XV WORLD FORESTRY CONGRESS
Building a Green, Healthy and Resilient Future with Forests
2–6 May 2022 | Coex, Seoul, Republic of Korea

Climatic and anthropogenic challenges in Sundarban Biosphere Reserve and plausible roads to sustainability

Oindrila Basu[1], Sudipa Pal [2], Sourav Samanta [3], Partho Protim Mondal[4], Isha Das[5], Sandip Giri[6], Abhra Chanda[7]

[1][Jadavpur University, India, IUCN CEM South Asia, oindrila.basu@ymail.com]
[2][Jadavpur University, India, sudipa.3019@gmail.com]
[3][Jadavpur University, India, sourav.samanta@gmail.com]
4[Jadavpur University, India, partho.iirs@gmail.com]
[5][Jadavpur University, India, ishadas2012@gmail.com]
[6][Jadavpur University, India, sandip189ju@gmail.com]
[7][Jadavpur University, India, abhrachanda1985@gmail.com]

Abstract

The Sundarban Biosphere Reserve (SBR), a UNESCO World Heritage site, is the Indian part of the largest pristine mangrove forest in the lower Gangetic Delta. The core area of SBR is the abode of the majestic Royal Bengal Tiger and the transitional area is heavily populated by 4.37 million people (2011 census), 34 % of whom are below the poverty level with an average monthly income of 62 US$. Our recent surveys reveal that a substantial number of poor and marginal people depend on forest goods - honey, crab, fuelwood, shrimp seed, and river fishing for their sustenance and livelihood. However, driven by the global seafood market and local poverty, there has been a significant increase in the aquaculture land from 3.59% in 1999 to 5.52% of total SBR in 2019, engulfing more than 1000 ha of mangrove forest, 2300 ha of mudflat, and 24000 ha of agricultural land, weakening the coastline at many places. SBR is the seat of frequent tropical cyclones and flood surges. Within the last 15 years, 4 super cyclones with floods have ravaged the landscape affecting the vitality and health of both humans and mangroves. Prawn seed and crab collection using thin nylon dragnets are disastrous for mangrove regeneration and restoration damaging seedlings and several aquatics irrevocably with negative impacts on UN SDG 13, 14, and 15. Adding to it, aquaculture ponds of the SBR can emit almost 5,21,02,87,00,000 micromole CO_2 per year (22ton CO_2 per hour ≈ 1,92,720 ton CO_2 per year). The flourishing of aquaculture ponds at the expense of mangroves, hence, not only results in a one-time loss of sequestered carbon by the pre-existing mangroves over centuries but also a land-use which acts as a steady CO_2 emitter. For Sustainable development of the Sundarbans, strict enforcement of the existing forest and coastal legislation coupled with the establishment of the state-of-art hatcheries, and promotion of organic shrimp farming preferably with the mangrove-aquaculture farming model is suggested.

Keywords: [Up to five keywords can be added here.]

Introduction, scope, and main objectives

Sundarbans is the world's single largest stretch of pristine mangroves that inhabits the charismatic Royal Bengal Tiger (Danda, 2011). The UNESCO World Heritage site is situated on the Ganga-Brahmaputra-Meghna (GBM) Delta, made by 102 geologically young islands are shared by Bangladesh and India (Banerjee, 1998). Although historically the entire lower Gangetic Delta had been dominated by mangrove forests and wetlands, over time those landscapes were considered wastelands and reclaimed for human settlements and agriculture. Today, the Indian Sundarban Region is a heavily populated land with a pressure of nearly 4.37 million people living in 9650 sq. km in 54 islands, roughly 996 people living per sq. km area, sharing the land with protected mangrove forests of Divisional Forest area, Sundarban Tiger Reserve and Sundarban National Park (Fig.1) (Sánchez-Triana et al. 2014). However, driven by the global seafood market and local poverty, there has been a significant

increase in the aquaculture land from 3.59% in 1999 to 5.52% of total SBR in 2019, engulfing more than 1000 ha of mangrove forest, 2300 ha of mudflat, and 24000 ha of agricultural land, weakening the coastline at many places (Giri et al., 2021). Prawn seed and crab collection using thin nylon dragnets are disastrous for mangrove regeneration and restoration damaging seedlings and several aquatics irrevocably with negative impacts on UN SDG 13, 14, and 15. Adding to it, aquaculture ponds of the SBR can emit almost 5,21,02,87,00,000 micromole CO_2 per year (22-ton CO_2 per hour ≈ 1,92,720ton CO_2 per year) (Giri et al., 2021). Furthermore, the unique location of the mangroves in the curve of Bay of Bengal, world's largest bay has also been a major fact for the landscape to be ravaged by tropical cyclones, storms, floods, and inundations repeatedly in the past (Ghosh et al., 2015). Within the last 15 years, 4 super cyclones with floods have ravaged the landscape affecting the vitality and health of both humans and mangroves.

Ninety percent of world's mangrove forests are found in developing countries of South and Southeast Asia and are facing challenges from the developing economies crippled with population pressure and rapid large scale clearance and conversion for agricultural and aquacultural activities (Ward et al., 2016), with prawn farming aquaculture being the major threat (Clough, 2013; Ramsar Convention, 2010; IPCC 2007). According to FAO (2007), the mangrove ecosystems are depleting at the rate of 0.66% per year and within a 100year entire ecosystem can be lost (Bhatt and Kathiresan, 2012). On top of it, climate change and sea level rise are looming over these coastal ecosystems treacherously (Ellison, 2015). In this backdrop the present study provides a picture of present status and drivers of changes in the Sundarbans with plausible future scopes.

Methodology/approach

The drivers of changes define the narrative and hence identifying their courses are crucial to develop realistic scenarios. STEEP framework provides the qualitative as well as quantitative basis for the scenario archetypes described with narratives driven by Social, Technological, Economical, Environmental and Political (STEEP) drivers (Hunt et al., 2012). This study is based on evidence review of available literature and semi-structured Questionnaire based survey with households across the delta, narrated as a scenario of Sundarbans with the evidenced drivers of changes identified under the STEEP Framework. For evidence review literatures on Sundarban linked with STEEP components were searched through search engine and top 20 relevant literatures were considered for each keyword - Social, Technological, Economical, Environmental and Political. Sundarbans was considered as a system, and following concept of Hunt et al., (2012) studies with most relevant STEEP drivers affecting 'Qualitative patterns of change in Market Forces (MF)' were identified (Table 1). From a semi structured household survey conducted across 2000 households in 40 villages in Sundarbans for UKIERI-DBT project, that authors were active part of, the mangrove dependency for various resources were identified and incorporated in the present study as field input to the Social Driver. This study is an attempt to identify the various drivers and document already available evidence base for the same, however no scoring of literature was done.

Table 1: [Characters of STEEP Drivers following (Hunt et al., 2012)]

Component	Characteristics looked for in review of literatures
Social	Individual choices, Governance, Demography, Urbanization, and Consumerism practices
Technological	Technologies used in management
Economical	Economic activities including export based international market forces
Environmental (and Climatic)	Environmental changes from pollution, Carbon emissions, deforestation, global warming, climate change, and climate disasters.
Political	State of environmental and sectoral policies.

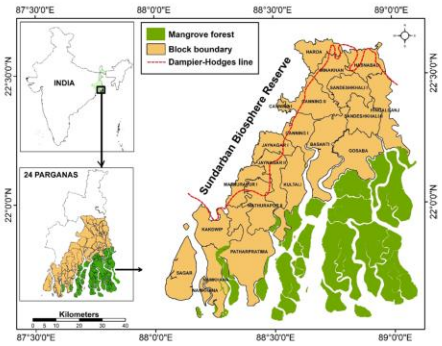

Fig 1. Sundarban Study area Map following Giri et al., (2021)

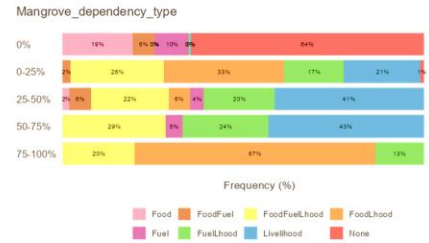

Fig 2. Mangrove Dependency in primary survey Across Sundarbans

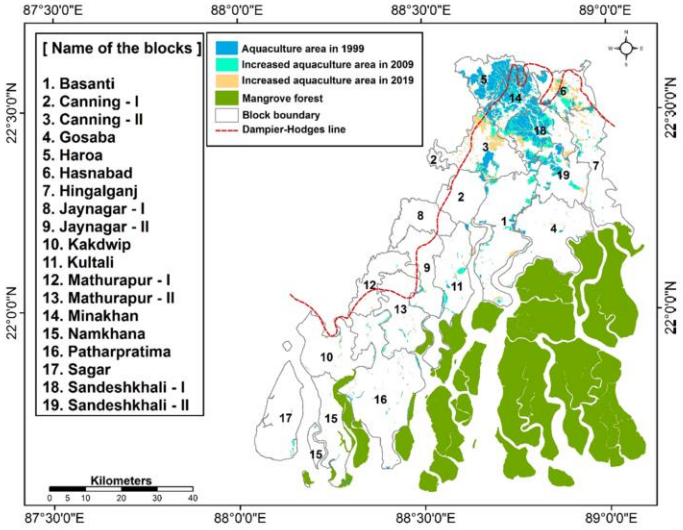

Fig 3. Sundarban Aquaculture change as studied by Giri et al., (2021)

Results

The drivers of changes in Sundarbans are multifarious and according to STEEP Framework they are summarized in Table 2.

Table 2: [The STEEP Drivers of Changes as identified in purview of Sundarbans]

Driver	**Indicator Description**	**Reference of evidence**
Social	Colonial rule and historical Land-Use change for agrarian revenue deforesting land	(Ghosh et al., 2015)
	Population influx post-independence and post Bangladesh formation causing demographic pressure	(Ghosh et al., 2015)
	Mangrove dependency and livelihood practices with risk of man-animal conflicts.	(Anshu Singh et al., 2010) , (Basu et al., 2018), (Das, 2021), (Sen & Pattanaik, 2019), (Chowdhury et al., 2008), (Chowdhury et al., 2016)
	Social vulnerability	(Das et al., 2021)
	Food security from Aquaculture demanding land conversion.	(Kumar, 2012), (Giri et al., 2021)
Technological	Circuit embankments that affected mangroves and sediment accumulation in islands adversely.	(Chakraborty, 2005)

	Circuit embankment construction altering geomorphology leading to soil auto-compaction causing island submergence.	(Rudra, 2014), (Bandyopadhyay and Bandyopadhyay, 1996)
	Intensive agriculture with Hybrid variety paddy	(Dhara et al., 2016)
	Exotic species *Litopenaeus vannamei* (white-leg shrimp) boom for fast growth, higher production, and salinity hardiness impacting adversely on the ecology of delta.	(Giri et al., 2021)
Economical	Land use change driven by aquaculture export	(Kumar, 2012)
	Man-animal conflict from forest venture driven by export value of crab-prawn.	(Kumar, 2012), (Chowdhury et al., 2008)
	Commercial tourism in name of eco-tourism	(Guha & Ghosh, 2007)
Environmental (and Climatic)	Climate Change induced sea-level rise, cyclones, and loss of lands	(Roy & Guha, 2017), (Ghosh et al., 2015), (Hazra et al., 2010), (Hazra et al., 2002)
	Island submergence creating landless migrants and livelihood shift from agriculture to multiple labourer.	(Das et al., 2021), (Das et al., 2020), (HDR, 2009)
	Climate change induced cyclonic hazards causing social vulnerability	(Das et al., 2021), (Das et al., 2020), (HDR, 2009)
	Climate change induced cyclonic hazards degrading the mangrove ecology and health.	(Hati et al., 2020), (Awty-Carroll et al., 2019)
	Deterioration of mangrove health from increased saline water flood surge, sea level rise, and reduced sediment laden freshwater inflow from upstream.	(Bhargava et al., 2020), (Ghosh et al., 2015)
Political	Historical policies of forest management and revenue collection.	(Ghosh et al., 2015) , (Richards & Flint, 1990)
	Lack of alternate livelihood strategies and weak eco-tourism involvement leading to poverty, uncertainty, and man-animal conflict.	(Sen & Pattanaik, 2019), (Dasgupta & Shaw, 2017), (Chowdhury et al., 2016), (Mistri & Das, 2015)
	Formation of protected area and tradeoffs	(Dasgupta & Shaw, 2017), (Mistri & Das, 2015)
	Sectoral policies needing local community involvement and integration for attaining SDG targets.	(Marcinko et al., 2021), (Dasgupta & Shaw, 2014)

Social Drivers: Historically the extensive land transformation in Sundarbans happened during the colonial period since 1771 for the agrarian revenue collection that continued even into the early decades of independent India (Richards & Flint, 1990). The delta further experienced a huge population influx from East Pakistan into the divided Bengal, in post-independence India, which again gained momentum with the formation of Bangladesh. Population pressure increased 3.54 times in 50 decades as per 2011 census report (Ghosh et al., 2015). Livelihood of reclaimed Sundarbans have always predominantly been agriculture. The traditional forest dependent communities collect various NTFPs from prawn seed, crabs, honey, and others. Collection of prawn seeds supports the emerging brackish water prawn farms and is one activity mainly performed by women and children (Sen & Pattanaik, 2019; Basu et al., 2018, A Singh et al., 2010,). These practices lead to high rate of man-animal conflict collectors being attacked by tigers and crocodiles regularly (Chowdhury et al., 2016). Our recent household surveys over 2000 households across the delta shows that households earning even 0% income from mangroves also are mangrove dependent for food or fuel from wood and litter. The households are grouped as dependency (Fig 2.) on only food (Food), only fuel (Fuel), only livelihood (Livelihood), food and fuel (FoodFuel), food and livelihood (FoodLhood), fuel and livelihood (FuelLhood), and all food, fuel, livelihood (FoodFuelLhood). The households with more than 25% income from mangroves have significant dependency for food, fuel – fuelwood and leaf litter, and livelihood from crabs, prawns, honey, wax (Fig 2.).

Technological Drivers: The British administration indiscriminately constructed circuit embankments (Chakraborty, 2005) to make islands habitable, which have, over 200 years, altered natural geomorphological processes of delta formation. The cumulative impact of altered geomorphology, and the construction of embankments have led to submergence of large tracts of land in the sea-facing islands from auto-compaction of the silt layers and effects of storm surges leading to retreating coastlines (Rudra, 2014; Bandyopadhyay and Bandyopadhyay, 1996). The climate change, sea level rise, cyclone hazards further intensified the vulnerability (Das et al., 2020) causing many to lose their lands and livelihoods in the highly populated delta. Majority of the populace, irrespective of their traditional livelihood, have presently adapted to multiple livelihoods round the year for earning their living, ranging from working as daily-wage labourers in agricultural fields, aquaculture farms, construction, fishing trawlers, tourism companies, brick-kilns, transport to developmental activities by state under MGNREGA (HDR, 2009). According to 2011 Census, while 4.6% of total population are cultivators, nearly double are the agricultural labourers with 7.6%. Seasonal migration has been on rise post 2004 tsunami and people migrate to all parts of the state and country in search of living. It is the principal source of earning in many households. Building capacity of these huge populace, more than 34% (HDR, 2009), of whom fall below poverty level (BPL) and upskilling them to alternate livelihoods is a necessity today for resilience of the delta.

Economic Drivers: Aquaculture is a fast-growing high economy generating sector worldwide, and the global productions doubled from 32.4 to 66.6 million tonnes within a decade from 2000 to 2012 (FAO, 2014). In India aquaculture has significant role in food security of growing populace, and also the second largest producer after China by contributing approximately 6.3% to global aquaculture production (FAO, 2014; Giri et al., 2021). High rate of poverty and high economic return from the global market demand for prawn and crab are the reasons for many to venture into the forest (Kumar, 2012; Chowdhury et al., 2008), and the major cause of land use change from agriculture to aquaculture in the delta has been the export of aquaculture (Kumar, 2012). In Sundarbans, with easy availability of tidal water, the brackish water aquaculture has flourished over the last 4 decades (Fig 3.) (Giri et al., 2021). In West Bengal scientific farming of black tiger shrimp *Penaeus monodon*, famous for its unique taste, dates to 1980s covering an area of around 39,000 ha (Mandal & Dubey, 2015, Giri et al., 2021) but off late since 2009, post cyclone Aila, farming of an exotic species *Litopenaeus vannamei* (white-leg shrimp) have boomed because of its fast growth and hardiness against diseases and salinity (Ghoshal et al., 2019).

Environmental and Climatic Drivers: Climate changes, frequent unprecedented cyclonic hazards have further affected the landscape adversely affecting both mangroves and the people of the delta. Many islands have been submerged in last few decades (Hazra et al., 2002). The mangroves of Sundarbans while protecting the human habitats inland from severities of cyclones of Aila, Bulbul, Amphan, and the likes, have themselves bore the brunt of the disasters. The landscape has been ravaged by cyclones repeatedly in a row since 1988, following a

sequence (1988, 1991, Sidr in 2007, Nargis in 2008, Aila in 2009,) (Ghosh et al., 2015), and the recent Bulbul in 2019 and massive Amphan in 2020. The Asian tsunami of 2004 had also adversely affected the mangroves with flood surges (Ghosh et al., 2015). Today there is a serious concern regarding the weakened health and regeneration ability of the mangroves. Spatio-temporal data analysis using remotely sensed data shows there is significant degradation in health quality and slow rate of rejuvenation (Awty-Carroll et al., 2019; Hati et al., 2020). The health of the mangroves is further deteriorated by increased saline water flood surge, sea level rise, and reduced sediment and freshwater inflow from upstream (Bhargava et al., 2020; Ghosh et al., 2015). The relative mean sea-level rise at Sagar Island, 12 mm/year, between 2002 and 2009, much higher than 3.14 mm/year in the previous decade (Hazra et al., 2010) is also higher than the global average of 3.27 mm/year between 1993 and 2010, and according to the IPCC estimation, a 45-cm sea level rise could inundate 75 per cent of the area and a 1 metre rise would completely inundate the Sundarbans (Roy & Guha, 2017). The predicted reduction of tiger habitat by the end of the century may leave less than 20 breeding individuals in the whole of the Sundarbans, way below threshold for species maintenance, which might lead to the tiger extinction (Ghosh et al., 2015).

Political Drivers: The Sundarban Tiger Reserve (STR) was formed in 1973, to conserve the Tiger population in Sundarbans, with the commencement of Project Tiger following the mandates of Wildlife Protection Act (WLPA), 1972. While colonial scientific forest management following Indian Forest Act 1927 criminalized the forest dwellers and forest dependent communities, formation of Sundarban Tiger Reserve (STR) further imposed stringent rules and regulations against the Scheduled Tribe (ST), Scheduled Caste (SC), Other Backward Class (OBC) communities, who were not provided with enough time, information, awareness in local language to register themselves for the Boat License Certificates (BLCs) leading to many of them losing the only opportunity to get official pass for lawfully engaging in their daily livelihoods – fishing and Non Timber Forest Product (NTFP) gathering. Forest Rights Act (FRA) 2006, designed to enable the rights of forest dwellers could not be of much help in minimizing these negative impacts owing to the riverine separation and distance between human habitat and protected area boundary (Dasgupta and Shaw, 2017; Mistry & Das, 2015). This led to socio-economic uncertainty to the huge number of traditionally Sundarban dependent communities leading to illegal leasing of BLCs, corruption, as frequently enough the BLC owners were found to not be actual fisherfolks (Mistry & Das, 2015). There is rising demand for other sources of income and while ecotourism could have been a viable alternative the policies and implementation have not let it boom beyond some specific pockets (Dasgupta and Shaw, 2017; Mistry & Das, 2015). Centralized policy making and enforcement without involvement of local communities, civil society organizations (CSOs), Non-government organizations (NGOs) involved with local people, lead to development action detached from ground reality, even with good intentions, as seen in case of Sundarbans (Dasgupta & Shaw, 2014). A Joint Mangrove Management (JMM) Model as was initiated in Pichavaram mangroves by M S Swaminathan Research Foundation with 28 Village Mangrove Councils might be thought for Sundarbans to make communities aware, accountable, responsible for their mangrove restoration-conservation management at one hand, as well as empowering them through the process on the other (Dasgupta & Shaw, 2014).

Discussion

Since 1996, India's mangrove loss has nearly doubled with 7.1% forests outside the protected areas than 3.6% inside them indicating the need of urgent restoration attention. The major cause of land use change from agriculture to aquaculture in the delta has been the export of aquaculture (Kumar, 2012), but commercial tourism in name of eco-tourism also plays an important role in the demand (Guha & Ghosh, 2007). That also affects the bio-geo-physical environment and degrades habitats in mangrove systems, salinizes soil and water, causes coastal and fresh-water pollution, alters local food web and ecology and also depletes wild resources like fish variety (caused by prawn seed collection) (Kumar, 2012). 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 in 11 years creating an additional carbon sink of 3 billion CO_2 equivalent for the forests by 2030 (Kathiresan, 2019). However mangrove planting efforts are often failure from non-consideration of ecological characters of

the area, and indicates the need of 'Ecological Mangrove Restoration' that takes into account the 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). Seasonal migration has been on rise post 2004 tsunami and people migrate to all parts of the state and country in search of living. It is the principal source of earning in many households. Building capacity of these huge populace, more than 34% (HDR, 2009), of whom fall below poverty level (BPL) and upskilling them to alternate livelihoods is a necessity today for resilience of the delta. Upskilling of rural communities and involvement of women in indigenous climate tolerant species-agriculture, raising mangrove nurseries, ecotourism, non-forest venture-based bee keeping, and community led mangrove-prawn silvo-fishery and mangrove eco-restoration, as tried elsewhere in Asia (Lewis, 2014) can add new livelihood opportunities and value to the landscape.

Conclusions/ wider implications of findings

There is an evident gap and lack of 'integrated yet decentralized' approach in national or regional policies and plans to have long-term, specific targets (beyond 2030) (Marcinko et al., 2021). Sectoral policies in agriculture, development, fisheries and aquaculture, social protection, tourism, coastal zone management directions need to be identified indicating the potential interactions (Nilsson and Weitz, 2019) to understand the trade- offs and synergies relating to the Sustainable Development Goals and targets. In a complex and dynamic coupled nature-human system, such as the SBR, the complexities related to sustainable development challenges require integration of knowledge across environmental and socio-economic disciplines and multidimensional frameworks (Marcinko et al., 2021) that successfully capture such wide-ranging and cross-sectoral knowledge and integrate different types of quantitative models alongside qualitative and participatory analysis are the need of the hour. For sustainable development, the practice of upskilling and capacity building of local communities with participatory local specific policy development and implementation in line of national and global visions need to be promoted.

Acknowledgements

We are grateful to UKIERI-DBT Funded project "Opportunities and Tradeoffs between SDGs for food, welfare, and environment in the deltas" and Prof. Sugata Hazra, the Principal Investigator of the project, and Professor, School of Oceanographic Studies for his constant support, encouragement, and guidance.

We thank everyone associated with the project for their contribution.

We dearly thank Dr. Shalini Dhyani, Chair IUCN Commission on Ecosystem Management South Asia, and Dr. Rajarshi Dasgupta, Senior Policy Researcher (Integrated Sustainability Centre), Institute for Global Environmental Strategies (IGES), Japan for their contribution in introducing and guiding us to the STEEP framework in National workshop on mangroves future at New Delhi, India.

The views expressed in this information product are those of the author(s) and do not necessarily reflect the views or policies of FAO.

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