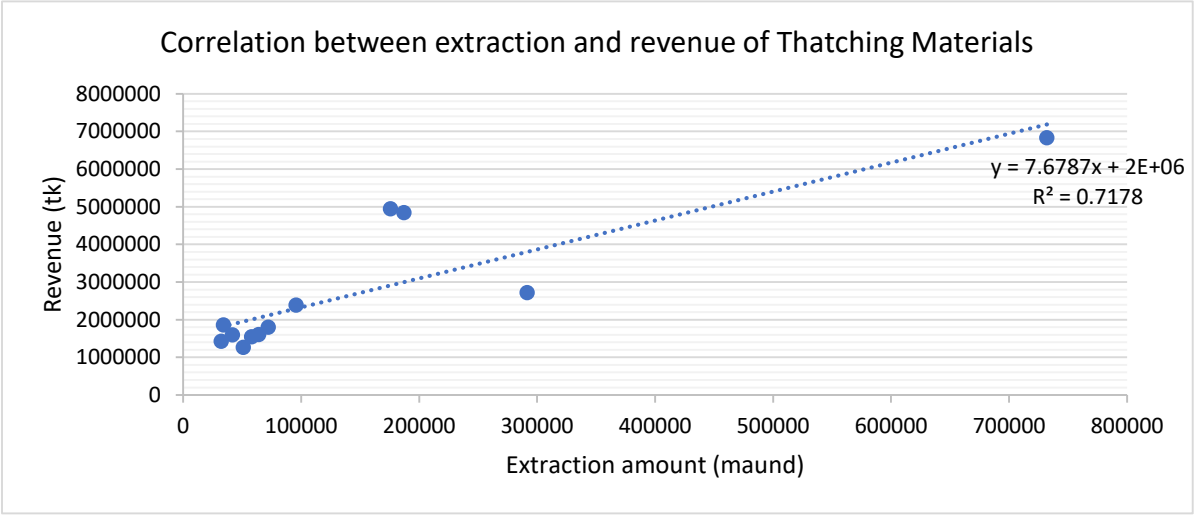


Figure 5.12: Correlation between extraction and revenue of thatching materials

Source: Author's preparation (2023)

5.1.4 Fuel Wood

The Sundarbans region's fuel wood harvest was separated out by income in the chart during a 12-year period. The huge growth in income from 2011-12 to 2013-14, which was fueled by strong contributions from all three categories, is one notable trend. Total revenue peaked during this time at 1.83 million taka in 2011-12 and 1.13 million taka in 2013-14. The lowest point in revenue across all categories was reached in 2021-2022, with 0.03 million, however this was after 2013-2014. This drop may be explained by variables like restrictions of collecting, environmental laws, or changes in the Sundarbans' supply of fuel wood.

Figure 5.13: Collection of fuel wood

Source: Forest department

In conclusion, the chart illustrates the dynamic nature of fuel wood revenue creation in the Sundarbans area. In addition to highlighting the necessity of sustainable harvesting methods and careful resource management, it also highlights the possible economic ramifications for the nearby populations that depend on this resource. The income swings over the years serve as a reminder of the difficulties and unpredictability involved with companies reliant on natural resources, such as the extraction of fuel wood.

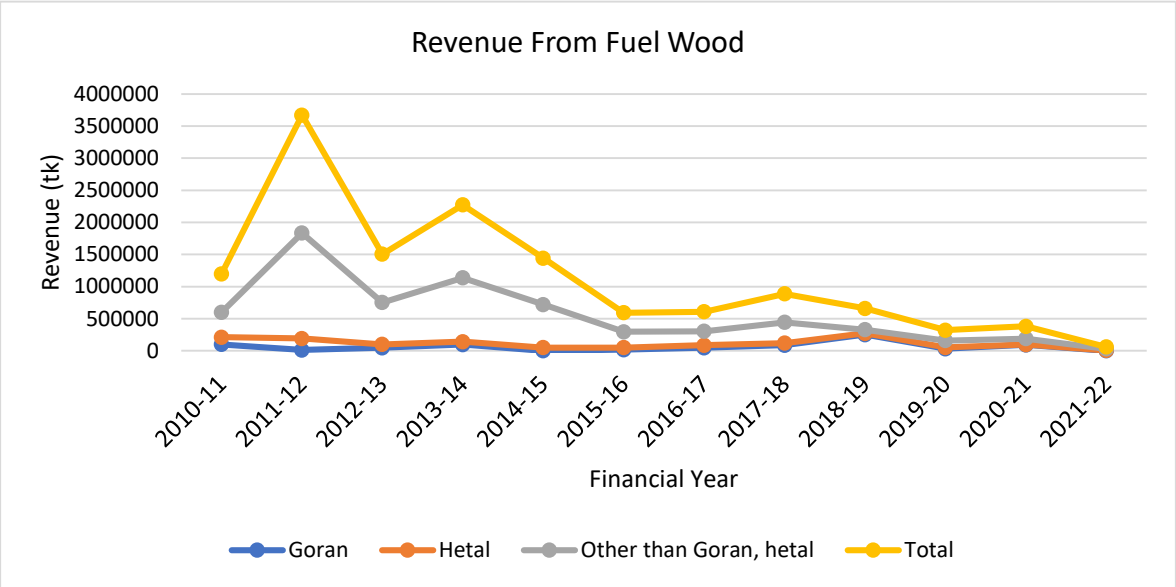


Figure 5.14: Revenue from Fuel Wood

Source: Author's preparation (2023)

5.1.5 Crab

The data showing the extraction of crabs and revenue from it over a twelve-year period provides important insights into the structure of this particular business. There was a reasonably constant level of crab harvest in the earlier years, from 2010-11 to 2012-13, with only small variations and no noticeable increases or decreases. With extraction levels averaging 8,000 to 9,000 quintals yearly, this represents a consistent and established business.

From 2013-14, there was a noticeable decline in crab extraction, with the lowest recorded amount at 5,153.661 quintals in 2021-22. This decline may be attributed to various factors, including environmental changes, regulations, or shifts in market demand for crabs. In 2016-17 when there was a substantial increase in crab extraction, reaching 13,814.7314 quintals. This spike may have been influenced by specific conditions or opportunities that year, leading to a temporary surge in crab harvesting. Crab extraction then noticed a period of relative consistency from 2017-18 to 2019-20, with the numbers changing within a particular range. The statistics from 2020-2021 to 2021-2022, however, indicate a large decrease in crab extraction, possibly due to difficulties or changes in the business because of the depletion of the resources.


Figure 5.15: Catching of crab Source: Field survey 2023, Google

The data collection on crab revenue from sales over a twelve-year period offers important insights into the economic condition of a sector directly related to crab fishing and business. From 2010-11 through 2012-13, there was a very constant amount of revenue, rising at Tk. 4.59 million in 2011-12. The revenue began to continue decreasing after 2013-14, reaching a low of Tk. 2.98 million in 2014-15. In 2016-17, there was a surprising turnabout when income increased significantly and reached Tk. 5.180 million. After that, between 2017-18 and 2019-20, there was a time of comparatively steady revenue, with numbers changing within a particular range but not nearly reaching the prior maximum.

It is clear that there is a relationship between these two variables. In the previous years, from 2010-11 to 2012-13, income climbed in step with the volume of crabs gathered. This positive correlation shows a clear relationship between the amount of crabs collected and the amount of money generated, perhaps showing a link between the two.

The trend shifted in a less visible pattern starting in 2013-2014. Although there were periods when more crabs were collected and more revenue was made, there were also times when more crabs were collected but less revenue was made, and vice versa. This implies that other aspects of revenue generation may have started to become more important at this time, such as market conditions, price, product quality and size. The data from 2020-21 to 2021-22 is particularly significant because it shows a substantial decrease in crab harvest in 2021-22 despite a significant increase in revenue. This might suggest that, despite lesser crab collecting, these years had extremely favorable market conditions for crab or the quality was good enough.

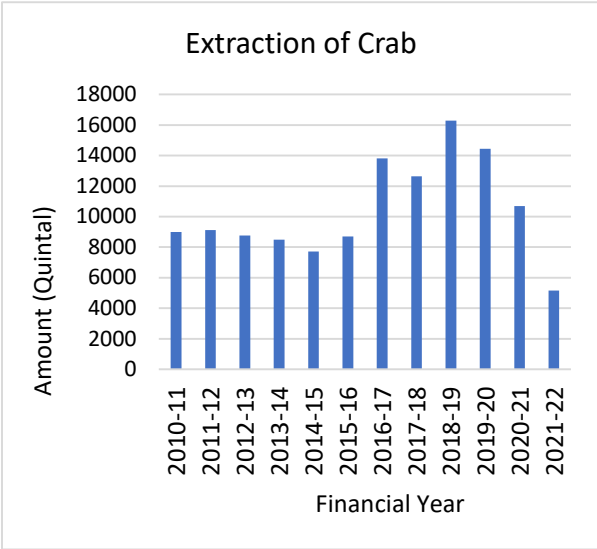


Figure 5.16: Amount of crab

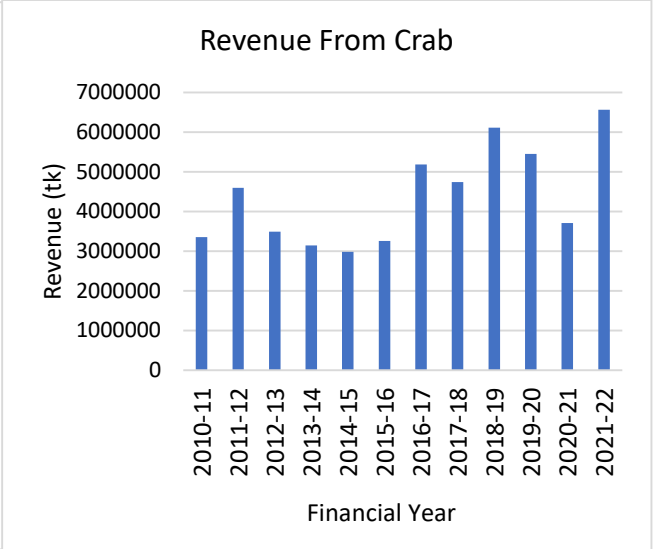


Figure 5.17: Revenue from Crab

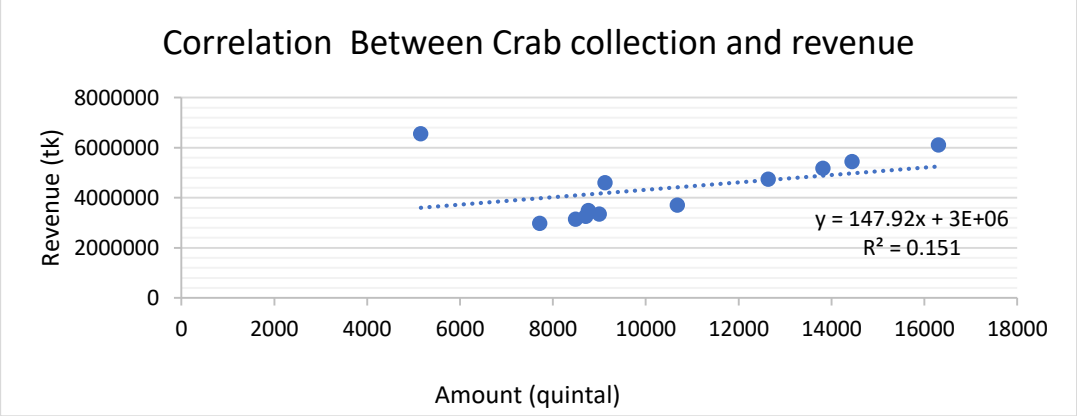


Figure 5.18: Correlation Between Crab collection and revenue

Source: Author's preparation (2023)

5.1.6 Honey and wax

The following chart gives a thorough summary of the amount of honey and wax extracted and the money made from collecting it in the Sundarbans during a 2010-2022. The amount of honey harvested fluctuates from year to year; the largest extraction was 3,419.15 quintals in 2020-21, which brought in Tk 2.56 million in income. 2011-12 had the lowest honey extraction with

1,258.21 quintals and Tk. 0.94 million in earnings. This fluctuation could be explained by elements like bee populations, environmental circumstances and the rules and regulations on extracting.

The local economy benefits greatly from the sales of honey and wax, with the year 2020-21 standing out with a total value of Tk. 3.59 million. While the amount of honey extracted fell to 2,320 quintals in 2021-2022, the income rose to Tk. 3.69 million, indicating a rise in the market price or demand for honey at that time. Similar to wax extraction, which produced 696 quintals and generated Tk. 1.53 million in income, this sector is still expanding.

Figure 5.19: Collection of honey Source: Google

In the early years, from 2010-11 to 2012-13, revenue from both honey and wax showed a gradual increase, reflecting a growing market for these products. This upward trend suggests that beekeeping activities were thriving during this period, resulting in higher sales and revenue for both honey and wax.

From 2018-19, there was a notable increase in revenue, which more than doubled from 2017-18 to 2021-22. Several causes, including rising consumer interest in organic and natural products like honey and wax as well as marketing initiatives to promote these goods, may be the reason for this significant growth.

So, the data illustrates a generally positive trend in revenue from honey and wax sales over the years, with periods of growth, stability, and a significant increase in recent years. This suggests that the beekeeping and apiculture industry has been evolving, with increased demand for its products and potential opportunities for expansion and marketing. The chart concludes by

emphasizing the fluidity of honey and wax extraction and income production in the Sundarbans. These priceless goods, which are substantial contributors to the local economy and a source of livelihood for several populations in the area, must be sustained over the long term through sustainable harvesting methods and efficient resource management.

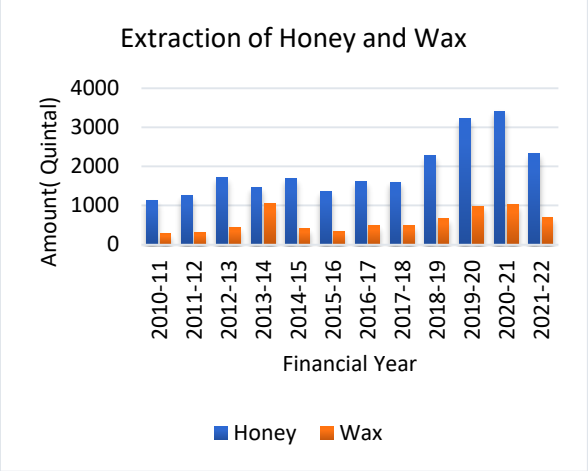


Figure 5.20: Extraction of Honey and Wax

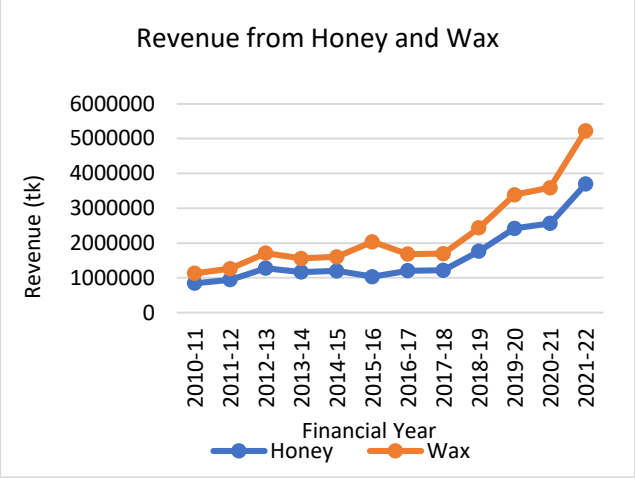


Figure 5.21: Revenue from Honey and Wax

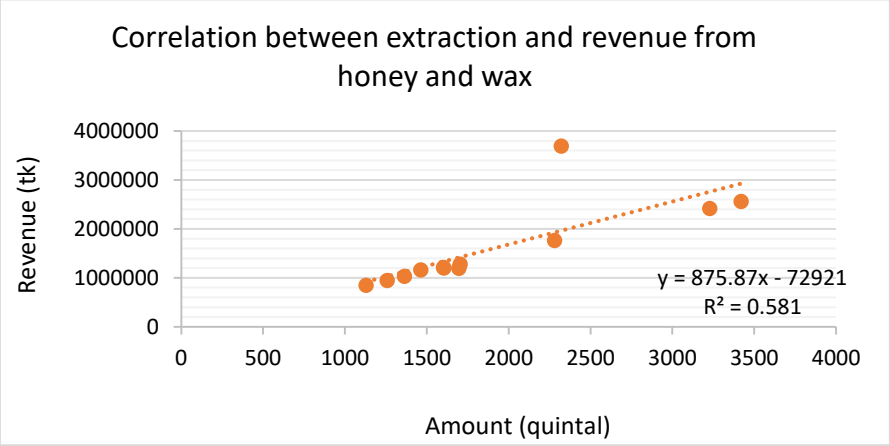


Figure 5.22: Correlation between extraction and revenue from honey and wax

Source: Author's preparation (2023)

5.2 Quantify the impact of tropical storms on ecosystem services and local communities

5.2.1Weekly income

The bar chart provides valuable insights into the average weekly income generated from various sectors in the Sundarbans region. It showcases the economic contributions of different activities undertaken in this unique and ecologically significant area. Fisheries stand out as a significant source of income, with an average weekly income of 2,625.71 taka, this highlights the importance of the fishing industry to the livelihoods of many in the region. Crab harvesting contributes substantially to the local economy, with an average weekly income of 1,313.64 taka. Honey collection, with an average weekly income of 3,030 reflects the value of beekeeping and the rich biodiversity of the Sundarbans. Golpata providing an average weekly income of 2,288.89 taka, showcases the potential of non-timber forest products. These figures collectively emphasize the diverse economic activities within the Sundarbans, with an interplay of traditional practices and natural resources contributing to the livelihoods of the local population. It's essential to consider sustainable practices and conservation efforts to maintain this delicate balance between economic activities and ecological preservation in this ecologically sensitive region.

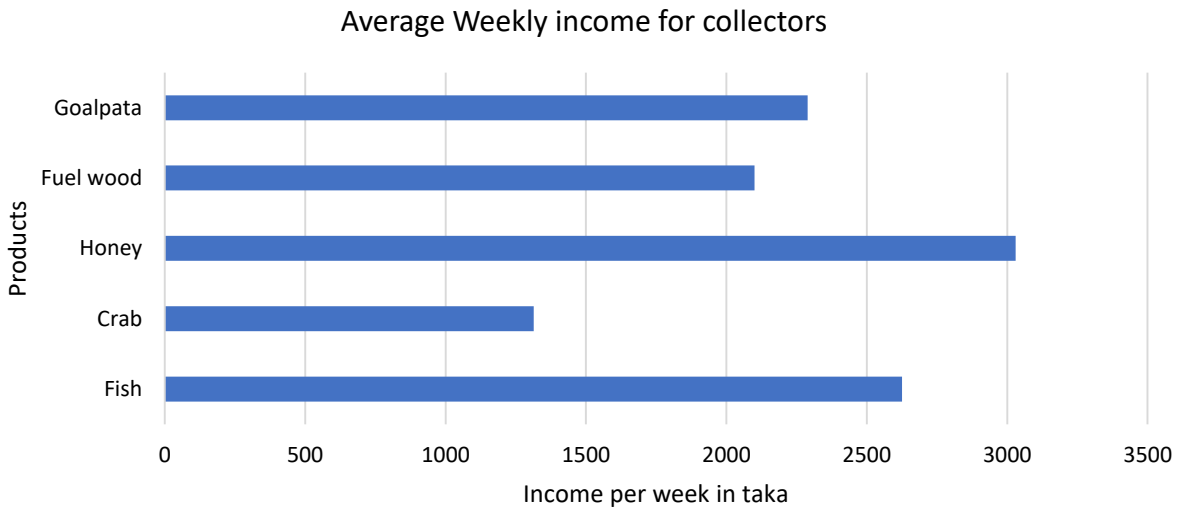


Figure 5.23: Average Weekly income for collectors

Source: Author's preparation (2023)

5.2.2 Direct Disturbance due to tropical storms

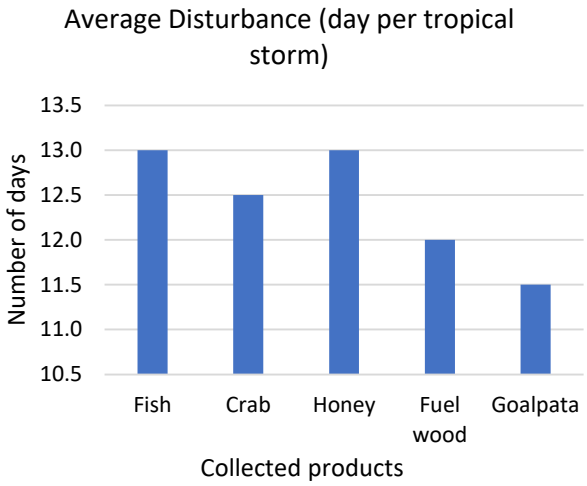


Figure 5.24: Average Disturbance (day per tropical storm)

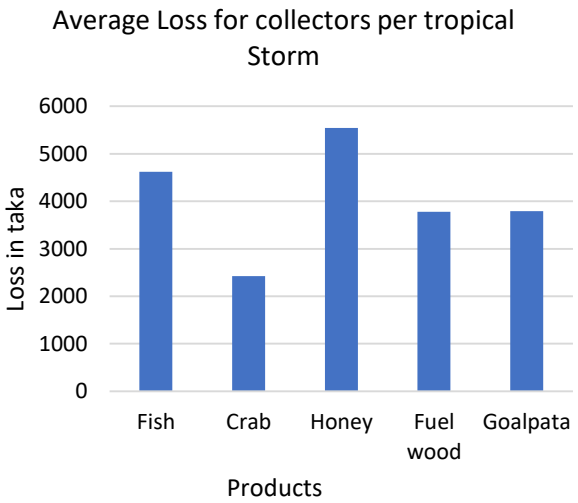


Figure 5.25: Average Loss for collectors per tropical Storm

The bar charts offer valuable insights into the average loss of income in specific sectors within the Sundarbans region as a consequence of the impact of a single tropical storm. This data presents both the average disturbance in days and the resultant average financial loss in taka for each sector.

People connected with fishing faces with an average disturbance of 13.0 days, experienced a significant average loss of 4,620 taka. This underscores the vulnerability of this sector to the disruptive forces of tropical storms, which can disrupt fishing activities and harm livelihoods. Crab harvesting, with a slightly lower average disturbance of 12.5 days, still incurred a noteworthy loss of 2,423 taka. This sector, though relatively less affected by the storm, demonstrated its susceptibility to such natural disasters. Honey collection and Fuel wood, both with average disturbances of 13.0 and 12.0 days, respectively, suffered substantial losses of 5,546 taka and 3,776 taka. These figures highlight the economic repercussions on activities reliant on forest resources, such as honey and fuel wood collection. Interestingly, Golpata, despite an average disturbance of 11.5 days, experienced a comparatively lower loss of 3,795 taka. This may suggest a certain level of resilience or adaptive capacity within the Golpata industry when confronted with the impacts of tropical storms.

In summary, the table illustrates the economic toll of tropical storms on distinct sectors in the Sundarbans, emphasizing the need for disaster preparedness, resilient livelihood strategies, and

sustainable resource management to mitigate these losses and safeguard the well-being of the local communities in this ecologically fragile region.

5.2.3 Difference in income before and after the storm

The chart provided gives a clear snapshot of the average income in taka earned by collectors in various sectors in the Sundarbans region, both one week before and one week after the occurrence of a tropical storm.

Before the tropical storm, fish collectors were earning an average income of 2,625.71 taka, but this income decreased to 2,124.29 taka in the week following the storm. This represents a noticeable 19% reduction in income, indicating the immediate negative impact of the storm on the fishing industry. Crab collectors also experienced a substantial income decline. Their average weekly income prior to the storm was 1,313.64 taka, but it dropped significantly to 672.73 taka one week after the storm, marking a substantial 49% decrease in earnings. This highlights the vulnerability of crab collectors to the disruptive effects of tropical storms. Similarly, honey collectors and fuel wood collectors faced income losses after the storm. Honey collection income decreased from 3,030 taka to 1,985 taka, reflecting a 34% reduction in earnings. Fuel wood collectors saw their income increase slightly from 2,100 taka to 2,516.67 taka, a 20% increase, possibly due to increased demand for fuel wood during post-storm recovery efforts. Interestingly, Golpata collectors maintained a consistent income level of 2,288.89 taka both before and after the storm, indicating resilience or stable demand for this sector despite the external disruptions.

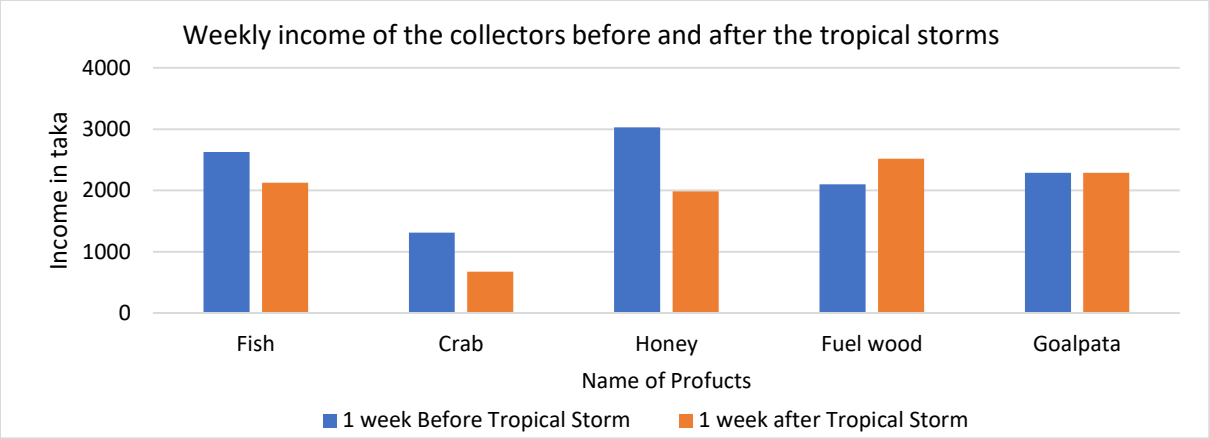


Figure 5.26: Weekly income of the collectors before and after the tropical storms

Source: Author's preparation (2023)

In summary, this data highlights the significant economic impacts of tropical storms on collectors in the Sundarbans, with income reductions across various sectors. It underscores the need for disaster preparedness, risk mitigation strategies, and support mechanisms to help cushion the financial blows suffered by local communities in the aftermath of such natural disasters.

5.2.4 Long term impact

Land cover change

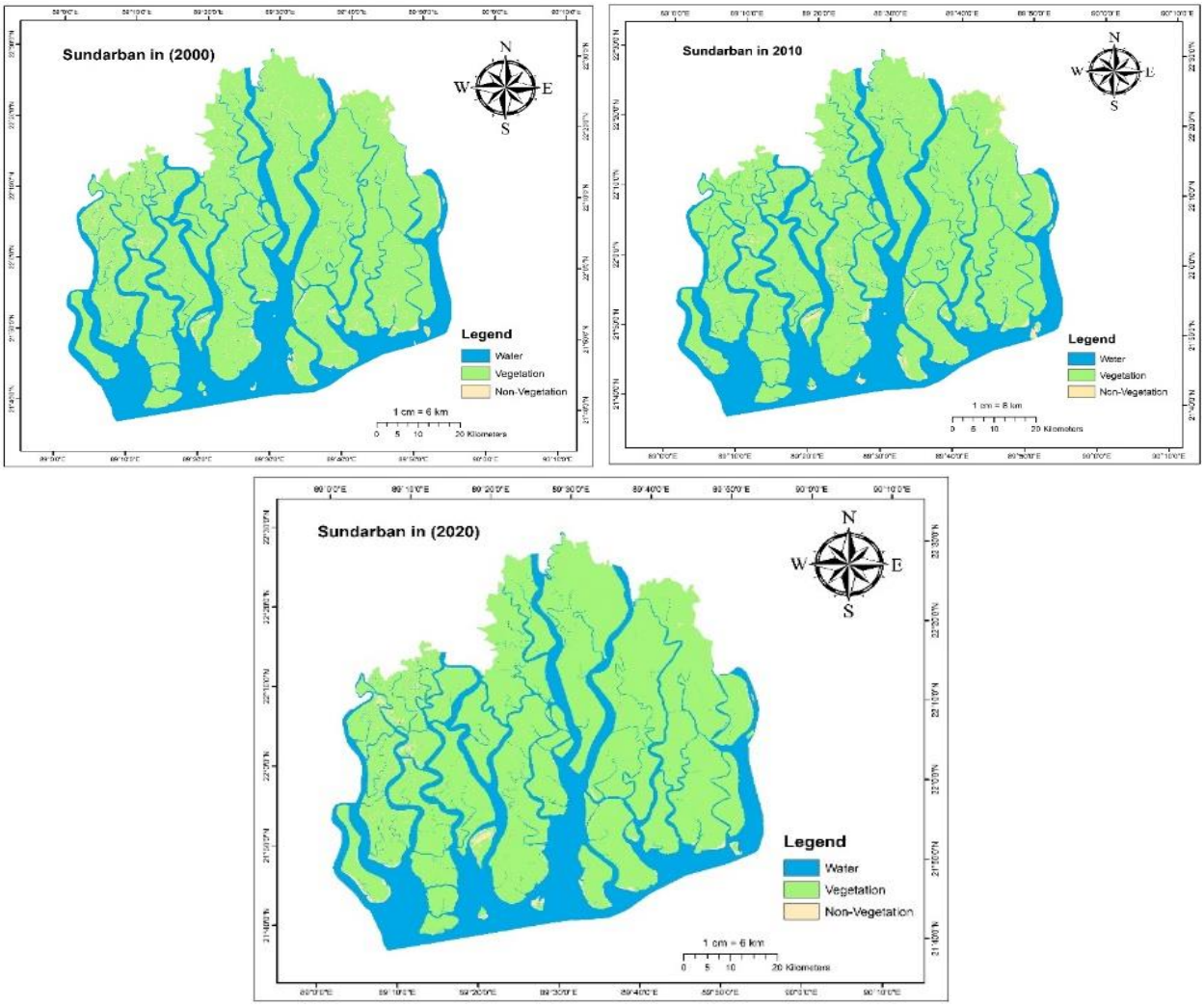


Figure 5.27: Land cover change

Source: Author's preparation (2023)

This provides a succinct examination of the changes in land cover in Bangladesh's Sundarbans during three important years: 2000, 2010, and 2020. The land is divided into the following three main categories: "Water body," "Vegetation," and "non-Vegetation."

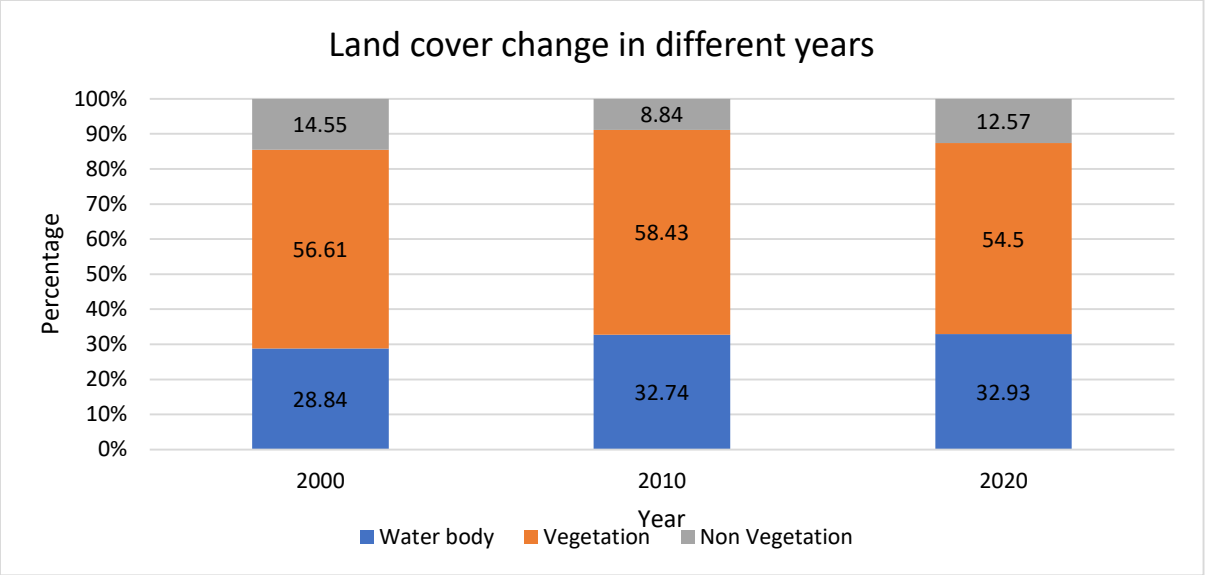


Figure 5.28: Land cover change in different years

Source: Author's preparation (2023)

The wide network of rivers, estuaries, and tidal water bodies in the Sundarbans region were reflected in the landscape's significant amount of "Water body," which made up 28.84% of the total area in 2000. 56.61% of the area was classified as "vegetation," which mostly refers to mangrove forests and other plant cover. Urban and agricultural land together accounted up 14.55% of the region's "non-vegetation" regions.

When it came to "Water body," there had been a notable growth by 2010, growing to 32.74%. This alteration might be a result of sea level rise or other natural processes, such as the growth of water bodies. Although it slightly fell to 58.43%, "Vegetation" nonetheless had a very dominating position despite this, indicating a consistent mangrove cover. Notably, "Non-Vegetation" areas significantly fell to 8.84%, possibly as a result of reforestation initiatives or changes in land usage.

With the percentage of "Water body" coverage continuing to rise in 2020 and reaching 32.93%, causes including climate change and tidal dynamics may be to blame. With a drop in "Vegetation" to 54.5%, there may be less mangrove cover, which is worrying for the region's biodiversity and ecological health. In addition, "non-Vegetation" areas grew to 12.57%, indicating a rise in urban and non-vegetated land that was probably caused by development activities.

This chart summarizes the dynamic changes in land cover that have occurred in Bangladesh's Sundarbans during the past 20 years. The expansion of the water bodies in the area, maybe

influenced by environmental causes, was accompanied by a worrying drop in the plant cover of the mangroves. Understanding and minimizing these changes' effects on the special and vulnerable Sundarbans environment and the populations that depend on it are essential for conservation and monitoring activities.

5.2.5 Tress in Sea Level Rise Scenario

The Sundarbans region's production of two important species, Sunduri and Gewa, is detailed in this table for the years 2001, 2050, and 2100 under various sea level rise (SLR) scenarios, with 2001 acting as the baseline year.

The appropriate habitat area for Sunduri was determined to be 80,489 square kilometers in the base year 2001, amounting to a production value of $402 million. The acceptable habitat area for Sunduri, however, decreases to 69,571 and 43,884 square kilometers in 2050 and 2100, with SLR reaching 32 cm and 88 cm, respectively, illustrating the negative effects of sea level rise. The economic value of Sunduri production falls from $348 million in 2050 to $219 million in 2100 as a result of the loss in appropriate habitat.

Similar data is available for Gewa, which has a base year of 2001 and a production value of $29 million due to a suitable habitat area of 59,027 square kilometers. The acceptable habitat area for Gewa is still reasonably steady, with only modest variations down to 58,992 and 55,021 square kilometers, despite SLR reaching 32 cm and 88 cm in 2050 and 2100, respectively. However, there is a minor decline in the economic value of Gewa production, which falls to $28 million in 2050 and stays at this level in 2100.

In conclusion, the chart highlights the Sunduri species' sensitivity to increasing sea levels in the Sundarbans, as seen by a sharp decline in both their acceptable habitat area and economic value over time. The habitat size and economic worth of Gewa, in contrast, seem to be more robust to these shifting environmental circumstances. This information emphasizes the demand for proactive conservation efforts and adaptation plans to protect biodiversity and maintain economic activity in the Sundarbans in the face of climate-related difficulties.

In conclusion, the charts highlight the Sunduri species' sensitivity to increasing sea levels in the Sundarbans, as seen by a sharp decline in both their acceptable habitat area and economic value

over time. The habitat size and economic worth of Gewa, in contrast, seem to be more robust to these shifting environmental circumstances. This information emphasizes the demand for proactive conservation efforts and adaptation plans to protect biodiversity and maintain economic activity in the Sundarbans in the face of climate-related difficulties.

Table 5.1: Tress in Sea Level Rise Scenario Source: CEGIS (2005)

Species	Year	SLR (cm)	Suitable area	Value(M us$)
Sunduri	2001	Base	80489	402
	2050	32	69571	348
	2100	88	43884	219
Gewa	2001	Base	59027	29
	2050	32	58992	28
	2100	88	55021	27

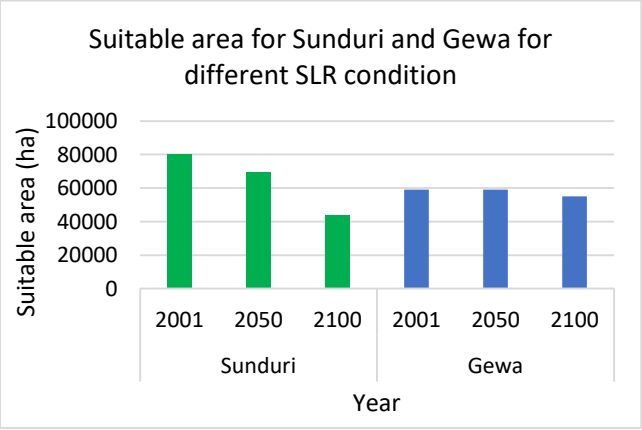


Figure 5.29: Suitable area for Sunduri and Gewa for different SLR condition

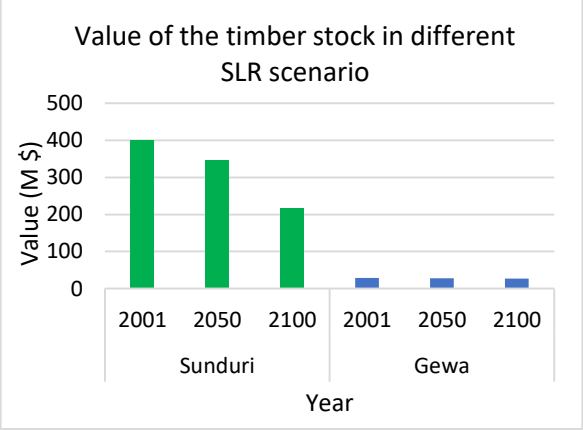


Figure 5.30: Value of the timber stock in different SLR scenario

Source: Author's preparation (2023)

5.2.6 Positive Impact of tropical storms on the biodiversity

It is predicted that a certain amount of product is not extracted because of the barriers in extracting the ecosystem services.

For fish population the stock will be increased because of the barriers of extraction which make the fish population available in the system in those storms days. The maximum expected extraction of fish per fisher per day is 2.79 kg. Almost 50,000 fishers stay at Sundarban for fish extraction every day. As the average disturbance day within which the extraction remain off is almost 13 days. It is predicted base on the maximum extraction which was possible in these days.

Fish stock increase due to off in extraction in tropical storm time can be estimated following this.

FS= MER *NF* ADD

Maximum extraction rate per fishers per day × number of fishers × Average disturbance day

So, the stock will increase by following number

Maximum extraction rate per fishers per day × number of fishers × Average disturbance day

= 2.79 × 50000 × 13

= 1813500kg

= 1813.5 tons

About 1813.5 tons fish is estimated will add in the total stock due to the barriers in extraction in the tropical storms days. So, the extraction rate just after the tropical storm should increase. But due to some externalities and uneven nature of the weather and biodiversity the extraction rate decreases just after the tropical storms. Reduction in extraction of fish stays for several days until when the weather gets back to its normal nature.

5.3 Management of Common Pool Resources

5.3.1 Situation of the Provisional Services

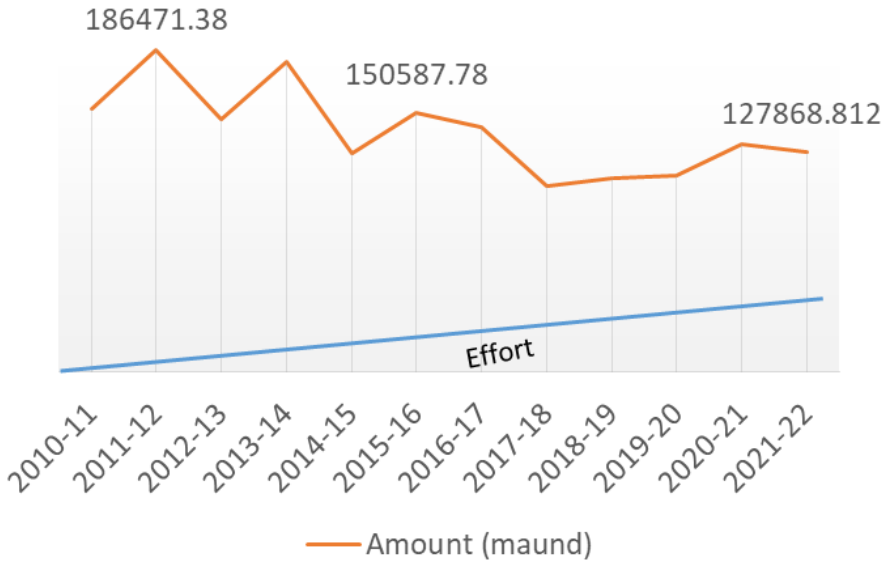


Figure 5.31: Situation of the Provisional Services

Source: Author's preparation (2023)

The following graph shows the amount of fish extract each year from Sundarbans and the effort of the fishers to catch fish. It is seen that the extract rate of fish is not increasing although year by year the effort by the fishers is increasing. Here effort of fishers includes time, technology, catching methods, equipment or other things that increase the efficiency and effectiveness of catching fish. As the fishers use updated technology, improved methods of catching fishes, more effort by giving more time and so on they expected more extraction of fishes. But the graph shows that the extraction rate is not as expected. Because of various effects like unauthorized extraction, over extraction, pollution, climate change effect, depletion and many more reasons are related to this. There is also problem related to the fishing method where many fishers use illegal ways of fishing to catch fish more in quantity in less time. They use the poison, illegal nets, in the sanction canals which is illegal to use and cause serious damage to the biodiversity of the system. All these reasons cause serious depletion in production although the effort is much more as well as the technologies and equipment.

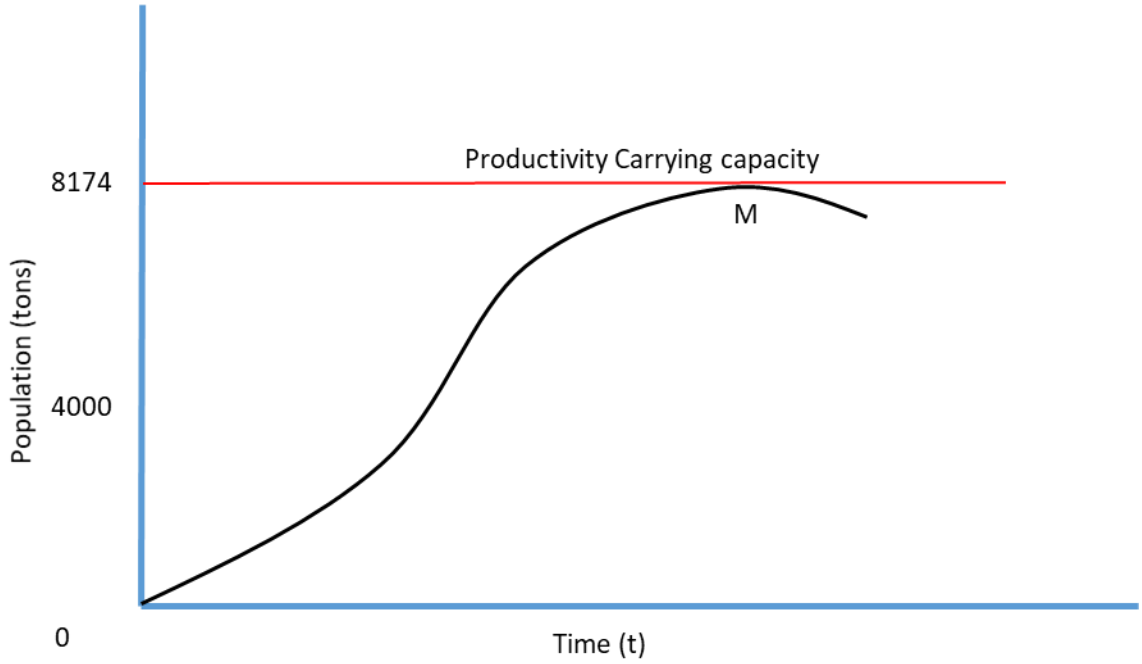


Figure 5.32: Carrying capacity of sundarban

Source: Author's preparation (2023)

The following graph represents the carrying capacity of fish of the ecosystem of Sundarbans by considering the population change with the change of time. It is seen that at first the growth rate is slow as the population was less but time by time the fish population is increasing with the increasing rate of growth. But after a certain point the population reach its maximum volume that the system can able to retain. And then the population is not increasing like previous. In the graph the M point represent the maximum volume point which is also called the maximum carrying capacity of the system and then time by time there starts the decreasing of the fish population. The carrying capacity of Sundarbans is almost 8174.2 tons. At first the growth rate was slow but after some time the growth rate is much more. Actually, that is the portion within which the growth rate is higher and fishing should be done by following this curve and that portion which is actually called maximum sustainable yield. Which may be situated at the middle of the curve where the growth rate is relatively high.

5.3.2 Initiative to Common Pool Resource Management

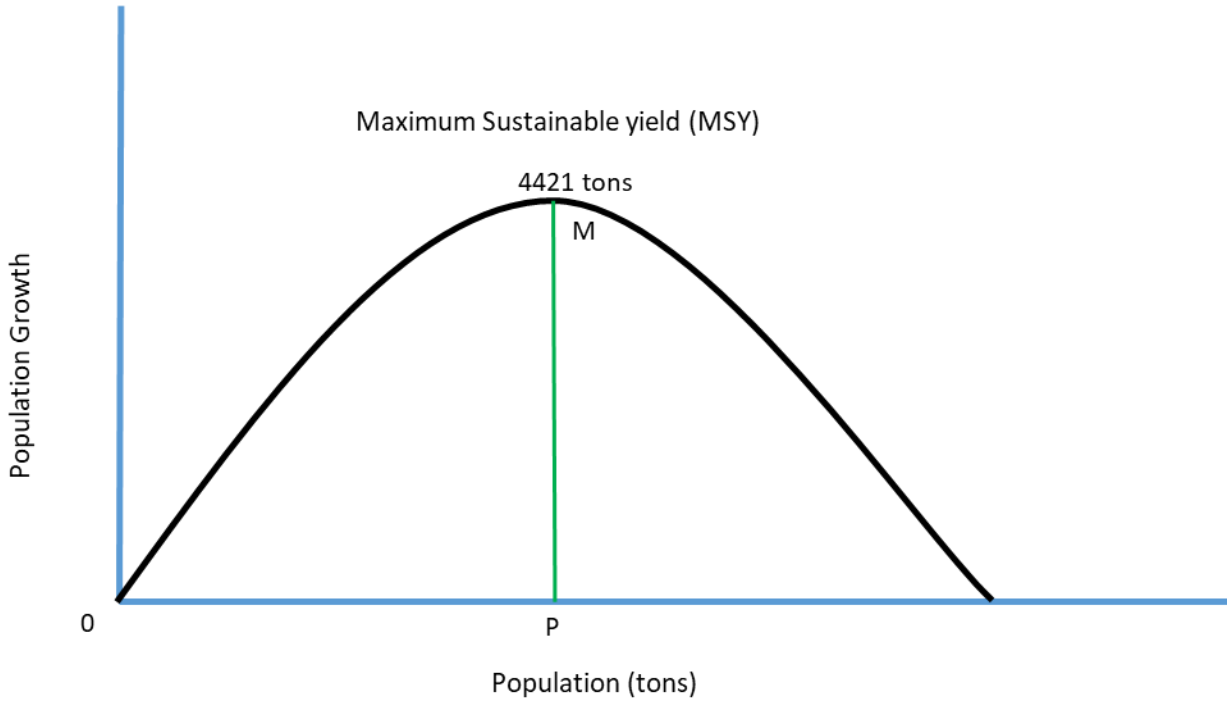


Figure 5.33: Maximum sustainable yield

Source: Author's preparation (2023)

The following graph represents the maximum sustainable yield which extent fishers can catch fish that will not affect the fish population. The graph is actually based on relating the population growth with population within which the any point on the graph represents that the fishers can catch that portion of fish which will not affect the fish population. At first the population was less as the growth rate was almost zero. But then with the increasing of growth rate the fish population start increasing significantly. The highest point where the growth rate is maximum is called the maximum sustainable yield point. Which actually represent that the ecosystem of Sundarban can allow this much fishing which will not affect the fish population. The maximum sustainable yield of Sundarban is almost 4421.2 m. tons. As so the Forest Department take various initiative by setting rules and regulations to make sure that the extraction never exceeds the maximum sustainable yield point. In order to control the extraction rate Forest Department, give permission a selected number boats who can extract fish. The extractor needs permission from Forest Department in order to extract the products. According to the FD the annual maximum BLC

issuance will be 12000 which means the maximum permit will be 96000 as each BLC has a permit of 8 times. But the present BLC issuance is already more than this. As the estimated MSY is 4421.2 tons the corresponding effort need to meet this amount is almost 110000 permits per year. So, the existing BLC permit is almost 100000. But actually because of overfishing by many illegal and dishonest fishers with no BLC as well as improper fishing methods like using poison, illegal nets and so on the extraction is much more than this line. Which actually results the depletion of fish population. Which makes the annual yield more than this and results depletion of the population.

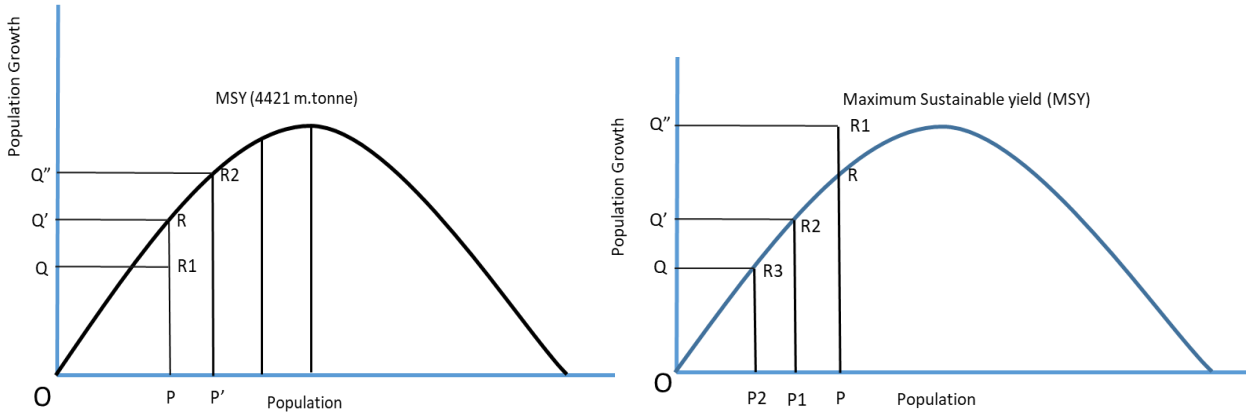


Figure 5.34: Population growth scenario Source: Author's preparation (2023)

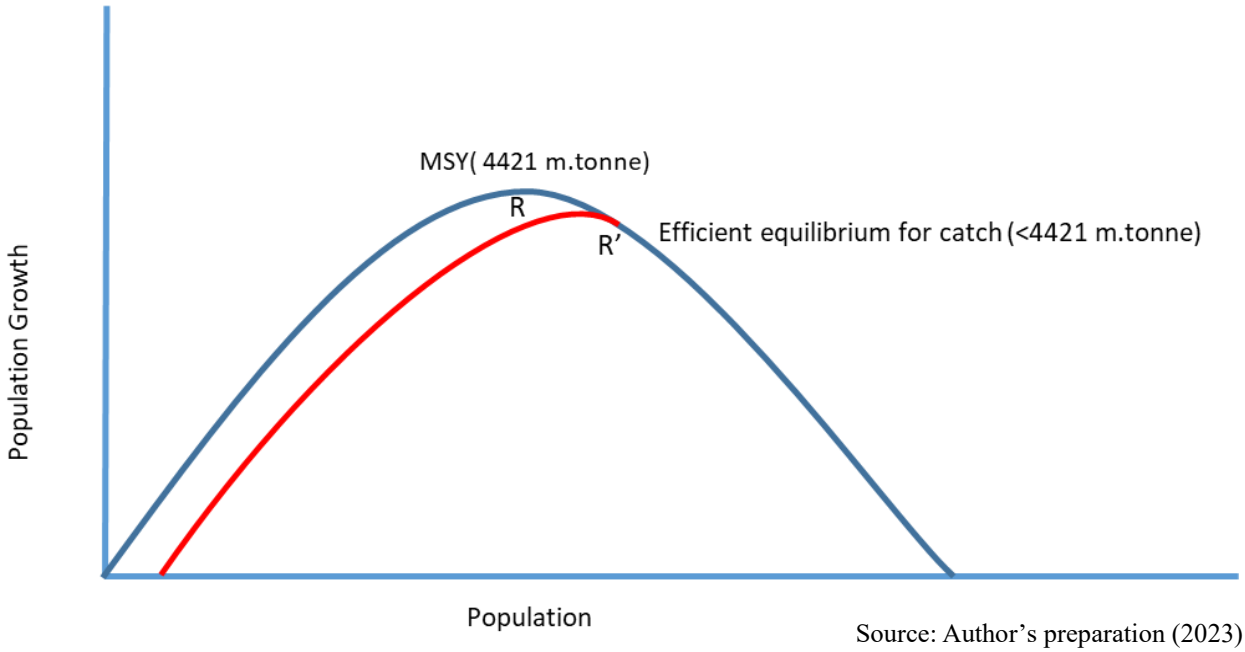
The second graph actually represents how the extraction should be done. In this curve it is seen that if extraction of fish is done under the line, then the extra portion will make the population increase. At R point the available of fish was PR. If the extraction rate is PR then there will be no decrease of population as it will increase with the growth rate. But if the extraction is PR1 then the extra RR1 portion will add to present population and will be increased in the next year which is P'R2.

In the third curve it is seen that if the available of fish is PR but the extraction is PR1 then the fish population will decrease by RR1 portion. So, extraction of any portion under the point will increase the population and any portion upper the line will decrease the fish population. Actually, this happened in Sundarban every year. The overfishing is one of the main reasons of fish population. Illegal and irregular activities by fisher's cause overfishing which cause the depletion in the fish population. According to Sarkar. A there are almost 23% of the fishers who are illegally catch fish which means they have no BLC. Actually, this means that along with 100000 permits there are

more 23% who use to catch fish. So, the amount extract by this extra 23% people causes overfishing problem which results serious depletion. The permitted people are enough to reach the maximum sustainable yield which was 4421 tons. But the extra 23% fishers create extra catch of fish which make the extraction volume more than 4421 tons. Actually, although the FD tries to keep the maximum sustainable yield 4421 tons but because of the illegal fishermen actually the total extraction can reach till 5500 tons. Along with this the illegal people with no BLC generally use illegal methods of fishing too in order to catch more fish in less time. These illegal methods created over extraction as well as pollute the system which results depletion of the various species of the system. The same thing also goes for the crab collectors. There is almost 29.5% people who have no permission of collection of crabs. This also created the over extraction of crabs.

5.3.3 Proposed Maximum Sustainable yield

So in order to solve the depletion problem the maximum sustainable point should be pointed in a place where the over fishing cannot affect much. So, the red line in the curve may represent as the efficient line for catch where the maximum sustainable yield point is less than 4421 tons. The overfishing is a serious thing to keep in concern and forest department takes different steps to monitor the fishing but the forest field staffs. But actually, the fishers give extra money as tips to the field staff and catch more fish. Although various example is there of punishing the illegal and irregular users but there are some people who get rids of all these monitoring and extract illegally. So along with the restrictions and proper monitoring the maximum sustainable yield amount should be also less than 4421 tons. By doing this if a little portion of extraction is done by the fishers by unintentionally. If 5% of the fishers catch fish illegally then the MSY should be around 4200 tons. If extraction is done around this margin, then every year the population will increase by a certain margin in the system. The same thing should be implemented for the catch of crab, shrimp and other species.



Source: Author's preparation (2023)

Figure 5.35: Proposed Maximum Sustainable yield

5.3.4 Maximum Sustainable Yield by Controlling Revenue Generation

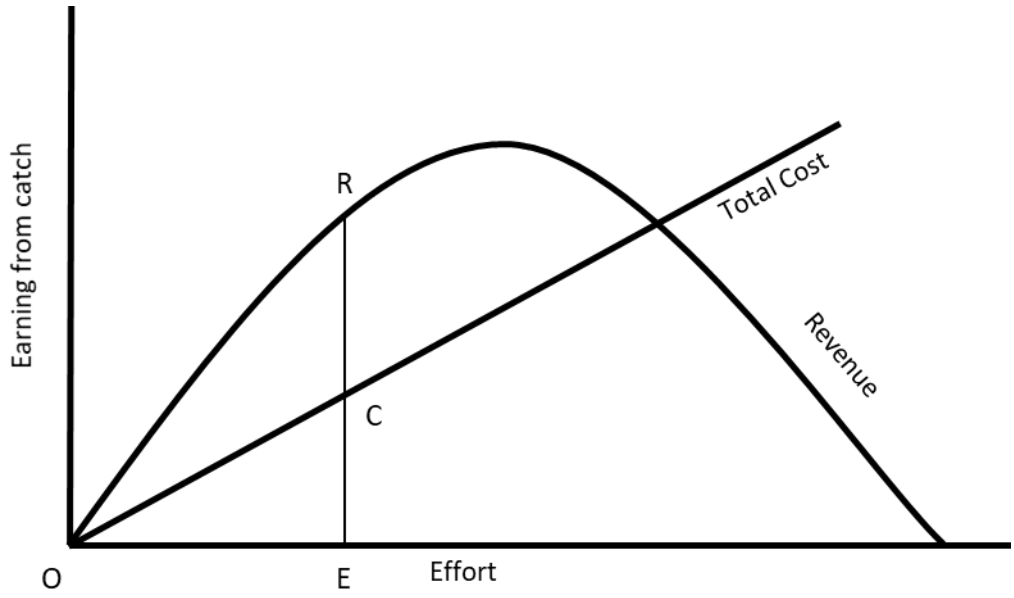


Figure 5.36: Maximum Sustainable revenue perspective

Source: Author's preparation (2023)

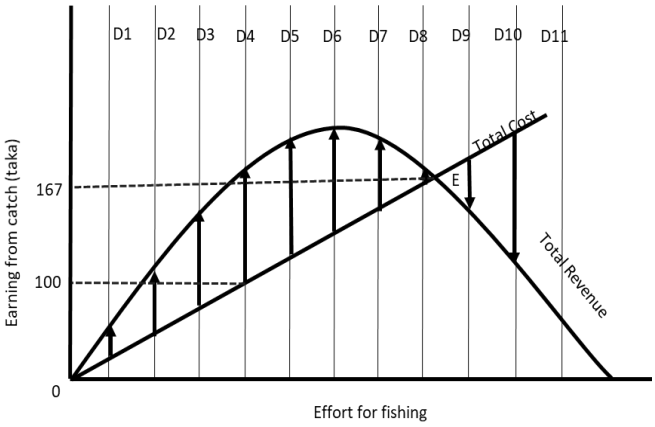


Figure 5.37: Total revenue & total cost

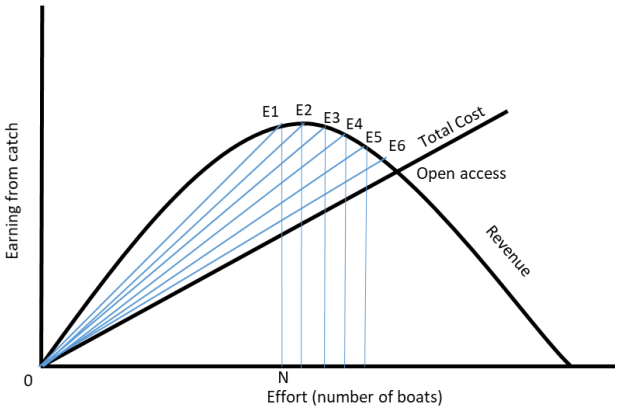


Figure 5.38: Total revenue & effort

Source: Author's preparation (2023)

Here the graph shows the relationship between the total revenue and the total cost of the fishers. At R point it is seen that the total revenue is ER whereas the total cost is CE. So, the revenue is CR. And the revenue is different in different point of this curve because after certain time the revenue rate started to decrease in respect of the increase in cost. Because time by time the increasing rate is cost do not match with the increasing rate of revenue. Because after a certain time because of some factors the fisher cannot get enough fish to generate revenue. Actually, the average cost of fishing is 167 taka per person per trip. There are also cost such as BLC cost, quantity tax, fishing permits and others. The revenue charge is almost 320 taka per quintal for fish and 375 taka per quintal for crab. And for shrimp and Hilsha it varies with the size of the products. So, all these cost and fishing cost are considered in total cost.

In the second graph total revenue and total cost from different day of fishers are considered. Whereas it is seen that at first day revenue and cost both are respectively low as it is just the starting of fishing so cost is minimum and volume of fish catch too. So, revenue and cost both are very low at first. And then day by day the cost is increasing but the increasing rate of revenue is attractive enough which encourage the fishers to give more effort on fishing and every day the earning is efficient enough to carry on. At day four the revenue and cost are almost equal. As the average cost of a fisherman to catch fish per trip is almost 167 taka so let assume in this point at day for the cost per fisherman was 100 taka so they can generate revenue of extra 100 taka in this point as the total revenue at this point is 200 taka. And after that day the revenue remain decreasing

in respect of cost till day eight. After day eight the total cost and total revenue is equal which represents any effort after this point may not help the fishers as the total cost is higher than the total revenue. Which means at this point at day 8 the total revenue is 167 taka and the total cost is also 167 taka. So at this point actually the fisherman generate relatively less revenue. If he stops the fishing at day four, he can generate more income percentage. So, the fishers should catch fish until the marginal revenue no longer greater than marginal cost of fishing that means fishers should fish till the extra day of fishing cost more than earning from the fish. But for group of people like a group of 3 people or more can generate revenue till the equilibrium point as they only think about the revenue and divide the revenue and cost among themselves. The average cost of a group of 2 to 3 person is almost 440 taka per trip.

This can also be considered for number of boats going to fish. At E1 point the revenue is OE1 for ON number of boats. After that for an extra boat the revenue will decrease because of the extra cost added to the total cost and the reduction of volume of the fish in respect of more effort and this decrease rate will continue till C point where TR=TC. So extra addition of boat cannot generate much more revenue after a certain point. But for a group of people or community this may generate extra revenue as they share the total revenue among themselves. They can generate revenue till C point where TR=TC. But for individual after the efficient allocation point the catching of fish is not efficient at all.

So as the fishers are not aware about these, they think more effort and more extraction may generate more revenue which is not actually possible and they face a huge loss after giving a huge effort in terms of time, money and activities as well as make hamper to the biodiversity by over extraction, pollution and so on.

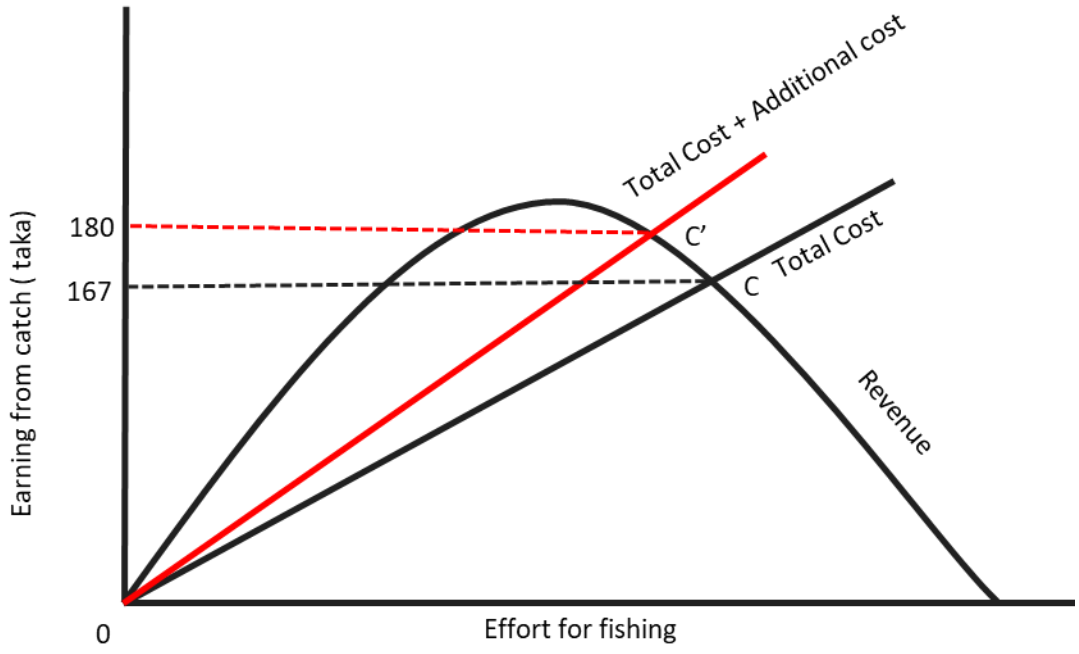


Figure 5.39: Revenue with additional cost

Source: Author's preparation (2023)

So, if some extra cost added with the main cost of fishers, then they will extract less amount of fish as the revenue rate will not efficient enough to continue fishing. From the local community perspective, they are willing to pay extra 13 taka per trip per person for the proper management of system. From their perspective the forest field staff should be more professional in order to monitoring and giving permission. They believe this additional cost will help them later in the time when the fishing is prohibited. So responsible authority can use this extra money as compensation or subsidy to the local people who are directly dependent of the Sundarbans. It can also help them later in the time of storms or other natural calamities or in the time of ban during the breeding season of fish.

5.3.5 Existing Quota System & Shared Quota System

The existing policy of controlling the fishing of the fishers are tax oriented as every fisherman cannot catch more than 2.79kg fish per day. And there is also catch fee rate for 3.20 taka per kg for white fish and there is also entry fee for fishers and crab collectors as they have 7 taka per week for fishers and 6 taka per week for crab collector. Before this every fisher should have been under a BLC holder where each BLC holder can fish 8 times a year per permit. A boat can catch fish maximum three times in a month. So generally, this seems quite good for controlling the over fishing and other depletion related problem.

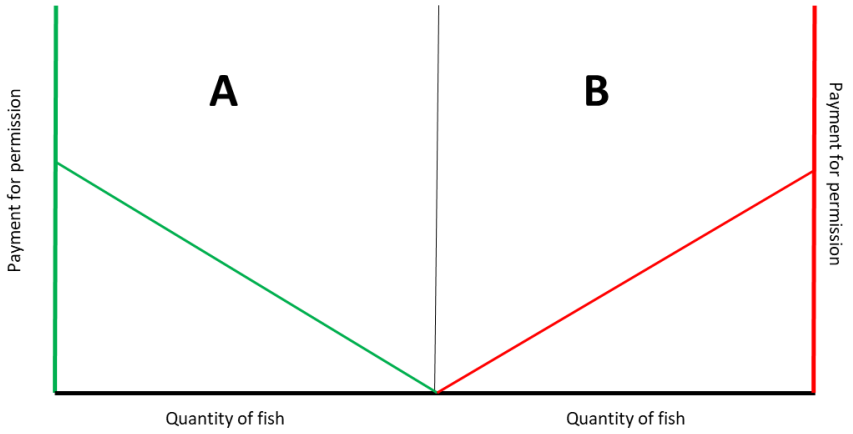


Figure 5.40: Existing Quota System

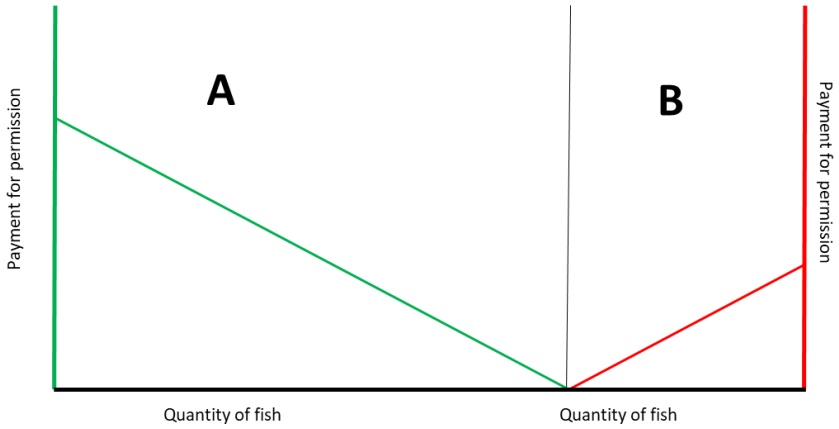


Figure 5.41: Proposed shared Quota System

Source: Author's preparation (2023)

But there is also a problem. These conditions are for every fisherman. But it is possible that there are many fishermen who is less capable and have less technology or equipment to catch certain quantity of fish. As he is not capable enough to catch the permitted amount of fish, he also willing to pay less for the permission related to fishing because of his poor economic condition. But he has no option rather than carry with these policies. Along with this there are also many fishers who has more equipment, improved technology which makes him more capable and increase his capacity of catching fish. But because of the restrictions and regulations he cannot catch much fish although he has the capability.

In the above curve if we consider two fishermen perspective there is A and B within which A is more capable and B is less capable. So, if there is trading quota system then the less capable fisherman can share some of his portion to the more capable fisherman. Sometime A can be enough capable that he can hire B and can take all of his quota. This can generate more employment opportunity as well as help the small fishers to generate more income.

5.3.6 Management for Timber species, Thatching materials and Fuel Wood.

Physical condition of the trees:

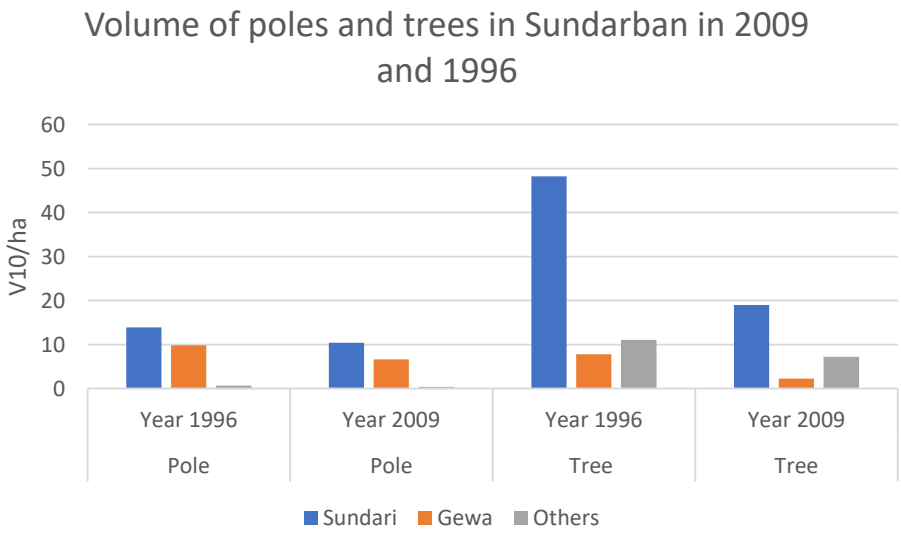


Figure 5.42: Volume of poles and trees in Sundarban in 2009 and 1996

It is seen from the above chart that the percentage of trees are decreased in a certain margin from 1996 to 2009. Sundari and Gewa which are two of the dominated species of Sundarbans are seen

decreased. The volume of poles of Sundari trees decrease in 3.525 per ha as well as tress decrease in 29.19 per ha. For Gewa species the volume of poles and tree decrease per ha is almost 3.19 and 5.57 respectively. So, because of over extraction, pollution, other climate change impacts like salinity increase in water, sea level rise and so on the production of trees are decreased day by day. Sea level rise is now a common phenomenon which may affect the mangrove in recent future by increasing the salinity level of water in which maximum of the trees may affected. Mane people who generally live their livelihood by extracting timber, fuel wood, thatching materials do not familiar with the maximum sustainable yield or maximum economic yield because of which they give extra effort for extracting these and results less revenue but unintentionally negatively affect the biodiversity. There are also many extractors who are actually illegal because they have no permission cause over extraction of the services because of which the tree species are decreasing day by day.

5.3.7 Sustainable Management options for Trees

The above graph shows the change in volume of timber year by year. Where the point which have maximum slope represents the maximum sustainable yield which is actually the total volume of the forest divided by the total time. Which means at that point R is the point of maximum sustainable yield after where the volume of the tree may not increase in an efficient way so that is the point which can be called as the allowable cut point in respect of volume. Actually, this point is the optimal harvest point which means maximum of wood the extractor can get from forest. Any portion after this point may called as old growing forest. And old growing forest is not efficient from the perspective of money making. The forest is not increasing in value so it needs to be cut down and be re grown. Although the growth rate depends on various factors such as topography, rainfall, temperature, elevation, fire, insects and many more things. If volume of timber is considered as Q(t) and value of timber is considered as S(t) the after certain year (t)

$S(t) = Q(t) \times P(t)$

That means volume of timber multiplies by the price of the log.

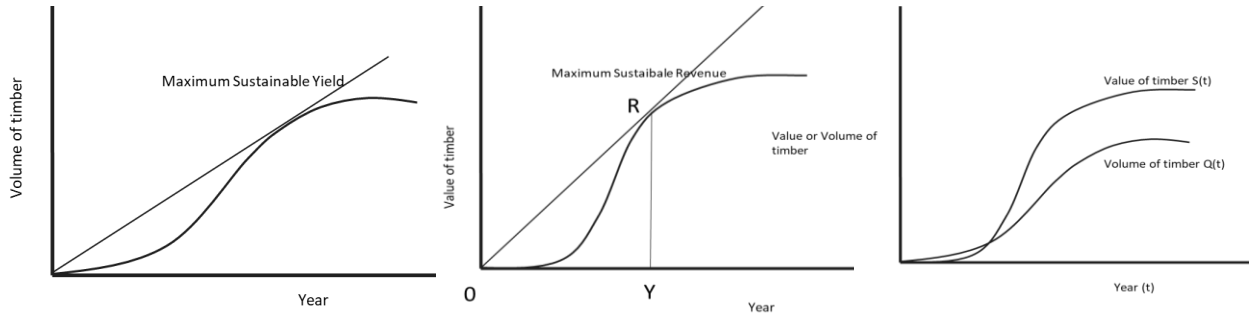
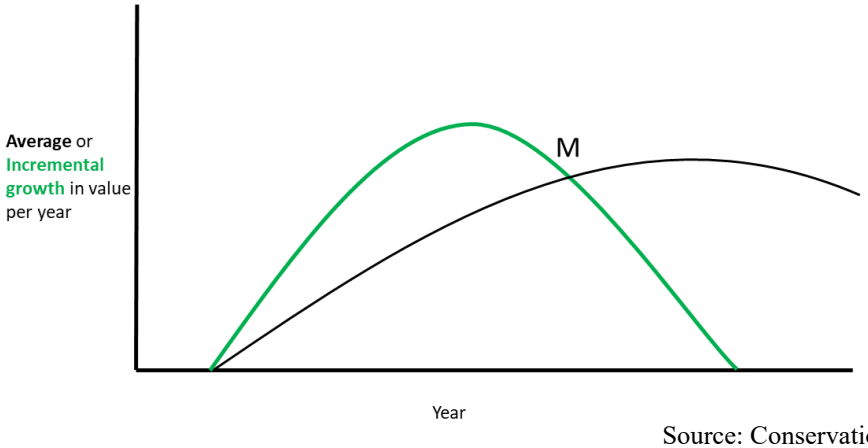


Figure 5.43: Sustainable management options for Trees

Source: Conservation-strategies.org

Then if the value of timber is considered then value will increase slowly at first as value of small trees are not efficient. After some year the value is much efficient and at point R the value is more efficient as the slope is maximum. Here the slope represents the total stumpage value divided by the year. In respect of the value of timber that should be the maximum sustainable revenue point. And in respect of value that point should be the allowable cut point which means the time needs to reach at that R point is the allowable cut point. Because after that point the value of forest is not increasing. Actually after this point the forest will grow in an identical fashion and extractor will get most money in this point from the forest. It the extractor continue the rotation they will get the maximum revenue from the forest. That is why it is called the maximum sustainable revenue.



Source: Conservation-strategies.org

Figure 5.44: Average or incremental growth

Now it represents the same relationships but from the perspective of average growth and yearly value of the trees. As time advances the average growth is relatively small but the incremental growth is bigger as the forest grows faster. And next year the incremental growth is higher where the growth is fastest. But then average growth is increasing but incremental growth is decreasing

as the trees are getting in each other's way. Here the M is the point where the average growth is maximum.

Now if the opportunity cost is considered to see from other perspective. By dividing the new growth with the value of forest right now will give the percentage of growth of forest in next year. This can be used to assess the obtain rotation age in respect of different interest rate. At beginning the percentage of trees growing by is more than 100% as there is no stumpage value. Although the growth is slow here the percent change in value is high because the new growth makes up such a large percent of total growth. Time by time as the growth rate is increasing but the new growth is constantly decreasing. Then at the end the incremental growth became zero and the percent growth in stumpage value became zero. At point R that will be the year which should be set as the rotation cycle to maximize economic growth. Because by letting forest growth the money is not growing as much as extractor can sold the stumpage rights and keep it to any bank. By considering opportunity cost it is possible to harvest time is sooner.

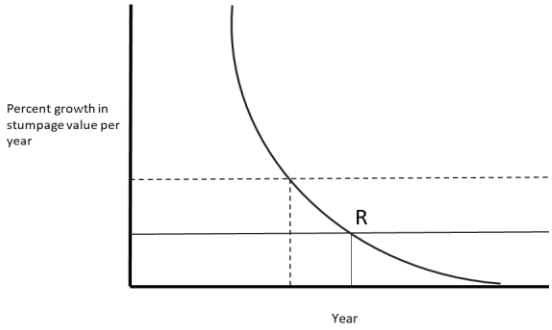


Figure 5.45: Growth percentage value per year

Source: Conservation-strategies.org

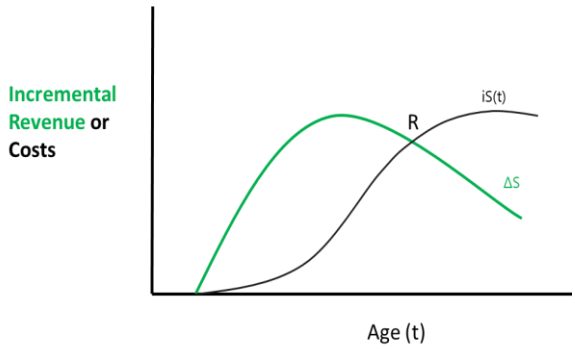


Figure 5.46: Incremental revenue or cost

Source: Conservation-strategies.org

The following graph shows two curves one is opportunity cost and other is the incremental stumpage growth. Both of these curves meet will correspond to the optimum rotation age. If the extraction is keep going the cost is increasing more which is not efficient. So, R is the point where the optimum rotation is efficient that means at this point the cut down can bring more revenue.

5.4 Annual Allowable Cuts (AAC) for Trees

Table 5.2: Annual Allowable Cut for different species in the Sundarbans Source: IRMP (2010)

Species	Growing Stock (V10/ha)	Increment (V10/ha)	AAC (V10/ha /year)	DBH limit (cm)	Total area (ha)	Estimated AAC (V10/ha/year)	Working Plan Suggested AAC	Removal of increment (cum)
Sundari	8.815	7.165	0.62	30	231159	143285	54000	82808
Gewa	0.462	0.41	0.033	15	296698	9887	53000	6081
Keora	0.945	-1.335	0.014	25	319201	4424	29852	-21308
Others	2.313	1.092	0.143	25	231159	33041	23000	12626

The AAC standards are crucial benchmarks for managing resources sustainably. With an AAC of 0.62 V10/ha/year, Sundari shows why it is an important resource in the Sundarbans. The estimated AAC (V10/ha/year) for Sunduri 143285. In order to protect the long-term sustainability of this species, the Working Plan Suggested AAC for Sundari, fixed at 54,000 V10, indicates the conservative approach to harvesting this species. Gewa and Others also show prudent management practices with their low AAC values.

On the other side, Keora has a negative AAC score, indicating that its present harvesting rate is higher than its rate of natural growth. To avoid overuse and potential resource depletion, this requires prompt attention and intervention.

Information on the actual removal of trees in cubic meters may be found in the Removal of Increment values. It reveals that 82,808 cubic meters of wood have been extracted from Sundari, which is much more than the recommended AAC and raises concerns about the sustainability of the project. Keora, on the other hand, has a negative number for the Removal of Increment, indicating the necessity of regeneration and conservation measures.

In conclusion, the chart emphasizes how crucial it is to strike a balance between resource extraction and sustainability in the Sundarbans. The unique environment of this area must be preserved while also ensuring that local residents' economic and livelihood requirements are met. This underscores the necessity for careful management and monitoring of common pool resources. Working plans

that are well carried out and AAC values are essential instruments in striking this precarious equilibrium.

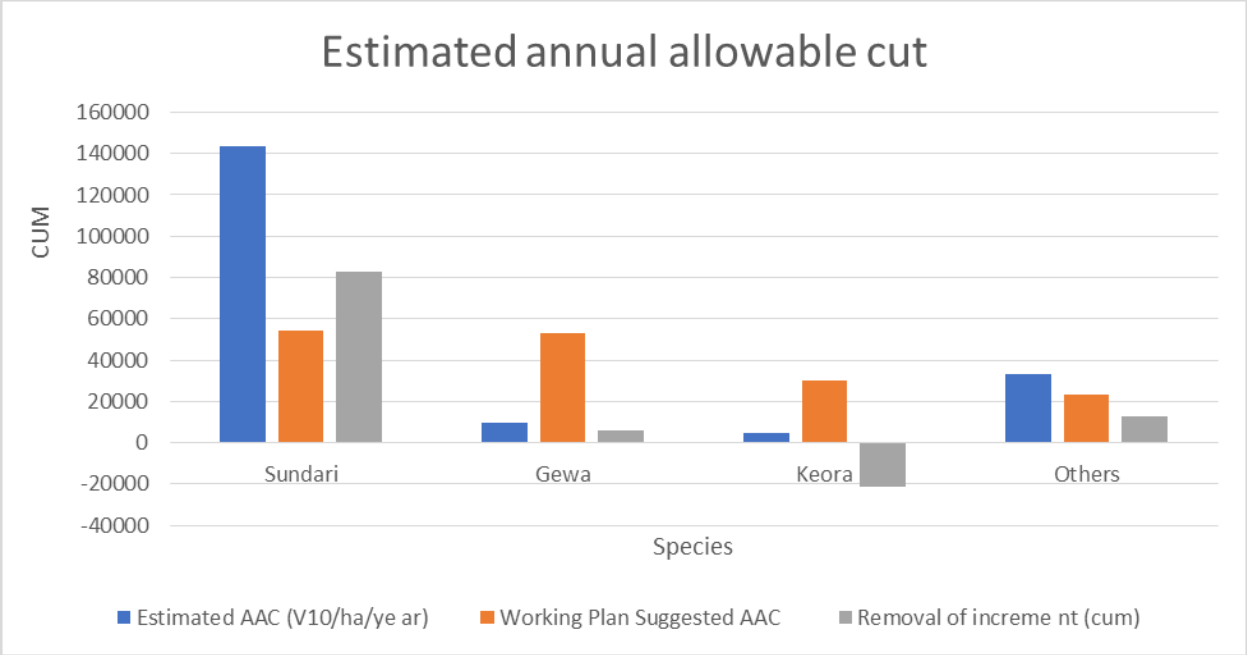


Figure 5.47: Estimated annual allowable cut

Source: Author's preparation (2023)

5.5 CPR management by Local people involvement

According to Ostrom the ideal governing policies will include some policies. These principles represent the formal and informal rules that communities can follow to create a successful governance system for common pool resources. So, in order to protect the environment and conserve the common pool resource of Sundarban at the community level it becomes important to understand what are the rules operating within that community. Some rules can be easily recognized as they are written in formal documents or coded in the law while other rules arise from informal practices like social and cultural norms. All these things can be easily recognized from a careful observation of the community. As there is no perfect rule which can provide a perfect

context so some experiment can be done with different strategies. Actually, good cultures of commons are associated with these things:

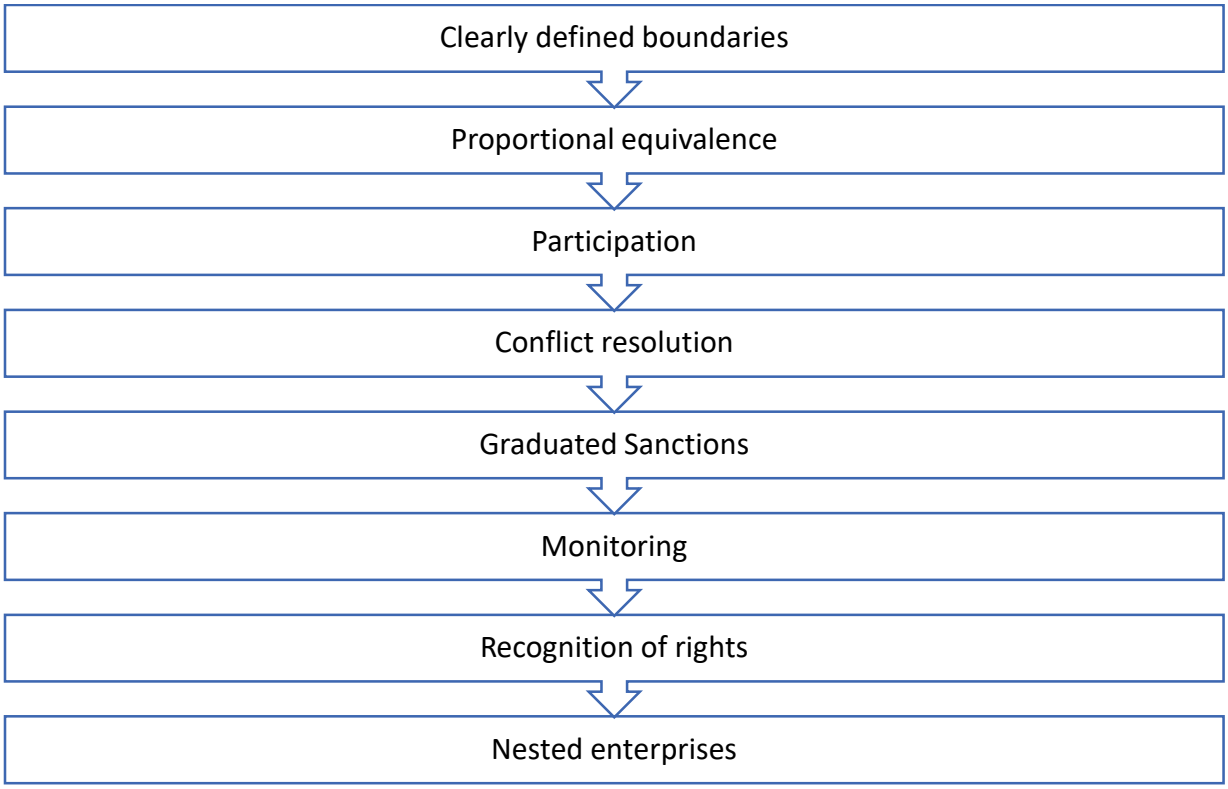


Figure 5.48: Ostrom's principles

5.6 Clearly Defined Boundaries

The defined boundaries of resource area will allow those people who have rights to use it and how much they can extract. It will also guide them to understand that what they are managing and for whom. Clearly defined boundaries also allow people to know who lies inside and who are outside the system and also about who should be considered for maintenance and who should be excluded from benefits.

According to Ali Hossain from FD, Khulna addressed that clearly defined boundary can be so effective to manage the common pool resources more efficiently. He also added that there are several zones and canals which are already protected and extraction of fish and other services are

banned here. Every water body in the three already-existing and future wildlife reserves. Additionally, a 1-km wide region on the sanctuary's northern boundary may also be included in the fishing area prohibition. There are also 18 canals where fishing is banned which are less than 25 feet wide within 3km of forest department camp. He also added that the BLC is given zone wise where BLC receiver from one division cannot receive another BLC from another division. And there are several colors such as green, yellow, blue for each zone which color should be used by the BLC owner on his boat. The decisions are taken by forest department in order to plan for IRMP.

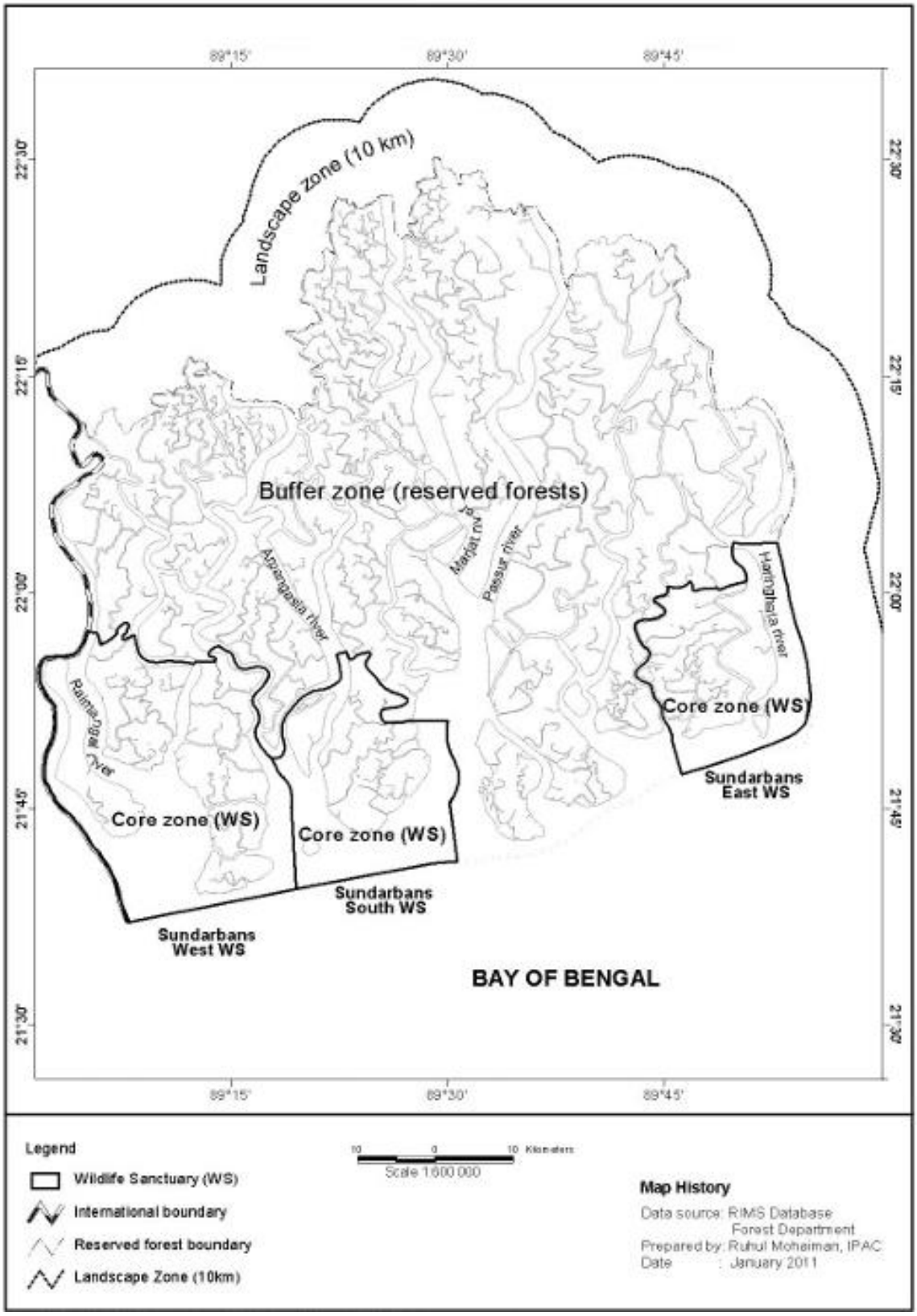


Figure 5.49: Buffer zone of SRF

Source: IRMP (2010)

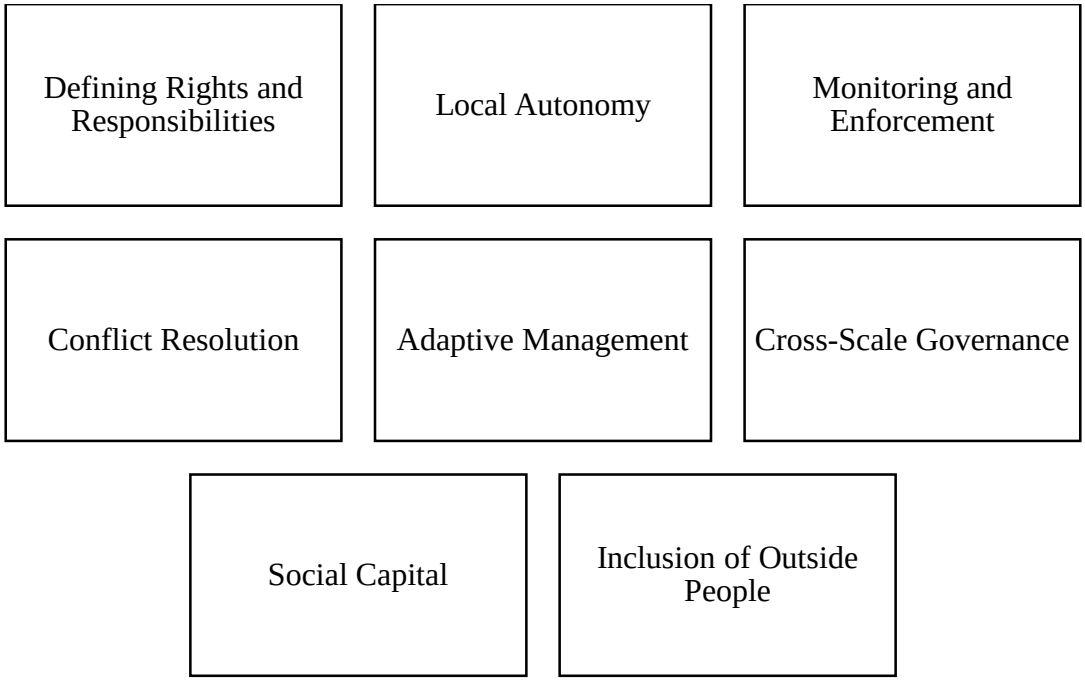


Figure 5.50: Clearly Defined Boundaries

5.7 Proportional equivalence

Proportional equivalent of costs and benefit generally concludes that those who receive highest portion of benefit from the resource should also pay the highest portion of cost require for maintenance of the system. This maintenance system includes monitoring, labor, material, subsidy, infrastructure building and so on. Whoever have the better tools, technology for extraction of the services will extract more and so this individual or group should pay higher for maintenance of the system. As like this an individual who extract less portion of services should pay less for maintenance. This means those who extract more will invest more to ensure long time sustainability than the persons who extracts less.

From FGD it is known that the present system of cost and revenue from ecosystem service is equal for extractor of every sector. The extractor of fish, crab, honey, fuel wood, timber, thatching materials are the persons who gave various information about the costing of extraction. There is a certain portion of tax they have to pay to enter in Sundarbans. According to them entry fee for each fishers per week is 7 taka and for crab collector it is 6 taka. And maximum extraction in a day

would not exceed 2.8 kg per day per person where each kilogram has tax of 3.20 taka for white fish and 12 taka per kilogram for Hilsha. But because of the irregular systems and some illegal activity by the tax collectors they have to pay much more which sometime exceeds ten times of actual tax rate. Another trader claimed that difficulties with Boat License Certificates (BLC) prevented many fishermen from going. He claimed that this year, the authorities are charging much more for the pass. Manosh Bepari said the traders who have more boats and worked with group of people have less cost but earns more revenue from fish and as they have advanced gears, they catch more fish in respect of individual fishers. They also want a system where the people who earns more money from the extraction should pay more for maintenance of the biodiversity.

Proportional equivalence helps in managing the common pool resources by :

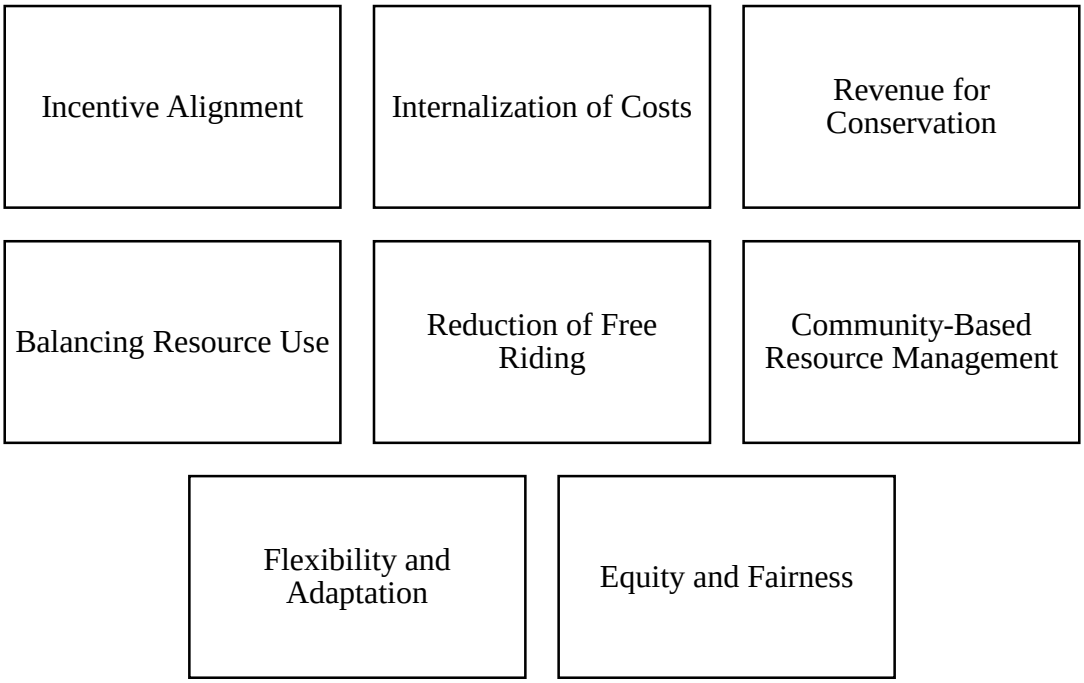


Figure 5.51: Proportional equivalence

5.8 Participation

Participation means participation of the stakeholders from every level in generating rules and regulation by the authority. People who are the direct user of the system are more responsible and experience about the system. Actually, individuals who are directly interacts with the services are in a better position for decision making.

Figure 5.52: Focus group discussion with local community

Source: Field survey (2023)

From the FGD the local people informed that they are always neglected in terms of any decision making or policy making activities. They claimed that the regulations, rules, ban reports on extraction of the resources are done without their participation. As so they suffer a lot during those days of sanctions. They claimed that form June to August there is ban in catching fish issued by the forest department due to the breading season of many species. As they are all depended on Sundarban they have to extract illegally because there is no subsidy from the responsible authority. Actually, there are almost 54% of the people who are willing to pay for the biodiversity conservation by which they will be benefited in the banned time. They claimed they have ability to cope up with other works if there is any way to switch occupation in this ban time. They suggested if the policy making and regulations are given with their concern and knowledge then

the initiative of banning the fishers will more effective for the local people and the biodiversity. They also suggest about some training of other works which can help them in earning by switching occupation in these ban time.

As local people are more interacted with Sundarbans, they can give the best possible ways of giving sanctions, making rules and policies as well as giving ban as they are indigenous and have more knowledge about the services of Sundarbans. Participation of local indigenous people can be so effective in achieving:

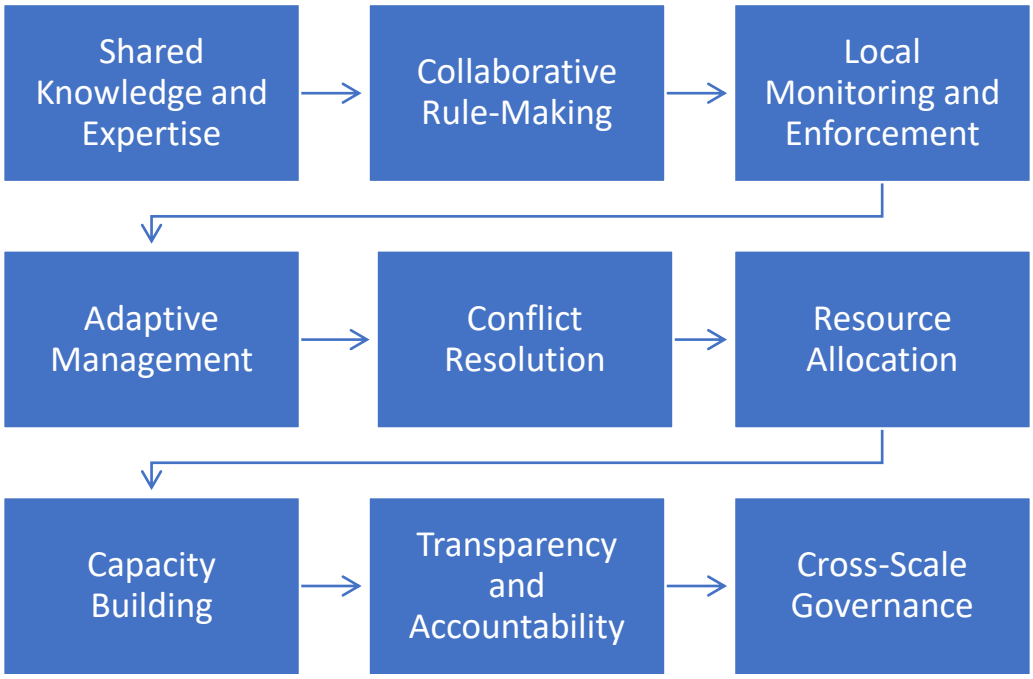


Figure 5.53: Pros of participation

5.9 Monitoring

Monitoring of activities is so important that it helps the extractor to know about the present condition about the resources which will ease the management of common pool resources. Management of common pool resources became easier when people have continuous update about the physical condition of resources and about the activities and irregular behavior of other individuals. But it is important the monitors of the system are also accountable to the users.

Forest officer Ali Mohammad from Khulna Forest Department provide a map locating different forest office point for monitoring the movement of the extractors as well as guide them and aware them in different moments. This office also monitors the fish catch per BLC and provide continuous update about the economic yield. These offices generally observe the extraction methods and movement either any of the extraction move in an irregular way or not.

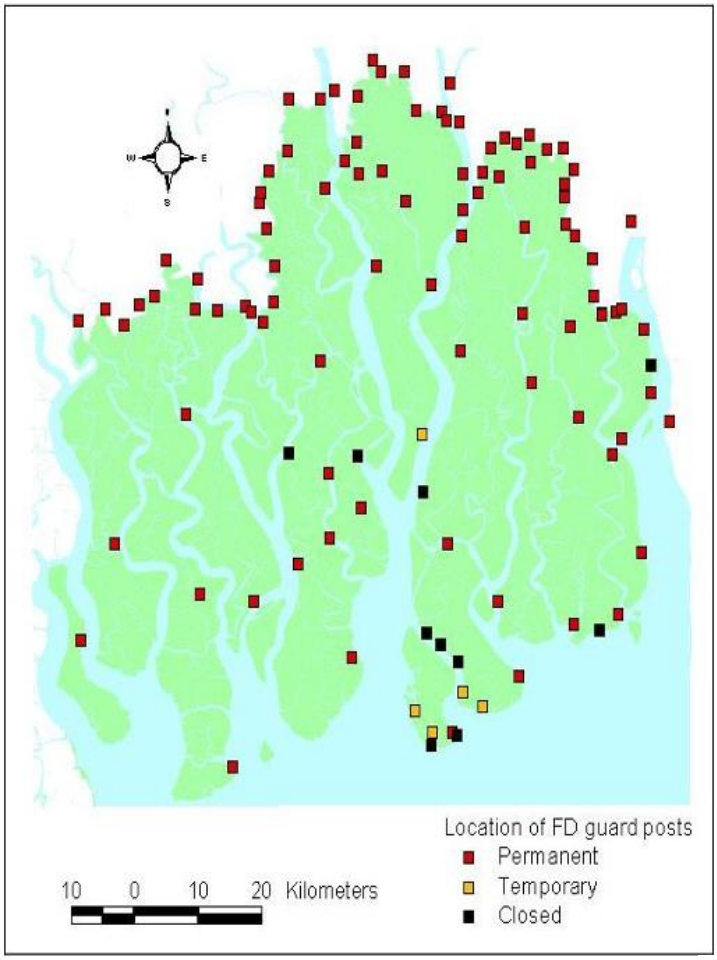


Figure 5.54: Location of guard posts Source: IRMP (2010)

The monitors of the forest department guard post will follow the following things:

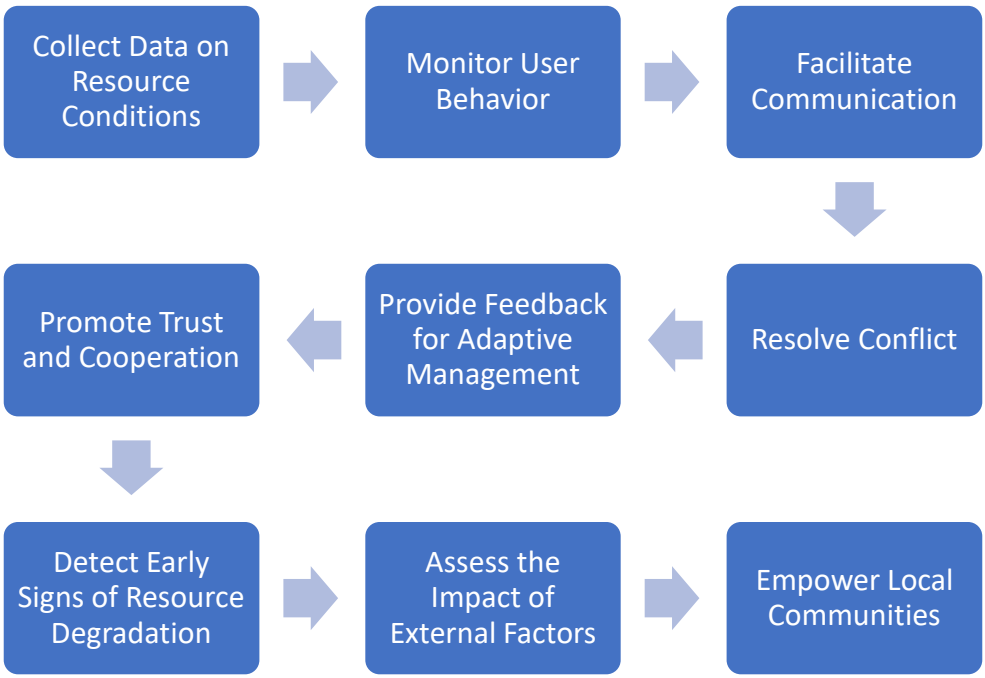


Figure 5.55: Monitoring advantages

5.10 Graduated Sanctions

This actually answered the questions related to what to do with the individuals who take irregular actions and violate the rules and regulations during extraction of resources from the system. So general penalty or punishment should be there to take action for the violations of the individuals by considering the severity of their violence and activities. Where the punishment is low for very first time and gradually increase for every repeated offence.

The FD informs that in the event that any of the conservation measures are disregarded by a person or fisher, the FD field personnel will act within the scope of their legitimate power and in accordance with the applicable laws and regulations. An official at the Forest Station in the East Sundarbans, said that while on routine patrol from the Ismail region of the Sundarbans, the forest guards saw a boat in the canal.

Figure 5.56: Local community during sanction time

Source: Field survey (2023)

Three people were "red-handedly caught at that time fishing with poison in the canal," he added, adding that the detained individuals will be sent to court when a Forest Act complaint was filed.

In the east forest division of the Sundarbans, the fishermen were arrested near Araibeki Junction of Sharankhola Station. The forest officer said that they had been taken away with four boats, six sets of nets, four solar panels, and four batteries. In order to facilitate fish reproduction in the rivers and canals of the forest, fishing is prohibited in the Sundarbans from June 1 to August 31.

5.11 Conflict resolution

Many prosperous communities have easily accessible, low-cost local arenas for resolving disputes among resource users or between users and the government. Having such a framework allows members to debate and settle what is and is not a rule, as well as which acts are and are not permitted. Individuals who make honest mistakes can also make up for their lack of performance in an equitable and suitable manner.

5.12 Recognition of rights

Communities can manage their resources successfully when their rights to organize and adopt rules for themselves are recognized by external authorities such as national or international governments and protected by courts. When community rights are not recognized, it is easier for persons outside the community to access, extract, and pollute the community's resources, and it is also difficult to hold community members or officials accountable for their activities.

Figure 5.57: Focus group discussion with the local community

Source: Field survey (2023)

From the FGD it is almost clear that some of the people get illegal support from the authorities and get extra privilege. And from the local people perspective most of them are outsiders who generally extract more than the margin whose only intention is revenue maximization. They also added that the outsiders never thought of the biodiversity or the futures even though they have also access in the sanctions time too. Actually, the extract much more than their limit which cause over extraction, pollution and depletion of the resources. According to them the local people have more knowledge about the extraction methods as they never cut down the whole bee hive, they leave a portion so that they can extract more honey later. They also added that the illegal people also use illegal method of fishing in order to catch fish quickly and in more quantity. They often use poisons and illegal nets to catch fish which hampers the sustainable the yield by over extraction and poison causes huge pollution. So, they think if the forest department groups take the local people in consideration for the local CPR management it will be more efficient and more effective and sustainable ecosystem will be achieved.

5.13 Nested enterprises

Nested enterprises recognizes that long-lasting, complex resource systems are typically organized into multiple tiers of nested organizations that work together to provide, monitor, enforce, resolve conflicts, and manage. Users can benefit from numerous scales of organizations to better manage their resources by nesting firms with one another.

Figure 5.58: Projects by enterprises

Table 5.3: The process of nested enterprises from different scale Source: Field survey (2023)

Chapter 6: Key findings and recommendation

User	Individual users or user groups engage with the CPR directly at the smallest scales. Local communities, fishers, farmers, or any other group that depends on the CPR for its survival may be among these users. In their local communities, users frequently create informal or formally codified norms and laws for resource use.
Local	The foundation for managing CPRs at this level is found in local communities or user groups. To monitor CPR usage as a group, users might form cooperatives, management committees, or community-based groups. Local institutions create resource access and usage policies that are frequently customized to the unique requirements and circumstances of their CPR.
National	Governments and regulatory bodies at the federal level are essential to CPR management. In order to encourage sustainable resource management and assure adherence to international agreements and norms, national policies, rules, and regulations are created. Governmental organizations may help local CPR management initiatives financially and technically, and they may also keep an eye on resource circumstances.
International	Some CPRs, like shared fisheries or trans boundary rivers, span international borders. International collaboration is crucial under these circumstances. To control the use and preservation of these CPRs, international accords and treaties have been developed. Examples include the several trans boundary water agreements and the United Nations Convention on the Law of the Sea (UNCLOS) for fisheries. International institutions, such the United Nations and regional organizations, may help with discussions, the exchange of scientific information, and the promotion of the best CPR management methods on a worldwide basis.

6.1 Key findings of the study

- The average annual revenue from timber of Sundari, Bine, Keora, Gewa and others from Sundarban is almost 8.07 million taka during the time period of 2011 to 2022. Because of the rules and regulation on extracting the timbers from Sundarban the extraction rate is very low from 2013-2014 financial year.
- The major revenue of Sundarban is generated from the revenue from fish. Dry fish, White fish includes various species, Hilsha, Bagda fry, Shrimp are the dominated species from where the average annual revenue is almost 48.5 million from 2011 to 2022. But with the increasing effort of the fishermen the average production is decreasing gradually.
- The average annual revenue from thatching materials is almost 2.7 million taka per year for the time period of 2011 to 2022 where thatching materials includes Golpata, Shan, Malia grass and so on.
- Fuel wood includes Goran, Hetal, Kakra and others from where the average annual revenue is almost 0.5 taka. The extraction amount is decreasing from 2013 because of the various sanction and regulations from the Forest Department.
- The average revenue earned from crab is almost 4.38 million taka per year for the financial year of 2011 to 2022. The value is depended on the size and gender of the crabs.
- The annual average revenue from honey collection is almost 1.61 million and from wax is almost 0.6 million taka. The average revenue is calculated for the financial year 2011 to 2022.
- The average economic value of the provisional services of Sundarbans is almost 65.86 million taka between the financial years 2010-2022.
- Sundarban get affected by tropical storms like cyclones almost three times per year. It affects the extractor of provisional services directly in extraction for an average of almost 12 to 15 days. And also affect the ecosystem for which just after the storm the extraction rate is less than usual time. The direct average economic loss occurs to the extractors are ranged between 4000 to 4500 taka for the fishers, 2000 to 2500 for the crab collectors, 5000 to 5500 taka for the honey collectors, 3500 to 4000 taka for the fire wood or thatching material collectors per storm. And difference in the weekly income of the collectors before and after one week of the storm is a significant amount which is almost 500 taka for fishers and more than 1000 taka for mawals who collects honey and wax.

- Although there are long term effect of these climate change events such as SLR, increase in salinity, land cover change which hampers the growth of population for various species and create depletion because of decrease in land portion but there is a positive thing that because of the disturbance in the extraction process the ecosystem gets benefited. The amount remains available in the ecosystem and help the biodiversity to grow more effectively and decrease the amount of over extraction.
- There are many problems related to common pool resources for which FD take various policies and fixed the maximum sustainable yield for fish which is almost 4421.2 tons. The annual allowable cut for several tree species is also fixed and also there are regulations on the methods of extracting and time period of extraction. But although all these initiatives is for maintaining the growth rate of the species the results are very disappointing as the yearly production represents different perspective.

6.2 Recommendation

- In order to save the Sundarban from depletion of the provisional services it should be ensured that the extraction of the services never excess the MSY. So, the responsible field staff of forest staff should continuously monitor the extraction volume and give update to the extractors. If the extraction reaches to the MSY then the decision should be taken to stop the extractions of ecosystem services.
- Legal procedures should be followed during the issuance of BLC and renewing the BLC. No BLC should be issued illegally after the maximum number of issuances. Now the maximum permit is 100000 for fisheries to meet 4421 tons. But as many illegal activities often occurs almost 23% illegal extractors which can be minimized by proper monitoring to 5% according to responsible authorities. So, the MSY should be fixed in 4200 tons and the permit should be fixed on 95000 per year. Which can be changed in every year by following the catch rate/BLC. If the capacity of Sundarban increases then upto 10% the permit as well as MSY can be increased.
- In the revenue perspective with the existing cost of 167 taka per fishers per trip there should be added some extra cost which can force them to stop over fishing which they did because of their poverty and other problems. About 54% the fishers are willing to pay another 13 taka as cost per trip in order to protect the fishing population by sustainable growth. For individual fishers they can stop at the point when the revenue is 334 taka per person per trip. And for the group of people of fishers they can extracts till the revenue of more than taka per person per trip.
- The shared quota system can be implemented among the fisherman. Among which the fisherman with less capable to pay tax and catch fixed amount of fish can shared a suitable portion of the quota to the fisherman who is more capable of paying more tax and catch more fish because of his improved gears and technology or methods. As there is a cost of taking permission and cost for paying tax which is 320 taka per quintal for white fish, 375 taka per quintal for crab, 750 taka per quintal for honey, 25 taka per quintal for Golpata every fisherman may not have the ability to catch much fish and pay this much money. So, they can share their quota to the person who has the capacity. Sometime he can share all his portion and work under the more capable fisherman which will bring more benefit to him.

- For the trees the annual allowable cut is estimated which is 143285 V10/ha/year for Sundari, 9887 V10/ha/year for Gewa and 4424 V10/ha/year for Keora. The working plan for annual allowable cut for Sundari, Gewa and Keora is respectfully 54000, 53000 and 29852. And the removal of increment is 82808 cum for Sundari and 6081cum for Gewa.
- Along with the sanction period during the breeding season of the fish the catch of fish should be banned when the extraction reaches the MSY point.
- In order to make the local people aware of depletion and encourage them to keep distance from any illegal activities financial support such as subsidy, soft loans, donation from government and non-government organization should be provide which will save them from taking loan from money lenders which is actually a burden for them.
- The recommendation from local people was also to include them in the policy making of various rules and regulations about the extraction of ecosystem services. In the meantime, proper training opportunity of other working sectors like farming, fisheries for the local people who only depended on the Sundarban for income in order to improving the occupational ability in several sectors to income during the ban period. And during several storms as they cannot go to the forest for extraction of services, they expect necessary relief to save their life. So alternative incoming opportunity creation initiative should be taken by responsible authority.
- The forest department should more responsible in monitoring the catch and extraction of the ecosystem services by the extractors and enhance the capability of the forest offices. There should be continuous update on the physical situation of the ecosystem services. There should be a coordination among the various enterprises as users, local, national and international authorities in order to manage the common pool resources sustainably.
- The responsible authority should adequately step to assess the tropical storms vulnerable zones as well as identify the alternative technologies for income. They should engage with local stakeholders in conversations about workable value chains and alternative revenue-generating technologies. And also, local authority, various NGOs as well as the FD should extend the activity related to priority value chains centered in communities, such as fisheries and tree nurseries.

Chapter 7: Conclusion

Managing the extraction of Sundarbans ecosystem services is very much essential from depletion as it contributes a huge value in the country's economy. Sundarban accounts for 40% of Bangladesh's forested land. Each hectare of SRF provides $793 in annual provisional services. But over extraction due to inefficient management of the common pool resources will change the whole structure of the system. In the perspective of contribution in economy, importance in ecology, saver from natural calamities and occupational hub for local communities the depletion is a great loss for every component from every corner of the country.

This study aimed to assess the economic value of the services extracted by the local communities, analyze the disturbance to local people in collection by tropical storms and ongoing common pool resource management to save the Sundarban from depletion and insure the livelihood of the local community. Here the strategies to manage common pool resources through local community with involvement of different level stakeholders are proposed where models from Ostrom, Gordon, Scheafer is used. All the management strategy is formulated in consideration of ensuring the maximum sustainable yield, maximum sustainable revenue, annual allowable cut, alternative incoming opportunities arrangement for local community and so on.

The economic importance of the provisional ecosystem services, impact of the tropical storms on these services are examined and existing managing policies of the resources are observed in this study. Although the economic importance is huge but because of poverty, climate change effect and externalities the collector use illegal and irregular procedures with or without the help from responsible authorities. Various management policy is taken by the Forest Department within which tax execution, fixed BLC, regulation on fishing method, regulation on time of extraction, alternative income opportunity arrangement, and boundary fixation. But the result is not efficient enough because of the illegal and irregular movement and activity of the extractors.

The improved management policy is proposed with the experts and local communities from the Sundarban who are directly associated with the services of Sundarbans. The local communities are willing pay extra money in order to better management on the common pool resources of Sundarban for their ensuring their better livelihood. Shared quota among the extractors, fixed a

MSY point with including some additional cost which the local people are willing to pay, community fishing and crop production, agricultural production options can be efficient in order to reduce the depletion of the resources. Here the local authority such as forest department has a huge responsibility to create coordination among users, local, national and international enterprises which can facilitate the local people economy by more income generating opportunity, financial supports, and subsidy and so on. This study actually showed the importance of ensuring the sustainability of Sundarbans ecosystem services and expected to improve the livelihood of the local community by improving their livelihood socially and economically.

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