Regenerating Mangrove Biodiversity in the Sundarbans Biosphere Reserve India

An assessment of scope and present interventions for ecological mangrove restoration in Sundarban Biosphere Reserve India

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An assessment of scope and present interventions for ecological mangrove restoration in Sundarban Biosphere Reserve India

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Caritas INDIA
The Joy of Service...

Contents

Foreword

Caritas India lives by its motto, 'The Joy of Service. The recent disasters in Sundarbans cyclones — Yaas, Amphan, Bulbul and Aila — have devastated and displaced millions of marginalised people in the Sundarbans. On one hand Caritas India feels sad and my heart goes out to all those families who are severely hurt by these disasters, those who lost their loved ones and all those who are still in search of a decent livelihood to put back smiles to their family's face. Climate change is increasing the frequency as well as the intensity of the cyclones that impact the Indo-gangetic delta. Mangroves are the only natural solution to this issue. Restoring mangrove vegetation can stabilise banks, attenuate wave pressure and hinder the wind damage during cyclones. Mangroves have been proven to be the best ecosystem-based disaster risk-reduction.

Scientists have indicated that after oceans, mangrove and sea grasses are the best carbon sink. Hence, mangrove plantation can be instrumental in sequestering GHG gases and halting the progress of harsh climate change impacts. Restoration of mangroves is the only option to save the 4.6 million people residing in the Indian Sundarbans from natural disasters. Natural methods are sustainable, eco-friendly as well as economically viable over technological alternatives. This document is part of an ongoing process exploring Caritas India's engagement Sundarbans . Caritas India have undertaken this study in three Gram Panchayats on the Sagar, Patharpratima, Namkhana islands to understand the respective exposure to multiple hazards like cyclone, inundation and erosion , prospective areas for mangrove plantation, and predominant plantation methods and mangrove species combination. The study acts as baseline for ongoing Disaster Risk Reduction programme and future advocacy tool.

Fr. (Dr.) Paul Moonjely
Executive Director
Caritas India

Executive Summary

Mangroves are the world's most productive ecosystems. High carbon sequestration potential, coastal protection, enrichment of coastal waters, support to coastal fisheries, and provision of forest products are some of the benefits offered by mangroves. For centuries, mangroves have supported the subsistence of coastal peoples, yielding firewood, charcoal tannin, dyes, food and beverages, medicines, poles and even timber. However, as Caritas India acknowledges, mangroves in the Sundarbans, located in the Ganges-Brahmaputra-Meghna Delta – home to 3% of Asia's mangrove forests, and the only one in the world with a tiger population – is under ecological threat due to rising salinity, tidal velocity, commercial exploitation, and human encroachment, which are responsible for degrading mangrove health and rising mangrove depopulation.

In keeping with the spirit of the Constitutional mandate to protect and preserve India's forest reserves, the National Forest Policy (1988) emphasizes the co-management of forests through the adoption of sustainable Joint Forest Management practices, ensuring the wellbeing of forest-dependent communities. The National Environmental Policy (2006) envisages environmental conservation in a cooperative and coordinated manner, and advocates Integrated Coastal Zone Management (ICZM) for sustainable management of the coasts, ensuring coastal livelihood and improving coastal economics. In recognizing the importance of multi-stakeholder partnership in conserving natural resources and recommending planning and implementation of environmental conservation plans at the Gram Panchayat (GP) level, the policy advocates cooperation with community-based organizations and other associated stakeholders for forest conservation. The Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act 2006, commonly referred to as the Forest Right Act (FRA), recognizes the historical injustice meted out to India's forest dwellers, particularly the tribal people (MoTA, 2006), and calls for the protection of these disadvantaged groups by ensuring that they have access to the forest products that are intrinsic to their subsistence.

In the last few decades, several studies have indicated that the Sundarbans is suffering from the ongoing relative sea-level rise, and that the principal estuaries of this region have lost their connection with the perennial upstream flow of the Ganges. Excessive salinity can lead to changes in species composition and, sometimes even extinction, of a particular mangrove species. The analysis of multitemporal Landsat data shows a significant erosion of mangrove forest in the core and buffer areas of the Sundarban National Park, whereas an increase of fringe mangroves in the transition area with human habitation is observed, thanks to natural regeneration and plantation efforts. Between 2000 and 2020, 110 km2 mangrove area, at a rate of 5.5 km2/yr, has been lost 81.2km2(4.06 km2/yr) area was gained in the fringe areas of the Sundarban Biosphere Reserve where human settlements are located.

As the present report states, natural regeneration and mangrove plantation with community involvement in the human habitation area has opened up a scope of offsetting the mangrove and blue carbon loss in the future.

The report details the findings of an investigation designed against such a backdrop, within the following scope of work for mangrove regeneration:

A. Assess and explore the scope of mangrove plantation in the Sundarbans to reduce disaster risk in vulnerable patches of the Sundarbans

B. Illustrate the importance of conservation and management of mangroves by involving the local populace and stakeholders, and adopting appropriate management strategies

C. Determine issues related to policy advocacy for mangrove conservation and management

In order to achieve the above objectives, three prospective sites for mangrove plantation in three Gram Panchayats on the Sagar, Patharpratima, Namkhana islands – have been identified, respective exposure to multiple hazards like cyclone, inundation and erosion quantified, prospective areas for mangrove plantation identified, and predominant plantation methods and mangrove species combination studied. Community-based

Ecological Mangrove Conservation using commonly practised plantation methods in India, such as the canal or trench method of plantation (also known as the fishbone method) of mangroves, which are being adopted in the Indian Sundarbans, and the alternative Riley Encased Method, have been detailed.

The survey could establish that 30 to 45% of the island communities depend on the resource of the mangrove ecosystem for their sustenance and livelihood. The following social and ecological successes associated with community-based mangrove regeneration have been noted by the research team:

a) Workdays for the local populace have increased in the areas adjacent to the mangrove plantations and nurseries

b) A sense of unity and cooperation has been infused into the local community involved in mangrove plantation and protection

c) Biodiversity has increased in the plantations and the nurseries. More diverse types of bees, birds, butterflies, and insects, and snakes, crabs are now being observed. The number of fiddler crabs has increased significantly

d) Beautification of mangroves in the riverbanks, which is a crucial aspect of ecotourism in Sundarbans has been achieved.

The report recommends that the following key factors associated with the promotion of community-based mangrove plantation and protection efforts in the Indian Sundarbans be addressed by effective policymaking and implementation:

I. It is essential to study the tidal velocities, salinities, and any other potential problems (e.g., grazing, prawn seed collection, embankment construction, boundary conditions, etc.] of the plantation sites prior to mangrove regeneration attempt
II. Mangrove plantation should be taken up only after the scope for natural recovery and regeneration has been exhausted and after re-establishing favourable boundary conditions.
III. Instead of rapid plantation, efforts and resources may be directed more towards protection and maintenance of the new plantation for years
IV. Multi-species plantation instead of single species of avicennia should be encouraged. Species combination may be scientifically selected after testing soil salinities, erosion/accretion and hydrodynamic condition around the sites by government agencies and NGOs
V. Women's SHGs in different islands should be appropriately trained and mobilized in establishing mangrove nursery, plantation procedure, and protection/maintenance for initial years. Adequate monetary compensation must be given to the participants.
VI. Ban on establishment or expansion of shrimp farms at the expense of mangroves should be strictly implemented by the Government within the ambit of existing legal provisions.
VII. Procedures for appropriate institutional reforms to implement the UN-sponsored REDD++ schemes, sorting out the issues relating to forest rights, forest use rights, rights of stakeholders and local people on carbon credit, in consultation with the Department of Forests, CSOs/NGOs and local Panchayat bodies must be undertaken.
VIII. The rejuvenation of freshwater river channels through the Sundarbans for reduction of salinity needs to be implemented.

This report promotes the understanding that successful restoration requires the study of previous failures and rooting out the causes for mangrove degradation. It is very crucial to develop plans for long-term management and governance for mangrove regeneration, and to equip the local communities with the capacities to adopt a self-sustenance model when funding from 3rd party agents stops, through village-level institutions, skill development, entrepreneurship, and self-governance training.

Ecological Restoration of Mangroves

"Reading that history from the tell-tale signs of today, is the artful skill of the silvi culturalist or restoration ecologist who is likely to succeed" - (Saenger, 2002).

The World of Mangroves

The Mangrove ecosystems are 'dynamic, unpredictable, subject to aperiodic and periodic extreme fluctuations, and, more importantly, each mangrove community has a history' which must be considered while planning their silviculture, management, or restoration (Saenger, 2002).

Figure 1 Global mangrove distribution (Giri et al., 2011)

Mangroves are one of the world's most productive ecosystems. With high carbon sequestration potential, mangroves contribute significantly to the global carbon cycle by storing organic carbon in above and below-ground biomasses well as in coastal soil (Kathiresan & Bingham, 2001). They protect the coastline, enrich coastal waters, support coastal fisheries, yield beneficial forest products, and serve as a habitat for various kinds of fauna and as sites for the ecotourism industry (Kusmana, 2015). Geographically distributed between 30° North and 30° South, mangrove forests extend from Japan (31° 22'N) and Bermuda (32° 20' N) in the north to New Zealand (38° 03' S), Australia (38° 45' S), and the east coast of South Africa in the south (Spalding et al., 1997). Areas in a total of 124 countries were identified to be hosting one or more true mangrove species (Saenger et al., 1983). Although major mangrove degradation occurred in the colonial era from unscientific commercial exploitation, in less than three decades between 1980 and 2005, mangroves decreased from 18.8 mn ha to some 15.2 mn ha worldwide, according to the FAO (2007) (FAO, 2007). The most extensive mangrove area is found in Asia, followed by Africa and North and Central America. Asia, accounting for the lowest forest area in terms of percentage of land area, has the largest extent of mangroves (approximately 6 mnha) (Kusmana, 2015).

Mangroves have been used by coastal people for subsistence for centuries (Lacerda et al., 1993), mainly for firewood, charcoal tannin, dyes, food and beverages, medicines, poles, and timber. Fishing and charcoal making were the basic economic activities around mangroves during the early commercialization based on the ignorant views of mangroves followed by large scale commercial mangrove exploitation for production of logs, charcoal, and chip woods during the colonial rule (Saenger, 2002), which continued from the 1930s until the mid-1970s. During the late 1970s to the early 1980s, with the gradual conceptualization of Sustainable Development, the realization of mangroves and associated ecosystems as sustainable units arose, but it collided with the contemporary practice of developing large-scale industrial aquaculture, mainly for prawns (Kusmana, 2015). With the inception of sustainable forest management by the enactment of the Rio Declaration on Environment and Development by UNCED in 1992, the concept of optimizing forests for the sustainability of economic, social, and ecological functions of the forest ecosystems came into being.

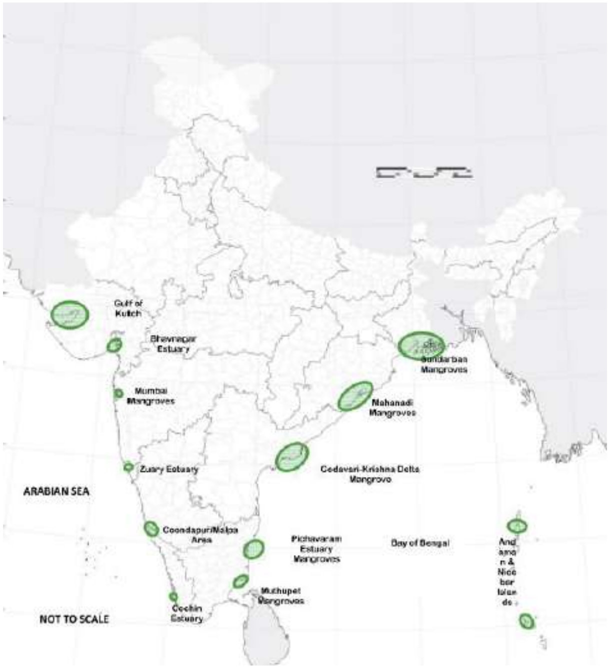


Figure 2 Mangrove distribution in India (Dasgupta and Shaw, 2013)

Mangroves in India

India, home to 3% of South Asian mangrove cover in the entire coastline, is home to the unique mangroves of the Sundarbans, the only mangroves to host tigers, shared with Bangladesh. The Sundarbans, in the Ganga-Brahmaputra-Meghna Delta, in the state of West Bengal, account for nearly half of India's entire mangrove areas (FSI, 2017). In India, the Constitution mandates the State (Art. 48 A) and every citizen (Art. 51 A(g)) to protect and develop a clean environment. The National Forest Policy (1988) mandates the sustainable forest management concept and emphasizes co-management of forest conservation measures, ensuring well-being of communities dependent on them through the Joint Forest Management practices (MoEF, 1988). Mangroves beyond the notified forested areas are considered Wetlands and the 'National Conservation Strategy and Policy Statement on Environment and Development, 1992' that identified the significance and uniqueness of wetlands, and that wetlands are being subjected to overexploitation, pollution, and other severe damages from natural causes, recommend micro-level planning for resource development, comprising management plans involving the village (MoEF, 1992). The National Environmental Policy 2006 envisages environmental conservation in a cooperative and coordinated manner, and advocates Integrated Coastal Zone Management (ICZM) for sustainable management of the coasts, ensuring coastal livelihood and improving coastal economics (MoEF, 2006). The policy recognizes the importance of multi-stakeholder partnership in conserving natural resources and recommends planning and implementation of environmental conservation plans at the Gram Panchayat (GP) level, in cooperation with community-based organizations and other associated stakeholders. The Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act 2006, commonly referred to as the Forest Right Act (FRA), acknowledging the historical injustice meted out to India's forest dwellers, particularly the tribal people (MoTA, 2006), provides for the allocation of land to traditional communities in all forests, including core areas of National Parks and Sanctuaries.

Sundarban Mangroves and Salient Features

The Sundarbans is not only the largest mangrove forest but also one of the most dynamic deltaic interfaces of the world (Hazra et al., 2016). This marvellous mangrove forest was crowned as a UNESCO World Heritage site owing to its rich biodiversity in all the strata of the ecological food chain (Chaudhuri et al., 1994). This pristine landscape acts as an abode to tens of thousands of flora and fauna (Gopal and Chuahan, 2006). Besides, the periphery of the Indian Sundarbans hosts a human population of approximately 4.4 mn people (Census, 2011) in the Sundarban Biosphere Reserve (SBR) (Fig), which is a severe threat to the wellbeing of this ecosystem (Danda et al., 2019).

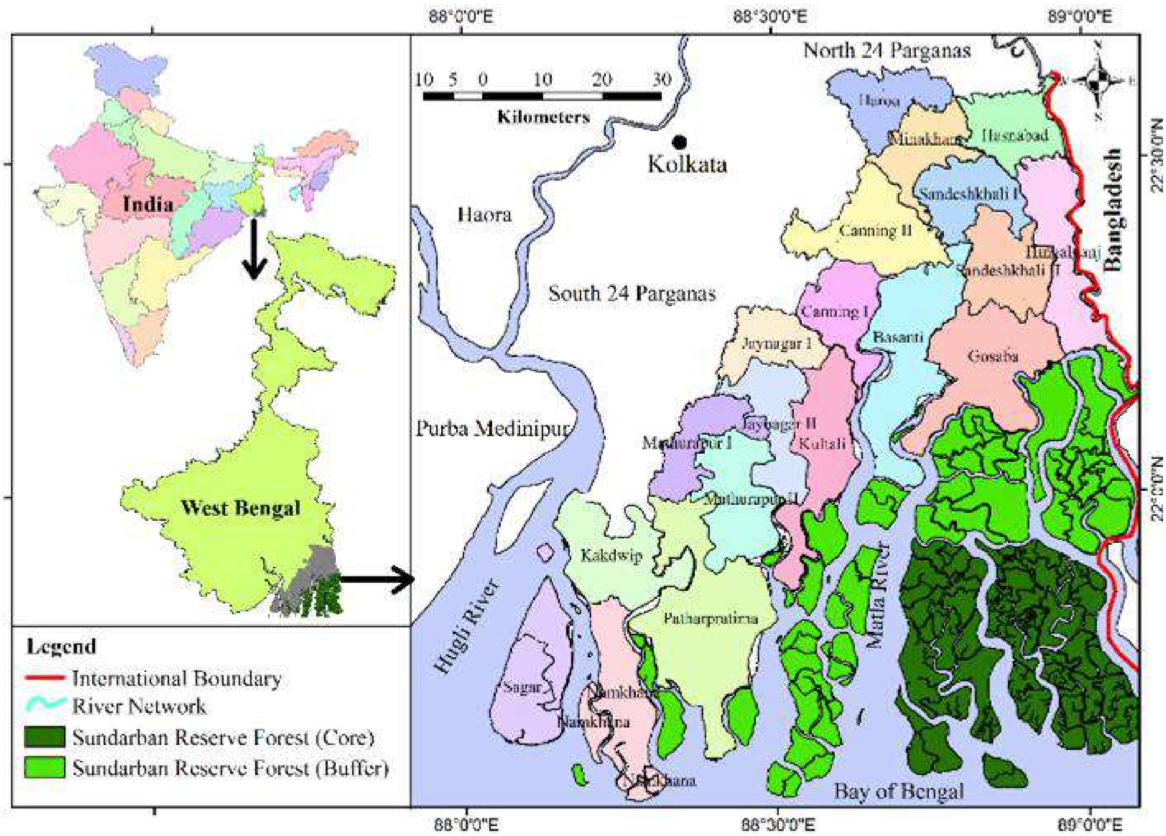


Figure 3 Sundarban Biosphere Reserve (India)

The total stretch of the Sundarbans encompasses one of the most biodiverse mangroves stands of the world. However, this eco-region is lately experiencing various types of stress due to multiple factors. In the past few decades, several studies have indicated that the Sundarbans is suffering from the ongoing relative sea-level rise (Hazra et al., 2002; 2016; Mukhopadhyay et al., 2018). In addition to this, the principal estuaries of this region have lost their connection with the perennial upstream flow of the Ganges (Bhadra et al.,2019). The monsoonal runoff from the upper reaches also plays a crucial role in maintaining the estuarine character of these mangrove estuaries (Raha et al., 2012). Indeed, mangroves require a considerable magnitude of salinity to thrive and flourish (Barik et al., 2018); however, excessive salinity can lead to changes in species composition and sometimes even extinction of a particular species (Banerjee et al., 2017; Rahman, 2020). The aquatic salinization of the adjacent estuaries incurs an inadvertent effect on the sediment salinity, which can significantly deteriorate the health of mangroves (Dasgupta et al., 2017; Mukhopadhyay et al., 2018; Hati et al., 2020; Choube et al.,2019). Chowdhury et al. (2019) have observed a significant decrease in the nutrient content in the mangrove sediment profile and acute stress in many floral freshwater-loving floral species followed by salinization of the mangrove sediments throughout the Indian Sundarbans.

Loss of landmass due to the incessant erosion taking place all over the Sundarbans toa spatially varying extent is another point of major concern (Quader et al., 2017). Accretion always accompanies erosion in a dynamic delta, and the Sundarbans is not an exception. However, the net loss of land is evident from various studies, which implemented remote sensing tools to evaluate the spatial as well as temporal dynamics of the landmass in this region (Hazra et al., 2016a,b; Bera and Maiti, 2019; Sahana and Sajjad, 2019). Between 1986 and 2012, Samanta and Hazra (2017) recorded the loss of a significant amount of land with mangrove forest cover. Bera and Maiti (2019) have pointed out that accretion rates are slow near the mangrove-dominated islands and the rate of erosion is increasing in the embankment-bounded inhabited islands, thus leading to net erosion. A recent study by Hazra et al. (2020, EGU) has indicated a loss of 110 km^2 area only from the core and buffer areas of the protected forest.

Moreover, this region, on the northern margin of the Bay of Bengal, suffers from frequent occurrences of tropical cyclones. Besides the human population that resides in this coastal periphery, the mangrove flora experiences the wrath of these cyclones every year (Dasgupta et

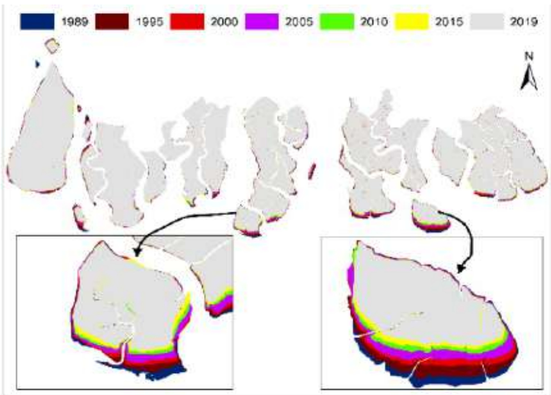


Figure 4 Loss of human and tiger habitat in the Sundarbans over the last 3 decades

al., 2019). Meteorologists have established that the frequency and intensity of tropical cyclones over the Bay of Bengal have increased manifold in the last two decades (Sattar and Cheung, 2019; Bhardwajet al., 2019; Bhardwaj and Singh, 2020). This has resulted in significant deterioration of the health of the mangroves (Samanta et al,under publication). Aside from all these climatic factors, human intervention and encroachment of mangrove lands has become a serious issue. Destruction of mangrove forests and their subsequent conversion to agriculture and aquaculture lands (Giri et al,2021) has become one of the viable alternative options of livelihood for the inhabitants of the Sundarbans (DasGupta et al., 2019). Despite so many factors constantly threatening the very existence of this ecosystem, the Sundarbans standstall with a forest area of around 2100 km^2 (Samanta and Hazra, 2017).

The present investigation was designed against such a backdrop within the following scope of work to be accomplished:

Scope of the Present Work

A. Assess and explore the scope of mangrove plantation in the Sundarbans to reduce disaster risk in vulnerable patches of the Sundarbans

B. Illustrate the importance of conservation and management of mangroves by involving the local populace and stakeholders, and adopting appropriate management strategies

C. Determine issues related to policy advocacy for mangrove conservation and management

A. Assess and explore the scope of mangrove plantation in the Sundarbans to reduce disaster risk in vulnerable patches of Sundarbans

1. Mangroves for Disaster Risk reduction

In a recent study, researchers(Sannigrahi et al.,2019,20) have identified and evaluated 5major regulating services of mangroves, like carbon sequestration, habitat function for biodiversity, water yield, sediment retention, and nutrient recycling, varying spatiotemporally in the SBR.The analysis showed a prominent decline of such ecosystem services during the 2000-2017 period, which might be ascribed to the erosion of forest areas and decline of the health of the mangroves due to salinity rise and climatic hazards.

Cyclonic storms frequently ravage the mangrove stands of the Sundarbans. However, a few studies have indicated that mangroves have a dominant role in disaster risk reduction, preventing damage to both humans and property. Akber et. al. (2018) have suggested that the storm protection service of mangroves has always remained underestimated and undervalued. They have demonstrated that a few villages in Bangladesh, that were protected by mangroves during Cyclone Sidr, suffered almost half the monetary loss compared to villages that were unprotected by mangroves. Sarker et al. (2020) have also emphasized the role of mangroves on a similar ground.

A wider patch of mangrove between coastline and village community have been proven to be beneficial in preventing death and destruction. Integrating mangroves into disaster risk reduction can be more effective than building infrastructure to protect coastal communities from flooding and deadly wave action. But when this natural infrastructure is lost due to development, alternate land usage, and the impacts of climate change.

However, in the Indian Sundarbans, cyclone track records over the last few decades indicate that cyclones mostly impact the human habitation from the south or south-western direction, while the mangrove forests are located on the east. Hence, unlike in the Bangladesh Sundarbans, mangrove cover in the Indian Sundarbans was unable to offer storm and surge protection to the villages. Therefore, it is imperative that mangrove bio shields surrounding the populated islands be grown through a well-planned mangrove regeneration programme. However, this may necessitate the relocation of 1700 households from the island margins to the interiors to leave room for the bioshields.

In order to assess the multi-hazard exposure of the islands at the village and GP levels, hazard index comprising cyclone incidence, resultant surge

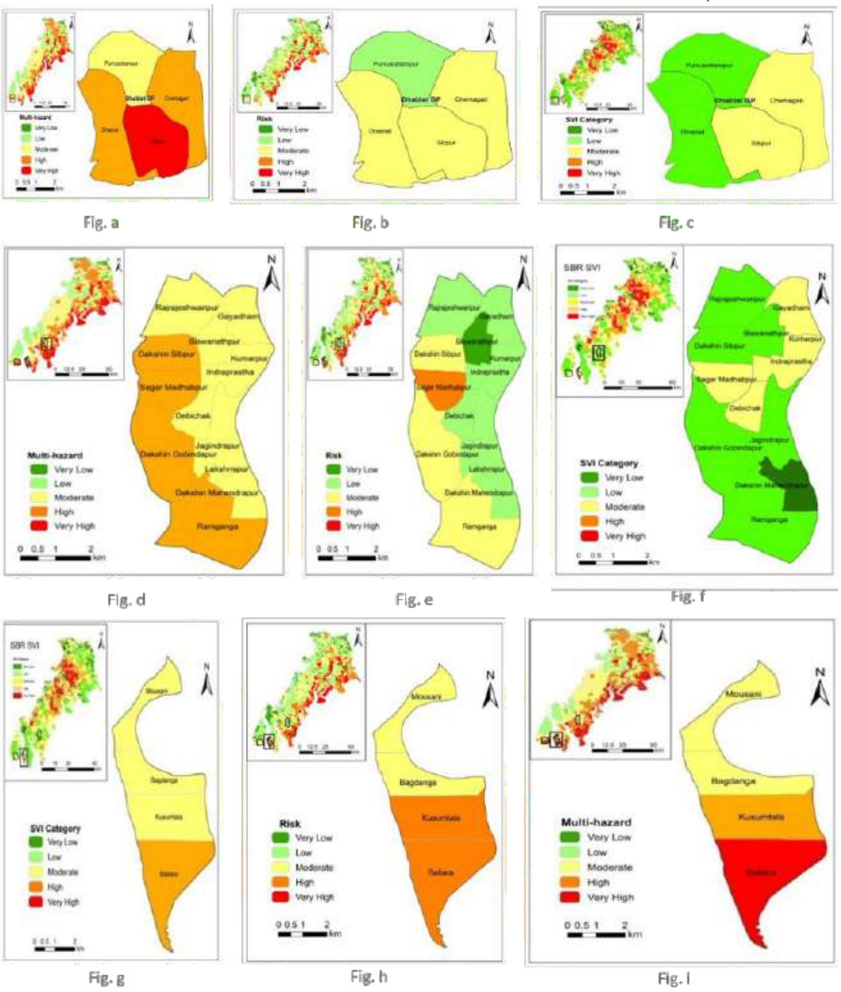


Figure 5 Multi-hazard exposure, social vulnerability and Riskindex to Climate Change and hazards in three Study sites of Sagar (Dhablat) fig a,b,c; Patharpratima (Ramganga) fig d,e,f; and Namkhanaisland (Mousuni) fig g, h, i

inundation, and costal erosion records were evaluated using multi-temporal satellite data (LANDSAT and RADAR) and tropical cyclone risk assessment modelling. Parallelly, social vulnerability indices at the village level were computed using Principal Component Analysis of sixteen socio-economic variables from the secondary data sources. Multi-hazard risk was computed using IPCC AR5 framework from the product of multi-hazard and social vulnerability indices of respective villages and Gram Panchayats (refer to Figs. 5,6, and 7).

The assessment indicates that, while the multi-hazard exposure of the Dhablat GP of Sagar Island is very high, comparatively low to medium social vulnerability of the people place this area under comparatively moderate risk. Ramganga GP of Patharpratima, with moderate exposure to multi-hazards, but with low to moderate social vulnerability of the populace, is found to be under moderate-to-low risk. Onthe other hand, Mousuni GP of Namkhana Island exhibits very high to high exposure to multi-hazards, high social vulnerabilities and high-to-moderate risk to climate change and climatic hazards.

It is essential that well-coordinated risk reduction measures including mangrove plantation and shore protection measures in tune with the 'building with nature' concept be initiated, prioritising Mousuni GP, particularly in the sea facing-villages of Baliara and Kusumtala in Mousuni.

2. Mangrove loss and gain in the Indian Sundarbans

In the last few decades, several studies have indicated that the Sundarbans is suffering from the ongoing relative sea-level rise, and that the principal estuaries of this region have lost their connection with the perennial upstream flow of the Ganges. Excessive salinity can lead to changes in species composition and, sometimes even extinction, of a particular mangrove species. The analysis of multitemporal Landsat data shows a significant erosion of mangrove forest in the core and buffer areas of the Sundarban National Park, whereas an increase of fringe mangroves in the transition area with human habitation is observed, thanks to natural regeneration and plantation efforts. Between 2000 and 2020, 110 km^2 mangrove area,at a rate of 5.5 km^2/yr,has been lost, but 81.2km^2(4.06 km^2/yr) area was gained in the fringe areas of the Sundarban Biosphere Reserve where human settlements are located.

This observation points to the ongoing crisis of mangrove forests in the Indian Sundarbans where they are unable to keep pace with the rapidly rising sea level in the northern Bay of Bengal, owing primarily to the absence of freshwater and sediment supply at the delta margin. Declining mangrove cover and the trajectory of tropical cyclonic storms is leaving the Indian Sundarbans highly exposed to severe storm and surge damage. Unless the tidal hydraulics and sediment retention are appropriately managed through the 'building with nature' paradigm, it will be difficult to sustain the tiger habitat and the blue carbon stock of this global heritage. There is an urgent need to promote mangrove conservation and restoration to protect the diverse flora, fauna, and people dependent on them for their survival and wellbeing.

3. The blue carbon dynamics of the Sundarbans

Usually, the quantification of blue carbon in the case of mangrove floras principally considers three compartments, the above-ground biomass, the below-ground biomass, and the soil organic carbon pool (Atwood et al., 2015). The carbon sequestration and photosynthetic carbon assimilation potential exhibit significant variability among the various species of mangroves in the Sundarbans (Nandy and Ghose, 2001). According to the controlled experiments performed by Nandy and Ghose (2001), *Heritiera fomes* has the highest photosynthetic rate, followed by Avicennia sp., *Excoecaria agallocha, Aegialitis rotundifolia,*

Sl. No	Years/ Islands	1969	1986	2001	2004	2006	2009	2012	2017	2020
1	Dhanchi	38.73	36.69	36.08	34.57	34.36	34.18	34.08	34.028	33.14
2	Dalhousie	79.22	74.83	67.1	65.82	63.89	62.201	61.96	61.05	57.11
3	Bulchery	32.81	29.64	26.91	25.27	24.17	23.28	23.06	21.773	19.23
4	Bhangaduni	45.49	39.7	31.31	29.55	27.57	26.15	25.89	23.82	20.98

Table 1 Loss of mangrove island area and tiger habitat in Indian Sundarbans (Island areas in km^2)

Aegiceras corniculatum, Bruguiera sp., Nypa fruticans, Rhizophora sp., Xylocarpus sp., and Phoenix paludosa. However, the biomass accumulation rate of the same species varies to a large extent based on the spatial location and variation of salinity. Banerjee et al. (2013) have observed that *Avicennia alba* and *Excoecaria agallocha* biomass show a positive correlation with salinity, whereas *Sonneratia apeta*la show a reverse relationship with salinity. Moreover, the heterogeneity of the mangrove cover in the Sundarbans makes it difficult to quantify the biomass of the mangrove floral composition (Joshi and Ghose, 2014). The floral composition of the Sundarbans can be best classified as species assemblage clusters (Mukhopadhyay et al., 2015). Mitra et al. (2011) have shown that freshwater-loving species (e.g., *Heritiera fomes* and *Sonneratia apetala*) usually exhibit higher biomass and hence, higher carbon content compared to the salt-tolerant ones (e.g., *Avicennia sp*. and *Excoecaria agallocha*). However, to date, one of the best possible estimates of carbon content in the Indian part of the Sundarbans is provided by Ray et al. (2011). Based on spatially explicit sampling, Ray et al. (2011) have reported an average above-ground biomass carbon of 39.93 ± 14.05-ton C ha-1 and live below-ground biomass carbon of 9.61 ± 3.37-ton C ha-1. They have also computed that the carbon accrual rate (4.71 – 6.54-ton C ha-1yr-1) in the Sundarbans supersedes the loss through litterfall (4.85-ton C ha-1yr-1). A modest upscaling for the entire Indian Sundarbans shows that the above-ground biomass stores 16 Tg C (1 Tg C = 109 kg), the below-ground biomass stores 5 Tg C, and the soil organic carbon pool 5.5 Tg C. This estimate shows that the entire vegetated area of the Indian Sundarbans stores ~ 26.5 Tg C. Though this estimate indicates that the Sundarbans has a substantial amount of carbon locked within the biomass, there is a dynamic and continuous process of biomass loss and gain, regulated by a suite of natural and anthropogenic processes. Akhand et al. (2017) have estimated that between 1975 and 2013, almost 107 km^2 mangrove area was lost, out of which 60% was washed away due to erosion, 23% was converted to barren saline blanks, and the remnants were converted to other landforms through human intervention. Akhand et al. (2017) have also observed accretion in various places throughout the island peripheries of the Sundarbans. However, they have laid stress on the fact that net erosion of > 100 km^2happened within four decades.

4. Scope of Mangrove Regeneration in prospective new areas

This scenario of mangrove loss made it imperative to look for avenues to enhance the blue carbon stock of this crucial ecosystem. The present analysis exhibited that there are substantial newly formed landmasses in the intertidal periphery of the islands, which can act as potential sites for mangrove afforestation through the plantation. The modest estimates (Fig.8) indicate that the core area at present has a 66.9 km^2plantable area, whereas the buffer and the fringes have 86.7 $km^2$and 85.4 km^2 plantable area, respectively on the mudflats and intertidal zone along the island fringes. This estimate sums up to a total of 239 km^2) mangrove plantable area in the Indian Sundarban to date. In addition, there are saline blanks of 76 km^2 in the core and 26 km^2 within the buffer mangrove area which can be taken up

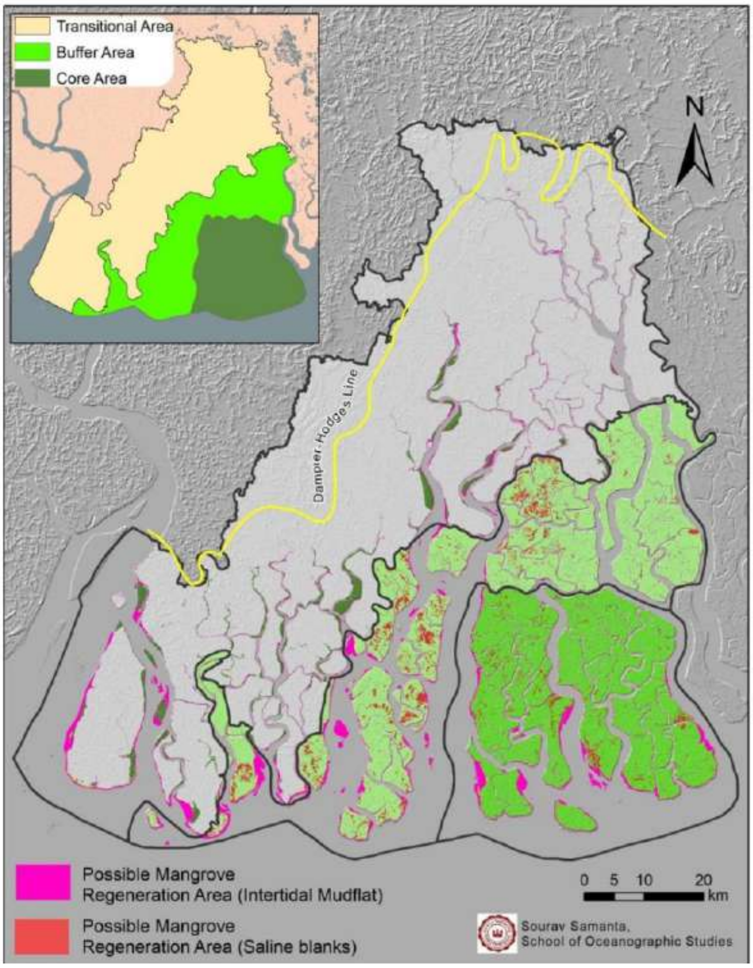


Figure 6 Proposed Mangrove Regeneration area (Intertidal mud flats and Saline Blanks) in the Sundarban Biosphere Reserve

for plantation using improved technology.

The present analysis further quantified that the present mangrove cover in the core and buffer regions comprise around 1902 km^2. The species assemblage map shows the dominance of *Excoecaria*, *Avicennia*, and *Ceriops* sp. in the Indian Sundarbans. Usually, it is advisable to maintain the same species assemblage, while carrying out plantation, as observed in the adjoining forested land beside the plantable area. However, delineating (unpublished report to Observer Research Foundation India,2021). In the similar method 998 hectares of new areas for possible mangrove plantation can be identified around Sagar Island, 90 hectares around the Patharpratima island and 277 hectares around Mousuni island Fig9,10 and 11) of Namkhana which are substantially more than such areas lost over the two decades.

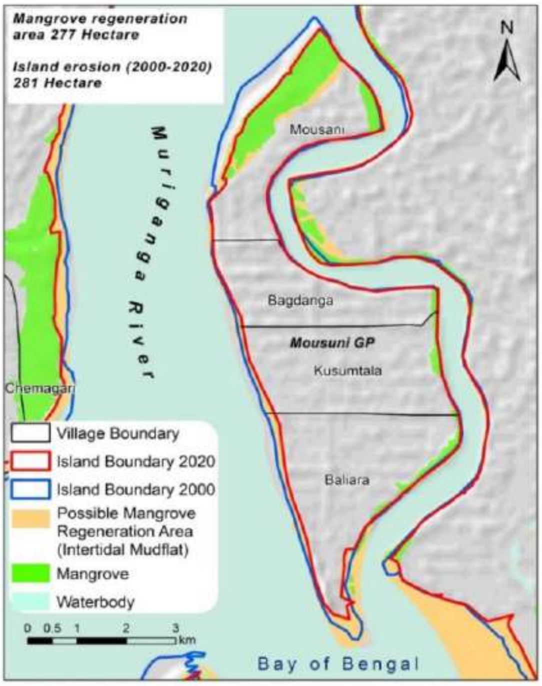


Figure 8 Possible mangrove regeneration sites in Namkhana - Mousuni

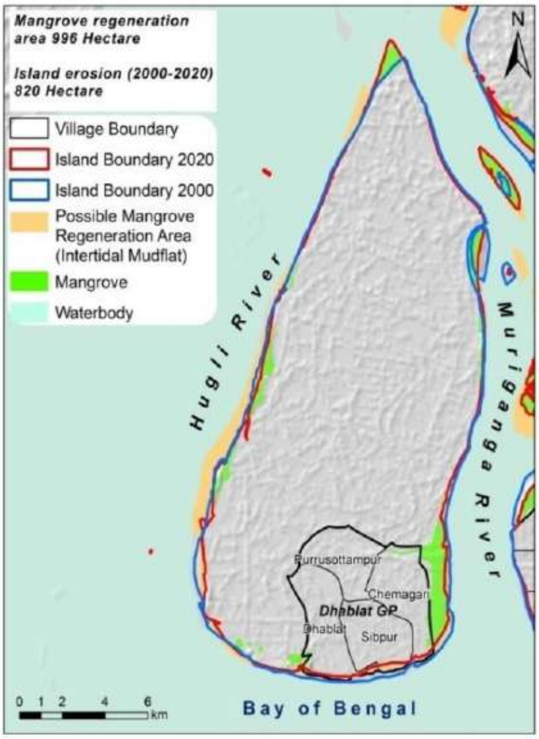


Figure 7 Possible mangrove regeneration sites in Sagar

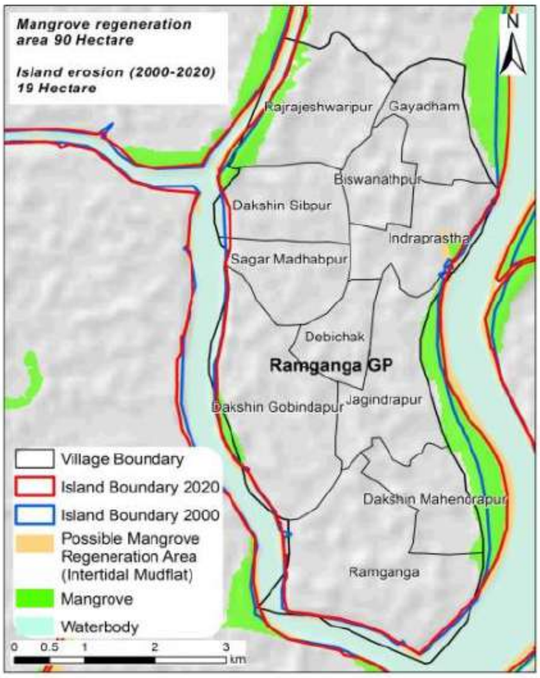


Figure 9 Possible mangrove regeneration sites in Namkhana - Ramganga

B. To illustrate the importance of conservation and management of mangroves by involving local populace, stakeholders and adopting appropriate management strategies

1. Community Dependence on Mangrove Ecosystem Services in the study sites (Baliara, Ramganga, Dhablat)

The Sundarbans mangroves provide the local people with innumerable direct and indirect benefits in the form of food, fuel, and livelihood resources. 54% of the population is mangrove forest-dependent in one way or another.

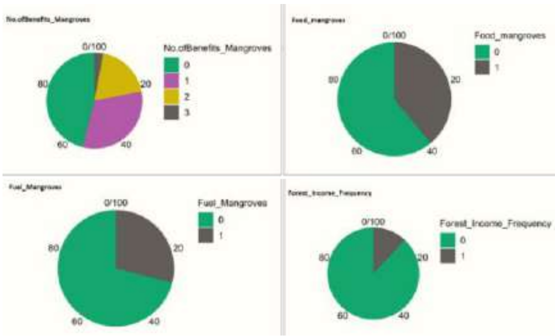


Figure 10 Number of Households benefitting from mangroves for food, fuel, and livelihood income

Out of the three major benefits of mangroves to the households – food, fuel, and livelihood, 32% households draw one of these benefits, 19% draw two and 3% draw all three. 40% of the population, comprising people of different castes and poverty levels, is dependent on the mangroves for their subsistence, 30% for fuel and more than 10% for forest-based income.

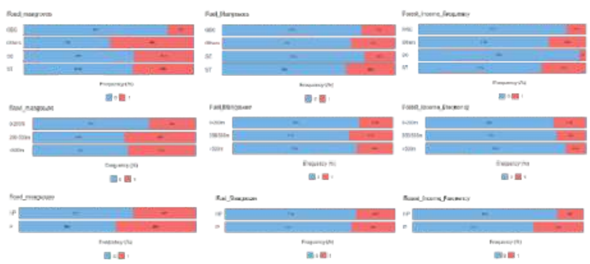


Figure 11 Mangrove Dependency of the households in studied villages classified by Caste, Nearness to creek, and Poverty level - Poor (P), and Nonpoor (NP)

In the study area, Scheduled Tribes (STs), households within 200m from the tidal creek or rivers, and poor households have comparatively higher economic dependency on mangroves. Among ST households, 12%gain all three types of benefits from mangroves, 16% secure 100% of their income from mangroves, and 50% have only two other income sources. But no household has more than six sources of income. Although non-

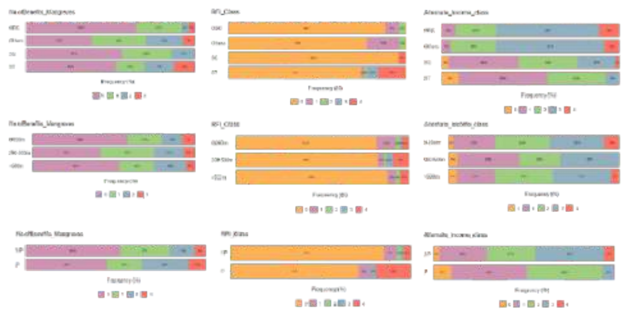


Figure 12 Number of Benefits acquired from Mangroves, Relative Forest Income (RFI), Alternate income availability of the households in studied villages classified by Caste, Nearness to creeks, and Poverty Level.

RFI classes: class 0 – No, class 1 - up to 25%, class 2 – from 25+ to 50%, class 3 – from 50+ to 75%, and class 4 – from 75+ to 100% income from mangroves)

Alternate income classes: 0 – No alternate income other than complete mangrove dependency, class 1 – up to 2 alternate sources, class 2 – 3 to 4 sources, class 3 – 5 to 6 sources, and class 4 – 7 to 8 alternate sources available and practiced by households.

Poverty Level: P – Poor, NP- Nonpoor

poor households are not affluent, households have higher mangrove dependency than non-poor ones, with 45% depending on mangroves for food, more than a quarter for fuel, and nearly 30% for income-generation. While 10% of the poor households draw all three benefits from mangroves, 19% are solely mangrove-dependent, and 42% have only two sources of income apart from mangrove harvesting.

Although households living within 200m from creek have a higher share of forest-based income, and cumulative relative Forest Income as well as a higher share in gathering all types of benefits from mangroves, households living between 200 m and 500m from the creek have the highest overall mangrove resource gathering, and the highest share of food and fuel gathering from the mangroves. Thus, it can be asserted that the weakest sections – the most socially (ST households) and economically (poor households) marginalized households are heavily dependent on mangrove ecosystem resources for their survival.

The major resources collected and marketed by the mangrove-dependent families are honey, crab, prawn seeds, fuelwood, litter, and fish caught from the creeks. 40% forest-dependent households are engaged in crab-collection, followed by artisanal fishery, fuelwood, litter, and prawn-seed collection. However, less than 20% households are engaged in honey-collection.

Among the poor households, crab-collection has the highest engagement (56%), followed by fuelwood (44%), honey (33%), and litter (22%) collection. Non-poor households demonstrate a higher engagement in prawn-seed collection (23%), and artisanal fishery.

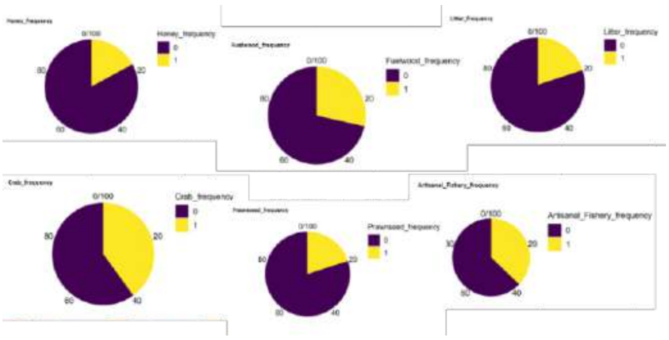


Figure 13 Pie chart showing percentages of Forest dependent households collecting various goods from mangroves marketed locally, nationally, and internationally

Prawn seed-collection supports the brackish water aquaculture farms which export to the international market. Crab and honey are sold in the local, national, and international markets. Fuelwood, litter, and artisanal fishery mostly cater to the local markets, markets in nearby cities and the tourism industry. Prawn-seed collection with dragnets, which non-poor households with as many as eight income sources, have serious adverse impacts on mangrove regeneration. Such unsustainable practices perpetrated by this section of the society that is not too socio-economically deprived must be regulated.

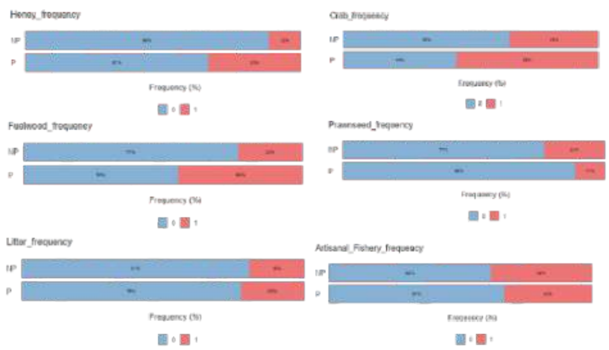


Figure 14 Proportion of economic mangrove resource collection among poor and nonpoor households

2. Stakeholders' engagement in Mangrove Regeneration and Management

A team of specialists led by the P.I. visited existing and potential sites for mangrove restoration in three Community Development Blocks (CDBs) in the SBR–Sagar, Patharpratima and Namkhana – from March 17, 2021, to obtain a fresh perspective on the present approaches to mangrove restoration and their potential benefits.

Sagar Island, under the jurisdiction of Sagar CDB, in the South 24 Parganas district of West Bengal is a popular site for religious tourism. Here, the historic growth in human habitation was accompanied by a high rate of mangrove depopulation. Lack of storm protection offered by mangroves exposed the island to heavy damages from tropical cyclones Aila (2009), Bulbul (2019), Amphan (2020), and Yaas(2021).The south western mouza of Dhablat which initially accommodated environmentally displaced migrants from the nearby eroding islands of Ghoramara in the 1990s, is itself witnessing rapid erosion, frequent inundation, and submergence now. Mousuni Island in Namkhana CDB (South 24 Parganas) is one of the islands where the most rapid land loss, particularly from the eastern and southern edge, is being observed. The mangrove patch on the northern mudflat of the island was partially cleared for aquaculture. The mangrove plantation on the eastern fringe is restricted by settlements on the west and the rising water of the tidal channel on the east. The island suffered saline inundation after the incidence of cyclone Aila (2009) and Amphan (2020). Out of the three CDBs targeted for mangrove regeneration, Ramganga. In Patharpratima CDB, situated further inland from the sea-facing edge of the island, appears to be the most stable, with a small mangrove plantation on the eastern side. However, even this region was inundated during surges accompanying cyclones Amphan (2020) and Yaas (2021).

A small questionnaire-based survey with some villagers from the three CDBs revealed the challenges, willingness, and future prospects of Community-based Ecological Mangrove Restoration (EMR) in the area. Women-led Self-Help Groups (SHGs) like Sagar Tirtha SHG of Mrityunjay Nagar, that have partnered with the Kalpataru Sabuj Sathi Mangrove Restoring Group of Sumati Nagar for the NEWS mangrove restoration project, were also surveyed.

Figure 15 Mangrove plantation on the eastern bank of Mousuni Island

Three mangrove plantation and protection groups were interviewed in this survey. All three groups reported the involvement of local SHGs in plantation and protection initiatives. Though the mangrove plantation and protection groups were reported to be run by funding agencies, the wages paid to the

Figure 16 a. Regerating mangrove at Shibpur, Ramganga, Patharpratima

Figure 12 b.Mangrove Plantation work in Shibpur, Ramganga, Patharpratima

planters were meagre, and the surveyors noted the need for better incentives to ensure the continued participation of members of the communities. Mangrove nurseries was created near the plantation areas and maintained by the SHG members. In almost all the cases, the plantation sites were selected on the basis of prior knowledge of mangrove regeneration on the part of the involved stakeholders, and expert guidance. Mangrove species were selected on the basis local species composition, slope and structure of the silt bed, and physico-chemical parameters of the river water, when corresponding datasets were available. Generally, data on water salinity and pH, soil salinity and pH, slope, inundation, soil texture, etc. were considered along with knowledge of local species composition to identify suitable mangrove species for a particular site.

During restoration, mangrove saplings are planted 4 to 6 ft apart, in a straight line. First pits are dug in the specified gaps and left for one month for the deposition of fresh silt in them. Then the saplings are planted. The surveyors found that *Bruguiera sp., Ceriops sp.,* and *Excoecaria sp*. were planted on the embankment side, away from the river, *Avicennia sp., and Rhizophora sp*. in the low-lying silt bed, and *Sonneratia sp., Avicennia* sp., and Rhizophora sp. in the riverbank. On average, the survival rate of the saplings was reported to be 79% to 85%. However, earlier, the survival rate was lower since the saplings were not fenced in. Almost all the silt beds had earlier been grazing grounds for livestock, The local SHGs and communities involved in regeneration initiatives worked to ensure that grazing in mangrove plantations was stopped.

The following key factors influencing the success of a mangrove plantation were identified by these mangrove plantation and protection groups:

a) Mangrove generally grows to a stable height within three years of plantation. It is, thus, imperative that alternate sources of income generation activities be made available to support the voluntary plantation and protection work carried out by the local populace.
b) Prawn and crab hunting along the riverbanks using nets cause the worst damage to a mangrove plantation. Regulation of these activities in the plantation sites is necessary to ensure sapling protection.
c) Awareness among the local populace is a key part of community-engagement in mangrove plantation and protection. The involvement of the GP in every aspect of the regeneration activities is crucial to ensuring that the existing knowledge pool of best practices is regularly updated.

d) Controlling the grazing activity in the plantation area was identified to be a major difficulty. To address this issue, alternate sources of fodder for livestock in adjoining areas must be developed.
e) The mangrove plantation and protection groups should be officially structured and organized as a central governing system so that the mangrove plantation activities can be regulated and monitored properly, not only during the plantation phase but also in the protection phase.

The following social and ecological changes at the plantation sites have been reported to the surveyors:

a) Workdays for the local populace have increased in the areas adjacent to the mangrove plantations and nurseries.
b) A sense of unity and cooperation has been infused into the local community involved in mangrove plantation and protection.
c) Biodiversity has increased in the plantations and the nurseries. More diverse types of bees, birds, butterflies, and insects, and snakes, crabs, are jellyfish are now being observed. The number of fiddler crabs has increased significantly.
d) Beautification of mangroves in the riverbanks, which is a crucial aspect of ecotourism in Sundarbans has been achieved.

Community-Based EMR

Promotion of community based EMR is a critical element added to Robin Lewis's Ecological Mangrove Restoration (EMR) model by Mangrove Action Project (MAP) (Lewis, 2014). Recognition of the fact that sustainable mangrove restoration requires the full participation of the affected local populace for whom mangroves provide food, fuel wood, fodder, and non-timber forest products is key to successful EMR activities. To involve the communities from the beginning of the project, it is important to learn about the past and present conditions of the proposed mangrove sites, and the relationships and uses of the mangroves by the local communities, in addition to evaluating past efforts towards mangrove regeneration. Involving members of the local community interested in acting as future monitors and resource managers at the selected sites serves to encourage community participation and helps build their capacities to manage and conserve their natural resource base better (Lewis et al., 2006). Once the community is engaged, a community-based restoration and management plan of three to five years can be developed. It is critical to the process, being the primary force preventing repeated degradation of the restoration site. Strong community stewardship ensures a central stakeholder role in future mangrove management decision-making. Attaining community-based management or co-management status will greatly aid the long-term protection of the restoration site. Community-based hands-on training should go on simultaneously for management and restoration to be effective.

The six steps of EMR begin with research on local ecology, previous restoration efforts, and their successes and failures (Lewis et al., 2006; Brown, 2008).

Step 1: Understand the local mangrove ecology of the naturally occurring mangrove species at the site, paying particular attention to patterns of zoning, reproduction, propagule distribution, and successful seedling establishment.

Step 2: Understand the normal hydrology controlling the distribution and successful establishment and growth of targeted mangrove species as each mangrove species thrives at a different substratum level, depending on the amount of exposure to tidal waters. It is important to study tide charts for the area and take measurements of healthy mangroves relating to substratum height and depth for the various species of mangroves occurring at each depth and note the critical periods of inundation and dryness that govern the health of the forest.

Step 3: Assessment of the modifications of the mangrove environment that have occurred and that may prevent natural secondary succession. Any plans for mangrove restoration must first consider the potential existence of stresses, for example, blocked tidal inundation, that might impede secondary succession, and plan on removing them before attempting a restoration. It is important to understand the past use of the area. Whether the mangroves were at all native to the area and the fact that mangroves are not to be planted on salt marshes or lagoons as that would be ecosystem conversion, not restoration, must be taken into consideration. Besides blockage of tidal exchange, there may be a lack of freshwater, hypersaline, or acid sulphate soils (usually found after intensive shrimp farming), overgrazing by livestock, shoreline abrasion, and lowered substratum levels. Human or boat traffic at landing sites, and over-exploitation of trees for fuelwood must also be checked.

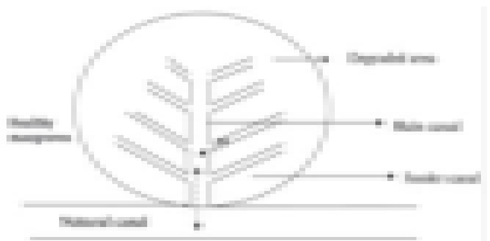
Step 4: Selecting appropriate restoration areas that are both likely to succeed in rehabilitating a forest ecosystem and cost-effective through steps 1–3 above, with consideration of available labor to carry out the project, including adequate monitoring of progress towards meeting the quantitative goals established beforehand must be done.

This step includes resolving land ownership and use issues necessary for ensuring long-term access to, and conservation of, the site.

Step 5: Design the restoration program for the sites selected in step 4 to restore the appropriate hydrology, including the original tidal streams, and to use natural volunteer mangrove recruitment for natural plant establishment.
Tidal streams run through mangrove areas from the terrestrial edge to the sea. They are narrower upstream, widening as they meander to the coast. They are fed from the landward edge by groundwater, springs, surface runoff, and streams. Being connected to the sea, tidal streams facilitate the exchange of tidal waters in and out of the mangrove area and are the routes for natural seedlings to enter and colonize. In disturbed tidal streams, seedling recruitment may be blocked, and the affected site's existing mangroves may dry out, and die over time. In the case of rehabilitating disused shrimp ponds, it may be enough to create "strategic breaches" in the dyke walls as the "tidal prism" (the amount of water that can enter an opened pond between high and low tide) needs to be channelled to the maximum extent possible through a few key openings that are wider downstream than upstream, mimicking the normal operation of tidal streams in mangroves. Fewer openings produce greater velocities as the flow is restricted, which in turn produces scouring which keeps the human-made openings open and reduces the chances of siltation and closure. Creating too many openings will distribute the tidal prism over many points, reducing the velocity and thereby inducing less scour and more siltation. Even if mangroves survive for several years in a rehabilitated area, they may remain stunted, or even die out, unless hydrological conditions are truly supportive of mangrove growth. If seedlings have been established in the rehabilitation area, but at lower densities than hoped for, planting may be considered.

Plantation Methods

In India, the use of the canal or trench method is in vogue. This method is used largely for restoration of historically clear-felled sites that have degraded because of the coupe system of management (Selvam et al., 2005). The method is also known as



ig a) ish Bone lanta on structure

Figure 13 Fishbone plantation: Fig. a, b: basic structure of the canals and their slope (Selvam et al., 2005), Fig c: the fishbone structure adopted in Orissa (Cabahug et al., 2016)

a) Fish bone plantations in Peechavaram, Tamil Nadu

a) Parallel plantations in Dhonchi, Sundarbans, West Bengal

Figure 14 Mangrove plantations aerial view: Fish bone plantation in Peechavaram, Parallel plantation in Sundarbans (Source: Google Earth)

the fishbone canal method because of its design and has been successfully applied in the Reserved Forests of Tamil Nadu, such as Pichavaram and Muthupet, and of Andhra Pradesh, such as Krishna and Godavari (Selvam et al., 2005). It has also been used in Gujarat at the Krishna Wildlife Sanctuary

salinity and saplings are planted (20-25 cm) from the top of trapezoidal canals at a 2 m distance. The canal method should not, however, be applied in areas beyond the boundary of the high tidal zone where there is no flow of tidal water.

Planting is done in October–November (in reduced salinity post-monsoon). Fishbone canals have been successful in Tamil Nadu and the coast of Orissa coasts, while in the Sundarbans, it's use it yet to be seen as more frequent parallel plantation is being practiced here. Longitudinal encasements following the Riley Encased Methodology (REM) (Riley and Kent, 1999) can also be used to ensure

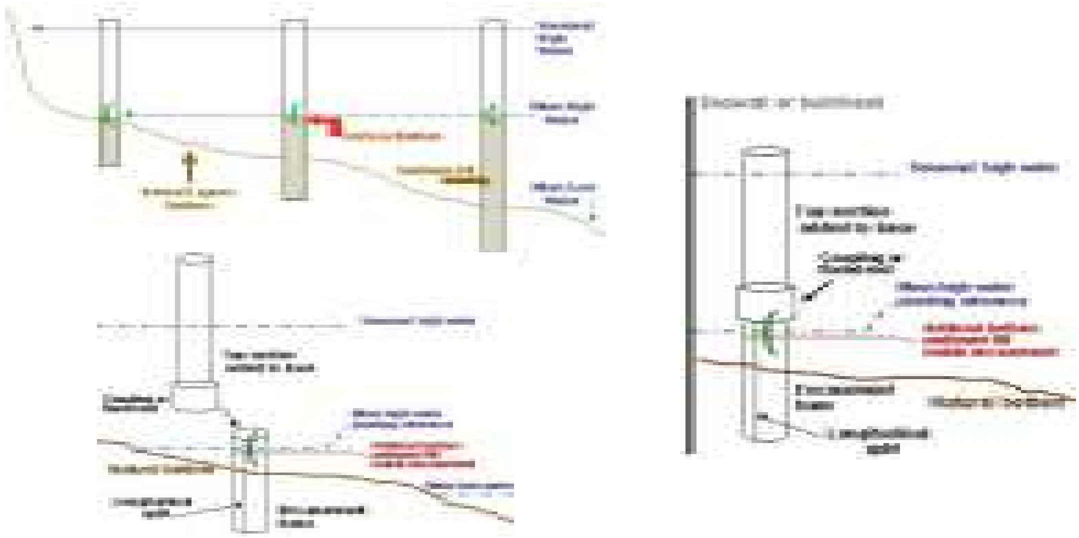


Figure 15 Longitudinal encased plantation following Riley Encased Methodology (Riley and Kent, 1999) (Source: http://www.niobioinformatics.in/mangroves/MANGCD/indo/method.htm#1)

the growth of seedlings and reduce the risk of seedlings being washed away. Longitudinal splitting encasements made of PVC pipes can be used in this case.

Step 6: Planting Plant propagules or seedlings only after determining through steps 1–5 above,

natural recruitment will not provide the quantity of successfully established seedlings, rate of stabilization, or rate of growth, required for project success. It is a good idea to do some small test plantings to ensure that conditions are suitable for the desired species rather than mass plantings. Mangrove species can be tested in small dense plots at the correct strata height. Any naturally occurring mangrove trees on site or volunteers will be an excellent reference for planting. As mangroves do not grow naturally in straight rows, these should be avoided.

There are four sources of seeds/propagules for mangrove planting:

1. Raising seedlings in a nursery from local seed sources

2. Direct planting of propagules

3. Transplanting of wild seedlings

4. Broadcasting fruits or propagules directly onto the water surface at incoming spring tides

C. To determine issues related to policy advocacy for mangrove conservation and management.

While India has an increase in the mangrove cover by 21.63% from 4,046 to 4,921 sq. km in three decades since 1987 and 54 sq. km to 2017, if counted from the 1960s we have lost 17.9 % of the original mangrove habitat available back then till 2019 with the Indian part of the Sundarbans, accounting for 43% of India's total mangrove cover, having only a marginal increase of 1.87% in the long three decades with an annual rate of 0.061% (Kathiresan, 2019).

Since 1996, India's mangrove loss has been nearly double with 7.1% forests outside the protected areas than 3.6% inside them clearly indicating the need of urgent restoration attention. India with a restoration area of 152.41 sq km., holds potential of 2% of world's restorable area, and have a goal of having 6000 sq. km mangrove area in the country- a coverage that was present in the 1960s- much higher than the global estimate in 11 years at the present rate of 91 sq, km per year, or with doubled efforts of 182 sq km restoration per year within 6 years creating an additional carbon sink of 3 billion CO2 equivalent for the forests by 2030 (Kathiresan, 2019).

However mangrove planting efforts are often failure at 46% failure in 48 restoration sites, with highest occurrence in the South Asian countries emphasizing on the need of 'Ecological Mangrove Restoration' that takes into account right tidal flow, land elevation, and suitable species for accelerated and successful recovery with focus on participatory monitoring and management of the activities ensuring active involvement of local communities (Kathiresan, 2019). Hence the following policy suggestions are of utmost importance to achieve successful mangrove restoration in the delta.

a. A sound restoration project must begin with assessing the local context by studying the land tenure and accessibility, participatory understanding of stakeholder, topography, tidal velocities, salinities, mangrove composition, and any other potential problems (eg. grazing, prawn seed collection, embankment construction, land tenure) of the plantation sites prior to mangrove regeneration attempt.
b. Mangrove afforestation should be taken up only after scope of natural and assisted natural recovery and regeneration after re-establishing favourable boundary conditions are exhausted.
c. Rather than exhaustive plantation, a blended plantation – protection – monitoring with active participatory involvement and local nursery raising must be approached for a sustainable ecosystem restoration.
d. Multi-species plantation instead of single species of *Avicennia* should be encouraged. Species combination may be ecologically selected after testing soil salinities, erosion/accretion, and hydrodynamic condition around the sites by the Govt. agencies and NGOs.
e. Women self-help groups in different islands should be appropriately trained and mobilized in establishing mangrove nursery, plantation procedure and protection / maintenance/ monitoring for initial years with adequate monetary compensation.
f. Ban on establishment or expansion of shrimp farms at the expense of mangroves should be strictly implemented by the Government within the ambit of existing legal provisions.
g. Procedures for appropriate institutional reforms to implement the UN sponsored REDD++ schemes sorting out the issues relating to 'forest right, forest use right, rights of stakeholders and local people on carbon credit, in consultation with the department of forest, CSOs/NGOs and local Panchayat bodies
h. Sundarban with decreased freshwater inflow and rising salinity is losing out on valuable crucial mangrove species, and for long term sustainability of the landscape scope of implementing rejuvenation of freshwater river channels through Sundarban for reduction of salinity must be explored.

Conclusion

Successful restoration requires the study of previous failures and rooting out the causes. In the case of Mangrove restoration, the local ecology is extremely vital and so is local participation for its effective protection. Mass scale awareness about resourcefulness of mangrove ecosystems, training, and simultaneously shift in unregulated practices needed. A major requirement is building capacities of communities to perceive and manage restored mangroves as valuable assets and not a fast and cheap source of economy. It is very crucial to develop plans for long-term management and governance and equip the local communities towards self-sustenance model, through village level institutions, skill development, entrepreneurship, and self-governance training, after funding from 3rd party agents stops.

Figure 16 Degraded mangroves in Mrityunjay Nagar, Sagar

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Figure 17 Site of Mangrove restoration, Mrityunjay Nagar, Sagar

Figure 22 Planted mangrove seedlings

Figure 23 Growth of mangroves beside a creek

Figure 18 Degraded coastline in Sagar Island

Figure 19 Aquaculture farm in southern part of Sagar Island, a potential site for combined mangrove and brackish-water aquaculture

Figure 20 Study of monoculture Avicennia mangrove patch

Figure 27 Survey with women-led Sagartirtha SHG, an active community for mangrove restoration

Figure 28 Survey with women led Sagartirtha SHG, an active community for mangrove restoration

Figure 21 Survey with women led Sagartirtha SHG, an active community for mangrove restoration

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