Securing the sustainable future of tropical deltas through mangrove restoration: lessons from the Indian Sundarban

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Summary

Mangrove forests are natural protectors of several tropical deltas, but are severely degraded and their restoration often fails due to the lack of a holistic approach. Here, we share lessons from the recent Indian Sundarban delta mangrove plantation programme and discuss potential solutions to remove barriers for successful mangrove restoration.

Climate change and anthropogenic activities threaten river deltas' geomorphology, ecology, and economic resilience worldwide. Identifying pathways to sustainable futures of deltas is imperative, especially for South and South-East Asian tropical deltas, which provide massive ecosystem services to millions. Intertidal mangrove forests thrive in many of these deltas providing coastal protection to habitats from strong winds, storm surges, and wave action, besides enriching the biodiversity and supporting local livelihoods. Protecting existing and restoring lost mangroves, rather than relying on engineered interventions, offer an optimal nature-based solution that does not harm the deltaic ecosystems. Although gray infrastructure options for coastal protection (e.g. seawalls) can be implemented faster than the (re)growth of mangroves to maturity, such engineered options have a tendency to result in maladaptation in the long-term.

Asia hosts nearly half of the world's mangroves, but sadly 3870 km^2 of South and South-East Asian mangroves have been lost in just a few decades, this equates to 45% of the mangrove loss globally[1]. Such widespread degradation has occurred due to environmental change from *inter alia* coastal urbanization, aquaculture, agriculture, and overexploitation[2]. To undo the damage and reinstate vital ecosystem services, multiple mangrove restoration schemes are now in operation across South and South-East Asian deltas. Attention towards mangrove restoration has increased in terms of public investment for the planting schemes and academic research to evaluate restoration success. Since 2005, an estimated US$900 million public finance investment has been spent on mangrove conservation activities globally.[3] However, despite this investment, over the past 40 years 48.7% of mangrove restoration projects have failed [4].

The Sundarban - a mangrove area that lies within the Ganges-Brahmaputra-Meghna delta – is the largest in the world and extends across India and Bangladesh. The Indian Sundarban lost 374 km^2 of mangroves between 2000 and 2017[5]. Following the May 2020 super-cyclone Amphan, which caused the further loss of 43% of mangrove forests[6], the government announced a restoration plan to plant 50 million trees starting from July 2020.. Such a large-scale plantation initiative was the first of its kind in Indian Sundarban and involved several thousand local people, led by the State Department of Forests. The programme was funded by the State Government of West Bengal and utilized a national government welfare scheme (Mahatma Gandhi National Rural Employment Guarantee Scheme: MGNREGS) for payment of wages to local people. Although the target was to plant 50 million saplings, by March 2022, 123.77 million mangroves had already been planted, with planned work for infilling to be continued regularly. This programme can provide useful lessons when undertaking large-scale mangrove restoration for ecosystem-based adaptation especially in tropical deltas (Figure 1). Here we argue that mangrove biology and ecology, equitable community participation, good governance, and better science-to-policy communication are essential to protect tropical deltas via mangrove restoration in a warming world.

Biological and ecological knowledge increases success

Considering mangrove biology and local ecology is vital to mangrove restoration success. While ecological restoration through natural mangrove colonization is increasingly being promoted[7], mangrove planting remains the primary choice, particularly in response to cyclones[8]. However, several mangrove restoration projects have failed in the past due to wrong species selection, poor site selection, and improper planting techniques. Unlike terrestrial afforestation, sowing mangrove seeds directly in the mudflats often do not materialize as the seeds fail to acclimatize with the plantation sites' conditions and eventually fail to germinate. Moreover, several past efforts focused on planting a single specie/genus, but such mono-specific planting leads to a lack of structural complexity and hence lower resilience, ecological functionality, diversity, and ecosystem services compared to natural mangroves[9]. Survival of mangrove seedlings requires a series of disturbance-free periods during this critical life cycle stage[10], which is often not achieved due to the lack of biological and ecological knowledge about the species and the plantation sites.

In the Indian Sundarban plantation programme, the initial establishment bottlenecks were surpassed by growing the mangrove saplings in nurseries for later transplantation rather than planting propagules directly on mudflats. Plastic bags were used to compact the rhizosphere during the seeds' growth into saplings in nurseries to further stabilize soils against erosion. Saplings were often planted alongside established saltmarsh vegetation, which naturally thrives in this mangrove habitat. Two-thirds of plantation sites already had *Porteresia coarctata* and

Suaeda maritima saltmarsh plants. These marshes stabilized the saplings by protecting them from wave-induced disturbances, thereby increasing the likelihood of their survival. To maintain species diversity, 6 dominant genera out of 19 native true mangrove genera of Indian Sundarban were selected (Figure 2). One new true mangrove genus was introduced in 47% of sites, with two new genera in 22% and three in 30% of sites. Ultimately, the Indian Sundarban Plantation Programmme encompassed 4,579 ha, of which 4,219 ha covered 217 sites within the eleven Community Development Blocks of the Sundarban Biosphere Reserve[11]. The reported average seedling survival rate was about 77% after 4 to 7 months[11] - higher than the global average of 51%[4].

Such an impressive survival rate, however, was assessed for a rather short-term, which is far below the standard time if we consider the long-term survival (at least a decade). Furthermore, such survival rates can often be overestimated - many samplings that could survive for a year or two may failure to mature into a tree, eventually defying the ultimate goal of the restoration programme. In addition, there is also a lack of holistic attention to ecological conditions. Mangrove ecosystems act as nursing grounds for several floras and faunas. In the Indian Sundarban, tourism centres around boat safaris plying along the deltaic waterways to catch a glimpse of the Royal Bengal Tiger, the Spotted Deer, and countless other faunas along the mangrove mudflats. Fences and nets were installed at many plantation sites to restrict grazing and damage by wildlife. Whilst this protected the saplings, it adversely impacted people's livelihoods when their livestock could not access the mudflats, affected tourism when tourists could not see the wildlife, and disturbed the ecology through fish larval mortality. However, in some sites, where no fence was installed, wave exposure and herbivory by fishes and snails led to sapling failure. A key lesson to learn is that, for large-scale mangrove restoration programmes, apart from building prior biological and ecological knowledge of the entire ecosystem and its functioning, persistent monitoring and nurturing for long-term mangrove survivals is essential.

Equitable participation enhances restoration success

Equitable involvement of local communities is key to the success of mangrove restoration as it builds a sense of ownership of the planted saplings, leading to better and long-lasting monitoring and protection by communities themselves. In the absence of equitable community participation, several large-scale restoration programmes worldwide have often failed. For example, the Red Cross restoration programme undertaken in the Thai Binh province of Vietnam after Typhoon Damrey in 2005 failed to achieve higher success rates due to poor involvement of the local communities[12].

In the Indian Sundarban plantation programme, a significant proportion of the local community were involved, which included forest-dependent population and local Self-Help group members. Individuals worked full time in this programme; however, MGNREGS can provide wages (approximately US$2.4 per day) to an individual for only 100 days in a financial year. In July 2020, when local communities were enduring the impacts of Cyclone Amphan and the economic fallout of COVID-19, mangrove restoration work provided employment opportunities for the local community, with an estimated 1.15 million workdays being generated[13]. A highlighted objective of the plantation programme was to build "women empowerment" to create the dual benefit of making women financially independent while ensuring close monitoring of the planted saplings as most women employed in the programme permanently reside close to the sites. More than 50,000 women were successfully involved in the restoration work - taking care of seed collection, nursery creation, and sapling plantation – appearing to achieve the claimed objective.

Despite of such a large-scale community involvement emphasising the role of women, the existing operational framework appears to cast shadows on equity. Today, out-migration is emerging in many deltas worldwide, with more than 30% of households having at least one migrant[14]. In the Indian Sundarban, more males (83% of total migrants) migrate seasonally, driven by lack of sustained employment opportunities at home and uncertain agricultural income. When the COVID-19 mobility restriction was lifted in India, although the plantation programme was still ongoing, many of the men employed in the programme returned to their former employment, where they are paid higher wages than the subsistence US$2.4 wage/day and only for 100 days/year. However, job cards issued by MGNREGS are assigned to households rather than individuals. Thus, in the men's absence, women of the households were often brought in to complete the work. From the government's perspective, women's involvement might equate to women's empowerment, but this could also be considered coercion and involuntary participation. Men's absence increases women's workload for the household and livelihood activities. Under such circumstances, women's participation in mangrove restoration program is often out of compulsion rather than voluntary, which is likely to cause a drastic drop in women's participation in the monitoring stage.

In the presence of better payments outside deltas that attract a large-scale male out-migration, governments must strengthen the financial support to plantation programmes to ensure sustained and healthier wages, not only to deeply engage with the local-community, but also to hold fast to inclusivity throughout.

Good governance for economic and environmental win-win

Good governance sets the seed for successful mangrove restoration with close attention to both economic and environmental benefits that the restoration efforts can provide. Unanticipated outcomes of mangrove restoration programmes such as stagnation or even failure can happen, in the absence of long-term resource management including but not limited to coordination and agreement between the different tiers of government or other actors involved in the mangrove plantation efforts.

Between 2020 and 2022, 71.58 million true mangroves (halophytes) and 52.19 million mangrove associates (glycophytes with certain salt tolerance) were planted under the Indian Sundarban programme, with an expenditure of 1.23 billion Indian Rupee (~US$1.5 million)[15]. Political will in the form of the Chief Minister's plea was instrumental in mobilizing funds for this massive plantation programme, ensuring its implementation. The mangrove restoration drive, viewed as a 'green recovery solution', therefore served as a win-win for economic recovery from COVID-19 and future disaster risk reduction through coastal protection, including protecting 600 km of vulnerable embankments.

However, in the first two years since the programme's implementation, a lack of agreement between the National (India) and State (West Bengal) governments on the MGNREGS has led to some non-payment of wages. This caused some community members to lose trust in the plantation programme. Furthermore, monetizing ecosystem services delivered via restoration efforts can lead to greater acceptance and appreciation within local communities. Recent estimates show that the Indian Sundarban mangroves provide ecosystem services worth 19,145 million US$/year[16]. However, such a value is rarely communicated to local communities. The carbon repository of the Indian Sundarban mangrove also has the potential to generate significant monetary benefits by selling carbon credits[17]. Local communities actively involved in restoring mangroves should reap those directly. However, initiatives that generate carbon credits by protecting mangroves and trading the credits under the Clean Development Mechanism of the United Nations are not practiced in the Indian Sundarban.

A strong national-level initiative is the need of the hour to trade mangrove generated carbon credits of regions like the Indian Sundarban, to facilitate long-term restoration success while providing financial benefits to local communities. The evaluation and trading of the mangrove carbon credits, however, must come under scrutiny to ensure the transparency and effectiveness of associated carbon offsetting.

Ensure effective science-policy communication

Effective science-policy communication is critical for improving the success of mangrove plantation, since scientific knowledge is essential for effective mangrove growth, and policy intervention is essential to support the implementation of the programme. Communication gaps between scientists and politicians could lead to misunderstanding, unrealistic expectations, and eventually deteriorate outcomes.

A year after the commencement of the Sundarban programme, Cyclone Yaas hit the region. The Chief Minister of West Bengal immediately enquired about the status of the ~50 million mangroves planted only since 2020 and unrealistically expected it should have already acted as a natural barrier in the event of cyclones[18]. Such an unrealistic expectation is a consequence of the rather late involvement of the scientific community in the programme when most of the plantation work was already executed. If the scientific community had been involved in the process from the outset, it might have presented a more realistic expectation to the administration: they would better understand the time needed (usually require a minimum of a decade) for the sapling to mature and maximise ecosystem service benefits, and would more likely prioritise the health of the planted saplings (i.e. quality) rather than solely focusing on the number of saplings being planted (i.e. quantity). Earlier engagement of the scientific community is particularly essential for prior monitoring of the hydrological conditions of the proposed plantation sites. In the absence of hydrological monitoring, plantation sites and mangrove species are often arbitrarily selected, leading to failures in the longer term. Besides this, it is also pertinent for policymakers and managers to incorporate funding and resources at the outset for longer-term monitoring of the plantation programme.

In April 2022, the Government of West Bengal invited academic institutions of West Bengal to share the programme's progress, whereby detailed reports were circulated, and the research community was invited to conduct participatory research to better inform future planting initiatives. Such efforts are commendable as this allows the scientific community to share their knowledge with policymakers and managers to better inform mangrove plantation efforts, thereby ensuring greater success. The government seems to have learnt a lesson, but for desired results, the involvement of scientific community in such policy decisions must happen across all stages of the plantation process - from concept development to execution and post-project monitoring.

A dearth of biological and ecological knowledge, an absence of equitable engagement of local communities, a poor governance that fails to attain environmental and economic co-benefits, and ineffective science-policy communications could all hinder the success of mangrove plantation. Multi-stakeholder partnerships that involve all key actors within and beyond tropical delta communities across all stages of the programme are critical to build the capacity for effective large-scale mangrove restoration. Transdisciplinary conversation across the scientific community, policymakers and key stakeholders is essential for knowledge and information exchange to better design science-based targets and aim for long-term success. All stakeholders should join forces to ensure protection of existing mangrove forest vis-a-vis restored forest, as a healthy deltaic mangrove forest builds sustainable futures for a resilient delta.

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Figures

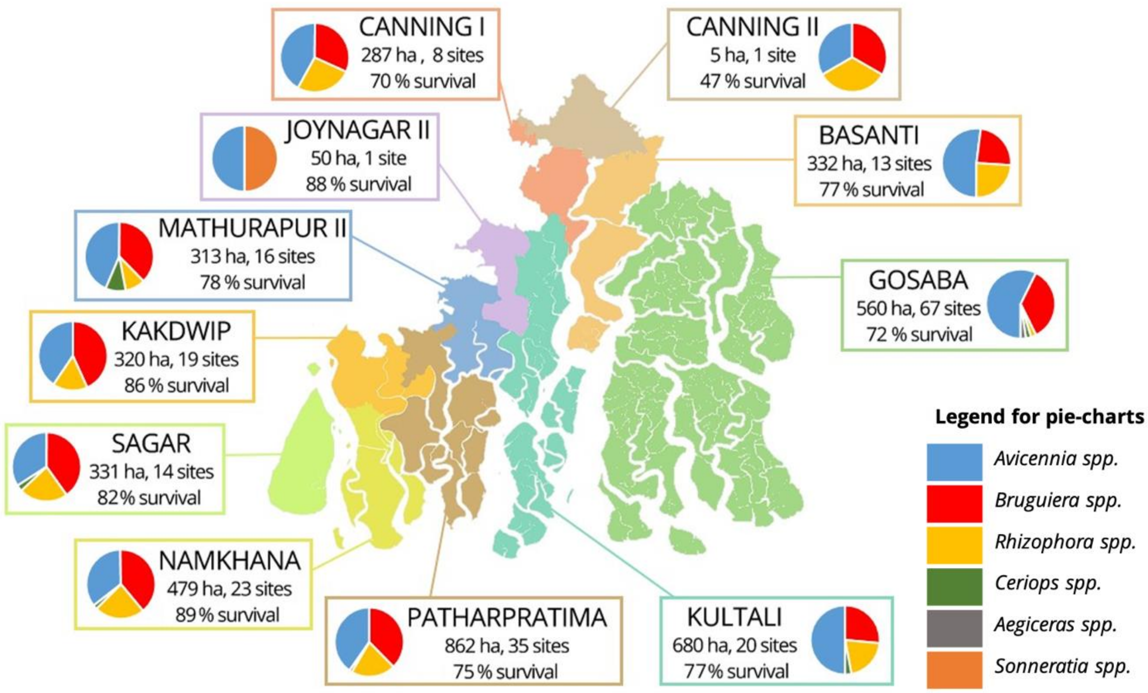

Figure 1: Bottlenecks and solutions for mangrove restoration programmes with observations from the Indian Sundarban Plantation programme.

	Issues	Solutions	Observations from Indian Sundarban Plantation programme
	Selecting wrong species for a chosen site	Characterising hydro-geomorphological traits of the potential planting sites and correlating them with species specific requirements	Prior hydrodynamic monitoring was not done while selecting the species
	Improper site selection	Involving academic experts in the concept development stage is critical	Academic experts were involved at a later stage of the programme to share the progress, but this involvement should have been from an earlier stage
	Mangrove restoration often leads to a decline in species diversity	Instead of promoting mono-specific afforestation, plantation programmes should retain the intrinsic species diversity	One new genus of true mangroves was introduced in 47% of sites, with two new genera in 22% of the sites and three in 30% of sites. 32% of sites experienced no genus change
	Survival of seedlings during the nascent stage of plantation	Transplanting seedlings and saplings grown in nurseries rather than planting propagules directly on mudflats helps surpass initial establishment bottlenecks	Until March 2022, 30 nurseries were operational, covering 1974 ha, producing six million seedlings which were compacted using plastic bags before planting in the sites
	Success is equated with achieving planting targets	Minimum of 5 years of survival of mangrove saplings could be considered a successful restoration outcome	Survival (77%) was higher than the global average, but this report was produced after only 4-7 months of monitoring which is a very short time
	Lack of involvement of local communities	Ensuring an equitable approach where communities are co-developers of the programmes	Local communities, especially women were involved but there remains traits of top-down approaches
	Failure of projects due to lack of political will	A strong political intent which authorises relevant administrative authorities to execute the projects	The Chief Minister urged the Department of Forests to ensure planting of 50 billion mangroves
	Lack of funding	Resource management should encompass the plantation period, and a ten-year period for long-term success	Funds to cover daily wages of the people involved was covered by a Central Government scheme. However, lack of agreement between the National and State governments has led to some non-payment of wages

Figure 2: Details of the Indian Sundarban Mangrove Plantation Programme. *Avicennia* (45%) was the most frequently planted genus, followed by *Bruguiera* (36%) and *Rhizophora* (17%). *Avicennia* was also the only genus that pre-existed in all sites.