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Mangrove Restoration in Bangladesh

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Abstract

Bangladesh is a deltaic country with a 710 km coastline and numerous newly accreted offshore islands in the central and eastern coastal regions. Natural mangrove forest (the Sundarbans) occupies about 100 km of coastline in the southwest, which protects the lives and properties of the coastal population of that area. The depletion of the forest stock of the Sundarbans was reported in 1875 due to the large-scale clearings by the woodcutters and uncertainty in natural regeneration. The restoration of the Sundarbans in the name of enrichment plantation and assisted natural regeneration was formally introduced in 1959 with *Excoecaria agallocha* followed by the introduction of mangrove and mainland (non-mangrove) species in the moderate to high saline zone and raised lands in the freshwater zone, respectively in 1975. Chakaria Sundarbans, the second largest natural mangrove forest on the east coast, was highly degraded with the rapid expansion of aquaculture between 1976 and 1989. Tremendous human interferences significantly altered the site condition, interrupting natural recovery. Coastal afforestation was initiated in 1966 with two pioneer mangrove species (*Sonneratia apetala* and *Avicennia officinalis*). Some afforested sites require attention for restoration due to natural and manmade causes. Bangladesh Forest Department adopted restoration activities with the technical support of the Bangladesh Forest Research Institute and other agencies. However, all the restoration activities for the Sundarbans, Chakaria Sundarbans, and coastal afforested sites had some success and failure stories. The success and failure of a mangrove restoration activity depends on planning (active or passive restoration), selection of suitable sites and species, planting materials, local community involvement, monitoring, evaluation and plantation management.

Keywords

Bangladesh, Coastal Areas, Manmade Mangroves, Pioneer Species,

Restoration, Sundarbans

1. Introduction

Mangrove is an evergreen plant community that grows in the saline-influenced water log habited in the tropical and sub-tropical sheltered coastline (Tomlinson, 1986) that form one of the most productive coastal ecosystems (Hossain et al., 2008; Ribeiro et al., 2019). Mangroves are distributed in 123 countries of the World, with 1,47,359 km^2 in 2020 (Leal & Spalding, 2022). The number of mangrove species is 114, belonging to 66 genera and 43 families (Tomlinson, 1986). Each species has a range of adaptive nature with the mangrove habitat. Bangladesh contains both natural and manmade mangrove forests. The Sundarbans and Chakaria Sundarbans are the natural mangrove forests of Bangladesh, encompassing 6,017 km^2 and 182 km^2, respectively. Considering the area coverage, the Sundarbans has become the World's largest single tract of mangrove forest. Some scattered natural mangrove forests are found in the coastal areas, but their area coverage has yet to be discovered (Hoque & Datta, 2005). On the other hand, Bangladesh contains the World's largest manmade mangrove forest in the coastal areas and offshore islands. The area coverage was about 200 km^2 (1.36% of the total land area of Bangladesh) in 2019, and the area coverage will increase shortly (Hossain et al., 2020) (**Figure 1**).

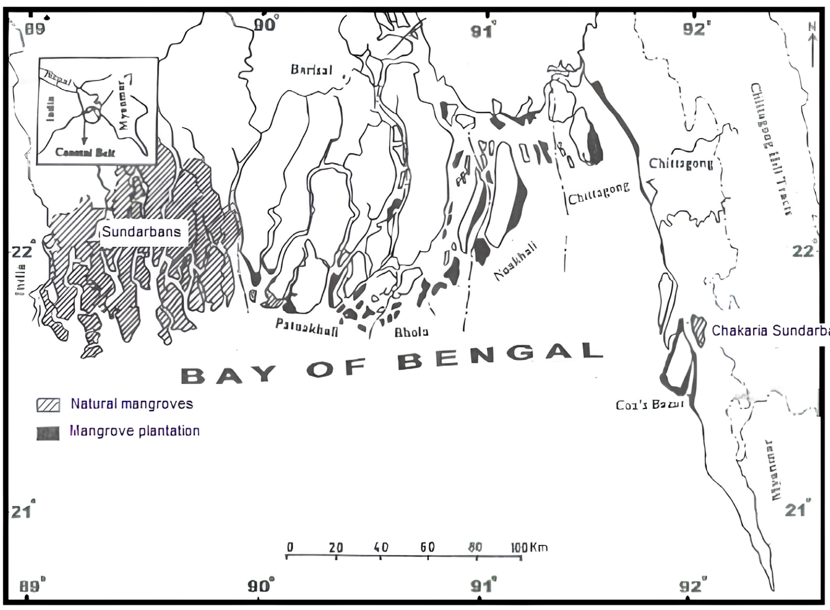

Figure 1. Distribution of mangroves in Bangladesh. (Source: Siddiqi & Khan, 2004)

Mangrove forests are sources of a wide array of wood and nod wood resources, which directly contribute to the local community's livelihood. Besides these resources, mangrove forests protect the life and property of the coastal people from tidal surges, tropical cyclones and tsunamis (Hossain et al., 2020). Mangrove forest entraps sediment, contributes to land formation and stability, acts as a carbon sink, supplies detritus to the aquatic environment that supports coastal fisheries, feeding and breeding ground of fish and marine animals, and supports juveniles as nursery ground (Field, 1995; Hossain, 2004; Hossain et al., 2005, 2007; Ahmed et al., 2024).

Despite the importance and function of the mangrove forest, these forests were known as devil's places and neglected as remote access and muddy and smelly areas (Field, 1995). The extent of mangrove areas declined rapidly around the globe for a long time before mangroves were understood to be important. The southern parts of Bangladesh were used as an economic, political and cultural frontier from 1200 to 1750 AD, significantly influencing the destruction/degradation of mangroves in Bangladesh (Hossain et al., 2021). About 90% of the global mangroves are growing in developing countries, and mangroves are critically endangered and nearly extinct in 26 countries. Governments of different developing countries and people have prioritized economic development, leaving behind the importance of mangroves. Presently, several factors or situations have been considered for the destruction of mangrove forests globally like sea and airport development, development and expansion of industrial estate, pollution from industries, ports, urban areas, overharvesting of wood and non-wood forest resources, aquaculture, and increasing events of natural calamities (cyclone, tsunami, tidal surges). However, the rate of destruction of mangrove forests around the globe has decreased significantly since 1996. We found almost similar area coverage from 2009 to 2020, with the highest degradation and accretion rates −0.26% and 0.17% in 2010 and 2018, respectively (**Figure 2**).

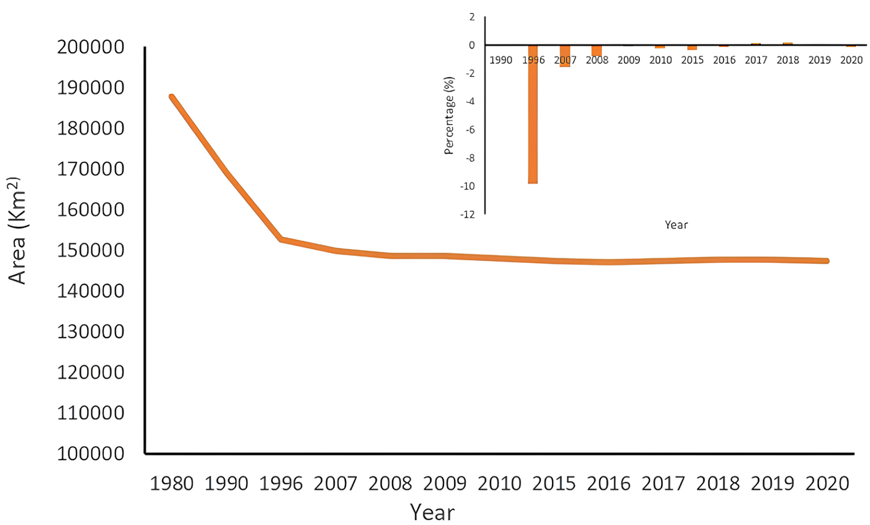

Figure 2. Area coverage of global mangrove and percentage of loss and gain from 1980 to 2020.

Considering the immense economic and ecological importance of mangrove forests, the degraded mangroves need to be brought under restoration initiatives (Leal & Spalding, 2022). However, the restoration of mangroves is a challenging task. The success of restoration activities requires expert opinion on species selection based on site conditions, raising of mangrove nursery, site preparation, planting activities and initial management of the plantation. This article focuses on the restoration initiative in Bangladesh and the possible best practices based on field, research outputs and literature. The findings of this study will help to understand site-specific factors like hydrology, salinity, sedimentation, and species suitability for successful mangrove restoration.

2. Mangrove Restoration Initiatives in Bangladesh

2.1. Sundarbans

2.1.1. The Origins of Mangrove Restoration: Early Scientific Insights and Initiatives for the Sundarbans

The first scientific article on the Sundarbans was published in 1875 and titled "Remarks on the Sundarbans." It was published in the first volume of "Indian Forester." This article described the importance of the Sundarbans and mentioned two important problems, e.g. large-scale clearance by the woodcutters and uncertainty in natural regeneration in the cleared areas. He recommended that the Sundarbans be taken under forest management without delay and that vacant areas be restocked (Hossain et al., 2021). The recommendation of filling the vacant areas of the Sundarbans was the urge for the mangrove restoration not only for Bangladesh (then India) but also for the globe. The restoration history of the degraded areas of the Sundarbans dates back to 1877, when an experimental plantation of mainland species was made in the less saline zone (Gani, 2003).

2.1.2. Industrial Use and Restoration Practices: The Role of Khulna Newsprint Mill

Khulna Newsprint mill was established in 1959 and used *Excoecaria agallocha* of the Sundarbans as raw material. As part of the management activities, the mill authority has to plant a field camp (operation camp in the Sundarbans) area of about 2.5 to 4 ha at the end of the raw material extraction. They used wildlings of *Excoecaria agallocha* that were two years old and had a height of less than 45 cm.

2.1.3. Enrichment Planting (Mangrove and Non-Mangrove Species) in the Sundarbans, Challenges and Lessons

Bangladesh Forest Department implemented some restoration initiatives in the name of enrichment planting from 1976 to 1991 (Karim 1995). There were statistics of about 10% of the total area of the Sundarbans being raised, poorly stocked and less productive, known as NCC (non-commercial cover) during 1975 (Rahman et al., 2001). Some climbers and non-commercial species usually cover these areas (Siddiqi & Khan, 2004). Bangladesh Forest Department and Bangladesh Forest Research Institute (Mangrove Division) planted valuable mangrove and mainland species in the NCC areas in 1975. A total of 1363 ha of NCC areas were bought under the plantation of mangroves and mainland (non-mangrove) species. *Heri-*

tiera fomes, Soneratia apetala, *Bruguiera sexangula*, *Avicennia officenalis*, *Xylocarpus moluccensis* and *Nypa fruticans* were mangrove species. The mesophytic and mangrove species were planted at a spacing of 1.8 m × 1.8 m and 1.2 m × 1.2 m respectively (Karim, 1995). The plantation of mangrove species in the NCC areas failed due to the unsuitability of the sites and the browsing and trampling effect of wildlife (deer and wild boar).

Almost simultaneously, the Bangladesh Forest Research Institute (Mangrove Silviculture Division) established 63 ha of experimental plantation with mainland species (Rahman et al., 2001). A total of 19 mainland species were considered for that enrichment plantation. The species are *Albiza saman*, *Albizia procera*, *Albizia lebbeck*, *Vachellia nilotica*, *Acacia catechu*, *Dalbergia sissoo*, *Senna siamea*, *Leucaena leucocephala*, *Tamarindus indica*, *Lagerstroemia speciosa*, *Neolamarckia cadamba*, *Diospyros blancoi*, *Calophyllum inophyllum*, *Caesalpinia pulcherrima*, *Toona ciliata*, *Swietenia macrophylla*, *Polyalthia longifolia*, *Melia azedarach* and *Azadirachta indica*. Among them, *Albizia procera*, *Albiza saman*, *Lagerstroemia speciosa* and *Vachellia nilotica* were found suitable only in the raised lands of the less saline zone. In contrast, plantations raised in the moderately and strongly saline zones failed. The plan of planting the mainland species in the Sundarbans' NCC area was discarded, considering the adverse impact on the Sundarbans ecosystem (Rahman et al., 2001).

2.1.4. The Sundarbans Biodiversity Conservation Project: Restoration Efforts and Outcomes

The Sundarbans Biodiversity Conservation Project (SBCP) was initiated in 1999 and ended in 2006 with financial assistance from Asian Development. As a component of SBCP, the Bangladesh Forest Department implemented restoration programmes in the name of Assisted Natural Regeneration (ANR), Enrichment Planting and *Nypa fruticans* plantation that covered 3453 ha, 1069 ha and 495 ha respectively (Gani, 2003; ADB, 2008). Enrichment planting was planned for areas with less than 30% canopy closure. The *N. fruiticans* plantations were established in the newly surfaced area where the inundation occurs yearly. ANR was implemented in areas infested by climbers, creepers, and bushes such as *H. tiliaceus*, *A. ilicifolius*, *A. aureum* and *P. foetida* and *Derris trifoliata*. The dense undergrowth vegetation suppresses the growth of selected seedlings particularly *H. fomes*, *X. mekongensis*, *B. gymnorhiza* and *E. agallocha*. The ANR activities included the removal of undesirable climbers, creepers, and bush species and pruning to open up spaces for sunlight (Benthem, 2001). However, the success of SBCP's restoration activities could have been more satisfactory (ADB, 2008).

2.2. Chakaria Sundarbans

2.2.1. History and Decline of Chakaria Sundarbans

Chakaria Sundarbans, once Bangladesh's second largest natural mangrove forest, initially spanned an area of 85.10 km^2. In 1905, the forest was designated a reserve (74.90 km^2) and protected (10.20 km^2) forest, ensuring its preservation for future generations. However, in the mid-20th century, parts of the forest were cleared for other land uses, including household needs, salt cultivation, and agriculture (Hossain et al., 2001). This initial deforestation marked the beginning of a series of anthropogenic disturbances that would affect the forest for decades.

2.2.2. Impact of Aquaculture Expansion

The expansion of aquaculture between 1976 and 1989 further aggravated the condition of Chakaria Sundarbans (Siddiqi, 2001; Alam et al., 2014). Establishing shrimp farms and ponds led to significant changes in the natural landscape, disrupting hydrological cycles and vegetation growth. These alterations, along with other human interventions, created an environment where the natural recovery of the forest became increasingly difficult, pushing the ecosystem to a state of degradation (Siddiqi & Khan, 2004).

2.2.3. Challenges in Restoration Efforts

Restoring Chakaria Sundarbans under such altered conditions has proven to be an immense challenge. The disturbance from deforestation, aquaculture, and other human activities has created a complex environment in which restoration efforts often struggle to succeed. Restoration attempts have sometimes failed due to the difficulty of re-establishing mangrove ecosystems in such a heavily modified landscape. The forest's diminished ability to recover naturally has made human intervention a critical necessity.

2.2.4. Community Involvement in Restoration

Despite the challenges, there have been success stories. Non-governmental organizations (NGOs) have played a significant role in recent restoration efforts, with community participation being a key factor in these successes. In 2004, IUCN Bangladesh launched a pilot project to restore a portion of Chakaria Sundarbans, involving local communities in the restoration process. This initiative successfully restored 20 hectares of mangrove forest using native mangrove species (Rahman & Chakma, 2018). This project highlighted the importance of community engagement in ecological restoration.

2.2.5. Ongoing Restoration Projects

Other organizations, such as the Organization for Industrial, Spiritual, and Cultural Advancement (OISCA), have also contributed to the restoration of Chakaria Sundarbans. Since 1992, OISCA has been actively involved in mangrove restoration efforts in the region, including the Chakaria area. OISCA's restoration program focused on planting pioneer species such as *Sonneratia apetala* and *Avicennia spp.* along the riverbanks and coastlines of Chakaria, covering 627 hectares (OISCA, 2021). These efforts aim to re-establish vital mangrove habitats and improve ecosystem resilience.

2.2.6. Future Prospects: Aquasilviculture Practices

As restoration continues, the introduction of aquasilviculture practices is being explored as a sustainable approach to managing degraded mangrove forests. This practice combines aquaculture and silviculture to create a more resilient and productive ecosystem. In the case of Chakaria Sundarbans, integrating mangrove species with aquaculture could provide an opportunity for ecological restoration while supporting the livelihoods of local communities. These innovative approaches hold promise for the long-term recovery of the region's mangrove ecosystems.

2.3. Coastal Afforested Areas

2.3.1. Geographical Context of Bangladesh's Coastal Vulnerability

Bangladesh is in a tropical to sub-tropical region, with a coastline stretching over 710 km. This coastline is dotted with newly accreted offshore islands, particularly in the central and eastern coastal areas. While the Sundarbans in the east remain relatively protected, the rest of the coastline is highly susceptible to tropical cyclones and tidal surges, which frequently affect the region.

2.3.2. Tropical Cyclones and Tidal Surges

Since the first recorded tropical cyclone in 1584, Bangladesh has experienced 77 tropical cyclones and tidal surges up until 2024 (Hossain et al., 2020; Wikipedia, 2024). These extreme weather events have caused significant loss of life and property, especially in coastal areas, severely affecting the local population's livelihoods. The vulnerability of the coastal regions necessitated proactive measures to protect both human life and infrastructure.

2.3.3. Coastal Afforestation Efforts in Bangladesh

Coastal afforestation in Bangladesh was initiated in 1966 to mitigate the devastating impacts of tropical cyclones and tidal surges. These afforestation efforts focused on planting pioneer mangrove species, such as *Sonneratia apetala* (85%) and *Avicennia officinalis* (15%), which were chosen for their resilience to coastal conditions. Alongside mangrove species, several non-mangrove species, including *Albizia saman*, *Casuarina equisetifolia*, and *Acacia nilotica*, were planted in the raised coastal lands to help stabilize the environment (Hossain et al., 2020).

2.3.4. Challenges to Mangrove Plantations

While the mangrove plantations have provided certain benefits, they have also faced significant challenges. The planting of mangrove species in newly accreted lands and low-lying coastal areas has led to changes in surface hydrology, river morphology, and bathymetry, which, in turn, have created unfavorable conditions for the pioneer species. These changes and the presence of pathogenic agents have caused high mortality rates in large-scale mono-species plantations. Studies show that the original density of plantations, which was 4444 stems per hectare, has significantly reduced to between 800 and 900 stems per hectare after 15 years of growth (Siddiqi & Khan, 2004; Islam et al., 2023).

2.3.5. Restoration Initiatives by the Bangladesh Forest Department

As the original mangrove plantations mature, significant gaps have formed in the forest structure, especially in areas with moderate accretion. Additionally, the natural recruitment of second-rotation mangrove species has been hindered by the lack of seed sources or stresses related to seedling establishment. These factors highlight the urgent need for restoration efforts to ensure the sustainability of these afforested areas. To address the challenges of degraded coastal lands, the Bangladesh Forest Department has introduced mainland species in raised coastal areas of Chittagong and Noakhali. These species have been planted to improve the ecological resilience of these areas. Furthermore, the Bangladesh Forest Research Institute has successfully introduced second-rotation mangrove species, such as *Excoecaria agallocha*, *Heritiera fomes*, *Xylocarpus moluccensis*, and *Nypa fruticans*, among others, to fill gaps in the afforested sites (Siddiqi & Khan, 2004).

2.3.6. Coastal Char Land Afforestation Project

The Bangladesh Forest Department launched the Coastal Char Land Afforestation Project between 2005 and 2010 to rehabilitate degraded coastal plantation sites. This initiative involved rehabilitating 2500 hectares of old plantation areas, focusing on planting non-mangrove species in collaboration with local communities. This project aimed to restore and enhance the resilience of these coastal lands, ensuring their ability to withstand future climatic stresses (Islam, 2006).

2.3.7. Community-Based Adaptation and ICBAAR Program

A more recent restoration initiative is the Integrating Community-based Adaptation into Afforestation and Reforestation (ICBAAR) program, launched in 2015. Supported by the UNDP and the Global Environment Facility, the ICBAAR program worked on restoring over 650 hectares of degraded mangrove plantation sites. This project adopted a participatory planning approach, engaging local communities in restoration. The goal was to create a more stable and climate-resilient green belt along the vulnerable coastlines of districts like Barguna, Patuakhali, Bhola, and Noakhali, using a diverse mix of 8 - 10 species (Hossain et al., 2020).

Restoration activities under Integrating Community-based Adaptation into Afforestation and Reforestation (ICBAAR) programme. (Source: Hossain et al., 2020)

3. Basic Principles of Mangrove Restoration and Bangladesh Perspectives

The success and failure of a mangrove restoration activity depends on planning, implementation, monitoring, linkage and socialization phases (Teutli-Hernández et al., 2021). Careful planning is essential for a restoration activity. A technical workshop with stakeholders (scientists, academics, local community members, social groups, environmental managers, related government organizations, funding agencies, etc.) helps to formulate the plan. Finding the answers to the following questions at this phase is also necessary.

- Who are the stakeholders and what roles will they play in the restoration project?
- Why is mangrove restoration needed in the degraded areas?
- What are the causes of mangrove loss or degradation?
- What factors are preventing natural regeneration in the affected areas?
- Who owns the land where restoration will take place?

Site selection is a key factor for the success and failure of a restoration task. Once the site has been selected, realistic and achievable goals and objectives should be fixed. Some criteria must be followed when selecting sites for restoration activities: site accessibility, financing, security, connectivity with other projects, land tenure, protection status, community benefits, anthropogenic pressure, disturbance level and hydroperiods (Lewis et al., 2019). Information on the frequency and duration of tidal flooding in the selected sites is crucial for the success of mangrove restoration. The excess and inadequacy of tidal frequency and duration are required to induce stress and death of mangroves (Lewis et al., 2016). The following six key pieces of information on the hydrology of the selected area are needed for possible restoration activities (active or passive restoration) (Kjerfve, 1990; Perillo, 2009).

- Size and extent of drainage basin
- Extent and area of mangroves at the down slope (i.e., toward the sea) end of the basin
- Topography and bathymetry of the mangrove areas including tidal streams
- Hypsometric characteristics to calculate the current tidal prism of the mangrove areas
- Rates of terrestrial input of water, sediment, and nutrients
- Climatic water balance

Moreover, this information is important for considering the hydrological and topographical rehabilitation (creating new canal, soil mound, dredging of natural canals) of the selected sites (**Figure 3**) (Hossain et al., 2020; Teutli-Hernández et al., 2020).

In the case of the Sundarbans and manmade mangrove restoration, some of the criteria were compromised. Characterization of the intended planting sites is the most important stage that can improve the planning of restoration activities. Site characterization includes the cause of degradation and present topography, hydrology, physio-chemical characteristics of soil and water (surface and interstitial), and the vegetation structure (species composition, density, height, diameter, basal area, importance value index, potential regeneration, density and height of pneumatophores). Implementation of the restoration activities is the next phase which includes passive and active restoration (Teutli-Hernández et al., 2020). In most of the cases, the mangrove restoration projects for the Sundarbans and manmade mangrove forest did not consider all the site variables of site characterization, passive restoration activities, monitoring of the restoration activities and management/maintenance of the plantations (**Table 1**). Active restoration (planting of seedlings) is only recommended when the natural regeneration is limited or absent, sites under the tidal influence, and the physical-chemical condition of soil and water are suitable for the successful establishment of the seedling (Teutli-Hernández et al., 2020).

(a) (b)

Figure 3. Hydrological rehabilitation (a) excavation of canals; (b) Cluster planting with soil mound. (Sources: Hossain et al., 2020)

Table 1. Basic principles followed in mangrove restoration of Bangladesh.

Basic principles (modified form Lewis et al., 2019; Teutli-Hernández et al., 2021)	**The Sundarbans**	**Manmade mangroves**
Working group	Government, academia, researcher, funding authority, civil society and community	Government, academia, researcher, funding authority, civil society and community
Objectives	Improve the timber stocking and maintain sustainable yield	Improve the vegetation cover to protect the life and property of the coastal community
Cause of degradation	Increase in salinity, rapid sedimentation, lack of natural regeneration, seed predation, top dying of *Heritiera fomes*, illicit felling, browsing effect, etc. (Gani, 2003; Islam, 2006; Hossain et al., 2021)	Mortality of the planted pioneer species due to the higher sedimentation, change in hydrology, natural calamities, grazing and tampering effect. Large scales stem borer (*Zeuzera conferate*) attack the mono stands of *S. apetala*, which create large-scale gaps (up to 80%) of trees in plantations. Very poor or no natural regeneration of tree species as second rotation crop (Islam, 2006; Hossain et al., 2020).
Land ownership	Forest Department	Forest Department

Continued

Current environmental conditions like hydroperiods, physiochemical characteristics, existing vegetation, natural regeneration and topography	Not studied properly.	Not studied properly.
Active restoration (plantation of seedlings or seeding)	Done	Done
Passive restoration (Hydrological rehabilitation)	Not done	Not done
Passive restoration (Topographic rehabilitation)	Not done	Not done
Passive restoration (Climber and bush cutting and creating some gaps in the canopy)	Done	Not done
Species selection	Autecology of the selected species was not considered. Site specific species selection was not done properly. Ecological consideration in planting mainland species were ignored.	Site specific species selection was not done properly
Community involvement	Involved	Involved
Plantation management	Not conducted properly	Not conducted properly
Monitoring	Initial survival and growth were conducted. Nevertheless, long term monitoring of the plantation and the site quality were ignored.	Initial survival and growth were conducted. However, long term monitoring of the plantation and the site quality were ignored.
Dissemination of the outcome	Disseminated	Disseminated
Research for update knowledge	Ongoing	Ongoing

4. Species selection

Selection of suitable mangrove species determines the success of restoration activities and ensures the ecosystem processes (nutrient cycling, energy flow). Planting the wrong mangrove species on the wrong site and planting monocultures are blunders. Site-specific environmental parameters (soil types, salinity, elevation, susceptible to erosion, hydroperiods, wind speed) (Lewis et al., 2019; Su et al., 2022), species-specific light requirement (Hossain et al., 2020) and community demands (livelihoods of local communities related to non-wood forest prost product) (Teutli-Hernández et al., 2021; Hossain & Monzoor Rashid, 2022) need to consider during the final selection of species for the mangrove restoration. Appropriate species selection in a mangrove restoration project enables the creation of a resilient and functional ecosystem that can provide numerous ecological, economic, and social benefits. Hossain et al. (2020) prepared a list of 20 mangrove species for the afforestation and restoration of mangrove forests in Bangladesh. This list contained pioneer, seral, mid-seral, climax specie, and their requirements for soil types, salinity, tidal inundation and light. However, this list has been modified to include the non-wood forest products used by the community (**Table 2**).

Table 2. Species specific site suitability for the mangrove restoration in Bangladesh. (Modified from Islam & Nandy, 2001; Hossain et al., 2020)

Species	Suitable habitat				Community use (Non-wood)
	Light condition	Soil condition	Inundation (months)	Salinity	
Aegiceras corniculatum	Tolerate full sunlight	Silt enrich soil	3 to 12	Low to high	Honey
Aglaia cucullata	Grows well in shade condition	Mature soil	-	Low	
Avicennia officinalis	Tolerate full sunlight	Grows well on the silt deposited muddy areas	-	Low to high	
Bruguiera gymnorrhiza	Tolerate full sunlight	Slightly raised areas	6 to 9	Moderate to high	
Bruguiera sexangula	Tolerate full sunlight	Slightly raised areas	6 to 9	Moderate to high	
Cerbera manghas	Tolerate full sunlight	Mature soil	-	Low	
Ceriops decandra	Tolerate moderate to full sunlight	Silt enrich soil	3 to 12	Moderate to high	Honey
Cynometra ramiflora	Tolerate moderate sunlight	Raised areas	3 to 6	Low	
Excoecaria agallocha	Tolerate moderate sunlight	Mature soil	3 to 9	Low to mod-erate	
Heritiera fomes	Tolerate moderate to full sunlight, but shade bearer at the early growing stages (seedling and sapling)	Well-drained mature soil	3 to 9	Low to moderate	
Kandelia candel	Tolerate moderate to full sunlight	Muddy banks of tidal rivers, canal, and variety of soil types	3 to 12	Moderate to high	
Lumnitzera racemosa	Tolerate full sunlight	Grows well on slightly elevated areas	6 to 9	Moderate to high	
Nypa fruticans	Grows well in full sunlight condition	Silt rich soft muddy areas	9 to12	Low to moderate	Thatching
Phoenix paludosa	Grows well in moderate to full sunlight	It prefers slightly raised areas	3	Low to moderate	
Pongamia pinnata	It can grow in full shade to full sunlight	It grows on variety of soil types	3	Low to moderate	Oil for lamp
Rhizophora mucronata	Tolerate full sunlight	It grows on variety of soil types	9 to 12	Moderate to high	
Sonneratia apetala	Tolerate full sunlight	Newly accreted sites	9 to 12	Moderate to high	Edible fruits

Continued

Sonneratia caseolaris	It grows in full sunlight condition	Areas with deep muddy river or canal bank	9 to 12	Low to moderate
Xylocarpus granatum	Grow well in full sunlight, but can tolerate light shade	It grows on variety of soil types	3 to 12	Low to moderate
Xylocarpus moluccensis	Grow well in full sunlight, but can tolerate light shade at the early growing stages (seedling and sapling)	It grows on variety of soil types, but grows well in muddy areas	6 to 9	Low to moderate

5. Planting Materials

Different planting materials are used for the mangrove restoration activities. It includes polybag seedlings, bare-rooted seedlings, seed broadcasting and pre-treated seeds. Propagules of *Rhizophora* spp. can be planted directly in the planting sites. The choice of planting material depends on several factors, including species-specific success rate, transportation time and cost involvement. *Avicennia officinalis*, *Excoecaria agallocha*, *Heritiera fomes*, *Bruguiera sexangula*, *Ceriops decandra* and *Rhizophora spp.* showed a very poor success rate with direct seed broadcasting. In contrast, these species show a very high success rate in planting polybag seedlings (**Table 3**). Polybag seedlings require huge cost involvement in the production and transportation to the planting site, while direct broadcasting is less expensive. Therefore, planting material is a tradeoff between success rate, time, and cost.

Table 3. Types of planting materials and their related success rate. (Source: Hossain et al., 2020)

Planting materials	Name of the species	Success rate
Direct sowing of seeds in the field by broadcasting	*Avicennia officinalis*, *Excoecaria agallocha*, *Heritiera fomes*, *Bruguiera sexangula*, *Ceriops decandra*, *Rhizophora mucronata*	Very little
Direct sowing of seeds in the field by dibbling	*Avicennia officinalis*, *Excoecaria agallocha*, *Heritiera fomes*, *Bruguiera sexangula*, *Ceriops decandra*, *Rhizophora mucronata*	Little
Direct sowing of pre-treated seeds in the field by dibbling.	*Avicennia officinalis*, *Excoecaria agallocha*, *Heritiera fomes*, *Bruguiera sexangula*, *Ceriops decandra*, *Rhizophora mucronata*, *Nypa fruticans*	Medium
Direct sowing of pre-treated seeds in the field by broadcasting.	*Avicennia officinalis*, *Excoecaria agallocha*, *Heritiera fomes*, *Bruguiera sexangula*, *Ceriops decandra*	Little
Seedlings from the natural forests/wildings and planting in the sites.	*Avicennia officinalis*, *Excoecaria agallocha*, *Heritiera fomes*, *Bruguiera sexangula*, *Ceriops decandra*, *Rhizophora mucronata*	Medium

Continued

Raised seedlings on nursery beds and out planting of the uprooted small seedlings	*Sonneratia apetala*, *S. caseolaries*, *Avicennia officinalis*, *Excoecaria agallocha*, *Heritiera fomes*, *Bruguiera sexangula*, *Ceriops decandra*, *Nypa fruticans*, *Phoenix paludosa*	High to Medium
Raised seedlings in polybags/pots and planting in the field.	*Avicennia officinalis*, *Excoecaria agallocha*, *Heritiera fomes*, *Bruguiera sexangula*, *Ceriops decandra*, *Rhizophora mucronata*, *Nypa fruticans*	Very high

6. Plantation Management

6.1. Management Interventions for Successful Plantation

Successful mangrove plantation requires intensive management interventions during the first few years after planting to ensure the survival and growth of seedlings. These interventions are crucial in the early stages to create a healthy foundation for the mangrove ecosystem. Management activities tend to decrease after the first two to three years, but continuous care is still necessary for long-term success.

6.2. Early Care for Seedlings

The first two to three years after planting are critical for the survival of mangrove seedlings. Some key management actions include:

- Removal of Floating Green Algae: Floating algae can compete for space and resources, affecting the growth of newly planted seedlings. Removing these algae helps protect the young plants.
- Removal of Encrusting Organisms: Organisms such as barnacles and oysters often attach to seedling stems, which can impede growth. These should be regularly removed to ensure that seedlings are not adversely affected.
- Entangled Algae and Seaweed Removal: Algae and seaweed can entangle seedlings, hindering their development. Regular removal is necessary to maintain a healthy planting site.
- Debris Removal: Plastics, metal pieces, dead trees, and other debris can be harmful to young seedlings. Clearing these items from the planting sites ensures a clean environment for growth.

6.3. Managing Lower Survival of Seedlings

In cases where seedling survival is lower than expected, management interventions are needed to boost the health of the plantation. One such intervention is:

- Gap Filling with Larger Seedlings: If a significant number of seedlings die, larger-sized seedlings should be planted to fill the gaps and maintain site density, ensuring the overall success of the plantation.

6.4. Expert Evaluations and Cause Identification

In plantations with high mortality rates of seedlings or saplings, it is essential to:

- Expert Visits: Regular visits from experts are necessary to evaluate the causes of high mortality and to suggest corrective actions. This helps identify underlying problems, such as poor soil conditions or water quality, that might be affecting seedling growth.

6.5. Protection from Livestock and Human Activities

Protection from external threats is critical for the survival of mangrove plantations:

- Barriers to Protect Plantations: Implementing physical barriers to protect the plantation from livestock and harmful human activities is essential. These measures help reduce damage from grazing and other destructive actions.
- Community Involvement: Involving local communities in plantation management can yield better results. Community members can help maintain protective barriers and prevent damage to the plantation.

6.6. Thinning and Pruning for Long-Term Growth

As mangrove plantations mature, thinning and pruning becomes necessary to ensure optimal growth and timber production:

- Thinning of Saplings and Trees: Thinning reduces competition in densely planted sites, allowing the remaining trees to grow more effectively. It also supports sustainable timber production by ensuring that trees have enough space to develop fully.
- Pruning for Timber Production: Pruning unnecessary branches and stems can enhance the height and trunk diameter of trees, making them more suitable for timber production. Guidelines for proper pruning include:

○ Only cutting up to 30% of the living branches over a 1- to 2-year period.
○ Avoiding over-pruning, which can harm plant growth.
○ Cutting larger branches through the branch and close to the trunk to prevent bark splitting.
○ After the plantation reaches around five years of age, thinning and pruning activities can contribute to the sustainable production of fuelwood and construction wood. These practices help ensure that the plantation remains healthy and continues to provide valuable resources over time.

7. Conclusion

Mangroves are destroyed around the globe, and they are converted to sea and airport development, agriculture, aquaculture, and urbanization. Bangladesh also had the same experience of mangrove destruction. The natural (the Sundarbans) and manmade mangroves protect coastal areas of Bangladesh from tropical cyclones and tidal surges. Mangrove restoration is an attractive initiative, but sometimes mangrove restoration is impossible because of the large-scale changes in site quality and social issues. However, the success of mangrove restoration requires careful planning, implementation and plantation management.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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