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DIVERSITY OF TREE SPECIES IN THE COASTAL ZONE OF BANGLADESH

DRAFT REPORT

ON

DIVERSITY OF TREE SPECIES IN THE COASTAL ZONE OF BANGLADESH

By

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Preparation of Payra-Kuakata Comprehensive Plan Focusing on Eco-Tourism Project

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Declaration

I, Dr. Md. Nazrul Islam, declare that all materials included in this report is the end result of my own work and that due acknowledgement have been given in the bibliography and references to ALL sources be they printed, electronic or personal.

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Abstract

Biodiversity benefits people through more than just its contribution to material welfare and livelihoods. Biodiversity is essential to sustainable socio-economic development. Through agriculture, forestry, livestock and fisheries- biodiversity provides food, fiber, medicine, timber and contributes significantly to national economy and employment. Bangladesh coastline extends 710 km starting from St. Martin‘s Island in the south-east to the Sundarbans mangroves in the south-west. The coastline consists of three major regions – the eastern, central and western. The eastern coast is comparatively stable whereas the central coast is very dynamic with highest rate of accretion and erosion. The western coast is dominated by mangrove forest ecosystems. The biodiversity of coastal and marine ecosystems are very rich. Moreover, coastal system of Bangladesh has a significant relationship with the Sundarbans mangrove forest. The coastal afforestation activities started in Bangladesh back in 1965. By 2013, Bangladesh Forest Department established plantation in 209,140 hectares of coastal area of which more than 93% was with mangrove species. This coastal plantation was done by Bangladesh Forest Department through different projects like “Community Based Adaptation to Climate Change through Coastal Afforestation Project” (2008−2016), “Climate Resilient Participatory Afforestation and Reforestation Project” (2013−2016), and “Integrating Community-based Adaptation into Afforestation and Reforestation (ICBA-AR) Program in Bangladesh” (2016−2020) by redefining coastal afforestation as a climate change adaptation measure. This approach was followed by “Climate Resilient Ecosystems and Livelihoods” (CREL, 2013−2018) project and is currently being followed by “Sustainable Forests and Livelihoods” (SUFAL, 2018−2023). In all these projects, emphasize has also given in community participation in the coastal afforestation to adapt and mitigate the climate change impacts.

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List of Abbreviations

MoEF	Ministry of Environment, Forest and Climate Change
CCC	Climate Change Cell
BFD	Bangladesh Forest Department
CERP	Coastal Embankment Rehabilitation Project
CGP	Coastal Green Belt Project
SBCP	Sundarbans Biodiversity Conservation Project
CDSP	Char Development and Settlement Project
DBH	Diameter at Breast Height

1. Introduction

The coastline of Bangladesh encompasses approximately 47,201 km^2 along the Bay of Bengal. The country's coastal region is characterized by extensive river networks, an enormous discharge of sediment-laden water, a large number of islands between the channels and rivers, and a shallow area along the entire coastline. It lies between latitude 21^0-23^0 N and longitude 89^0-93^0 E. This region now includes 19 coastal districts adjacent to or facing the Bay of Bengal (Islam et al. 2006). In the south along the Bay of Bengal, the coastal and offshore regions include tidal, estuarine, and river floodplain regions. There are numerous small and large old and new islands. Twenty percent of Bangladesh's land area and twenty-eight percent of its inhabitants live in the coastal zone (Islam 2004).

As a low-lying nation, Bangladesh is among the most vulnerable nations in the world to the earliest effects of climate change (MoEF, 2008). Climate change issues now pose a grave threat to the lives, livelihoods, and sustainable development of the nation (CCC, 2009). This region has a population of 36.8 million, and more than half of them are poor (52 %) (Islam, 2008). As most of the poor live in coastal areas, they are the most susceptible to the negative effects of climate change and the primary victims. The observed and anticipated effects of climate change and vulnerability include sea level rise, increasing salinity trends, growing drainage congestions, greater monsoonal rains and reduced dry season precipitation, increasing frequency and intensity of tropical cyclones and storm surges, erosion of soil and coastal embankment, and deteriorating coastal ecosystems (MoEF, 2005; Alam, 2010). As a result of climate change, the people of Bangladesh, particularly in the coastal regions and char islands, are being affected by natural disasters more frequently. Coastal areas have inadequate road infrastructures, power, housing, sanitation, transportation, and coastal protection. Every year, they lost their homes due to natural disasters, particularly cyclones and windstorms.

During the years 1960-1980, a coastal embankment was constructed in an effort to preserve agricultural land and increase rice production in the coastal region. In the coastal region, a total of 5017 kilometers of embankments were constructed against nature's will (Rahman and Rahman, 2015). However, the embankments are threatened by rising sea levels and cyclonic storm surges. To mitigate the effects of climate change, Bangladesh must cultivate sustainable forests along its coastline. By acting as a protective shelterbelt during extreme natural events, mangroves and non-mangrove coastal forests can play an important role in reducing damage and protecting human life. Mangrove afforestation is a soft adaptation measure that has significantly reduced the loss of life and property in coastal areas due to tropical cyclones and storm surges (Nandy and Ahammad, 2012). Mangrove forests also serve to preserve and stabilize newly accreted land and foster the development of a biodiverse environment (Papry, 2014).

The Bangladesh Forest Department (BFD) began afforestation in the coastal belt in 1966 with the primary goal of protecting the lives and property of coastal residents from cyclones and tidal bores (Das and Siddiqi, 1985). Until 2010, approximately 190,000 hectares of accreted land were planted with coastal mangroves (Islam et al., 2013) where the most successful species were *Sonneratia apetala* (keora) and *Avicennia officinalis* (baen) (Siddiqi, 2001). Presently, *S. apetala* accounts for approximately 94.4 % of all established mangrove plantations, while *A. officinalis* accounts for only 4.8 % (Siddiqi and Khan, 2004). Other important mangrove species, such as *Heritiera fomes* (sundri), *Excoecaria agallocha* (gewa), *Xylocarpus mekongensis* (passur), *Aegiceras corniculatum* (khalshi), *Nypa fruticans* (golpata), etc., were found to be promising as experimental trials within *S. apetala* plantations (Siddiqi et al., 1992). Some mainland tree species, such as *Samanea saman* (rain tree), *Casuarina equisetifolia* (jhao), *Pithecilobium dulce* (payra), and *Acacia nilotica* (babla), were discovered to be suitable for planting on the elevated coastal lands after a lengthy investigation (Siddiqi, 2002; Islam et al., 2014).

Beside these coastal plantations to protect the life and livelihoods, coastal people raise homestead gardens to support their immediate crisis. Fig. 1 shows the distribution of trees in Bangladesh using Shannon-Weiner Diversity Index. Some of the species are considered "Life support species" because they are vital to the livelihoods of millions of people living in rural Bangladesh (Rahman et al., 2009) (Fig. 2). During natural disasters such as flood and cyclone, the only place where people can seek shelter and safeguard their future is their homestead. During this period, especially the poor and pro-poor are completely reliant on homegrown plants and vegetables. Consequently, the local population is increasing homestead plant species to aid them during their time of need. 70 % of Bangladesh's fruit, 40 % of its vegetable, 70 % of its wood, and 90 % of its firewood and bamboo requirements are met by homestead production systems (Miah and Ahmed 2003). However, according to a recent study by Miah and Bari (2002), the number and productivity of homestead plantations, particularly sweet water-loving fruit species, have been declining in recent years due to increasing soil salinity in water, which will ultimately affect the food security of the inhabitants.

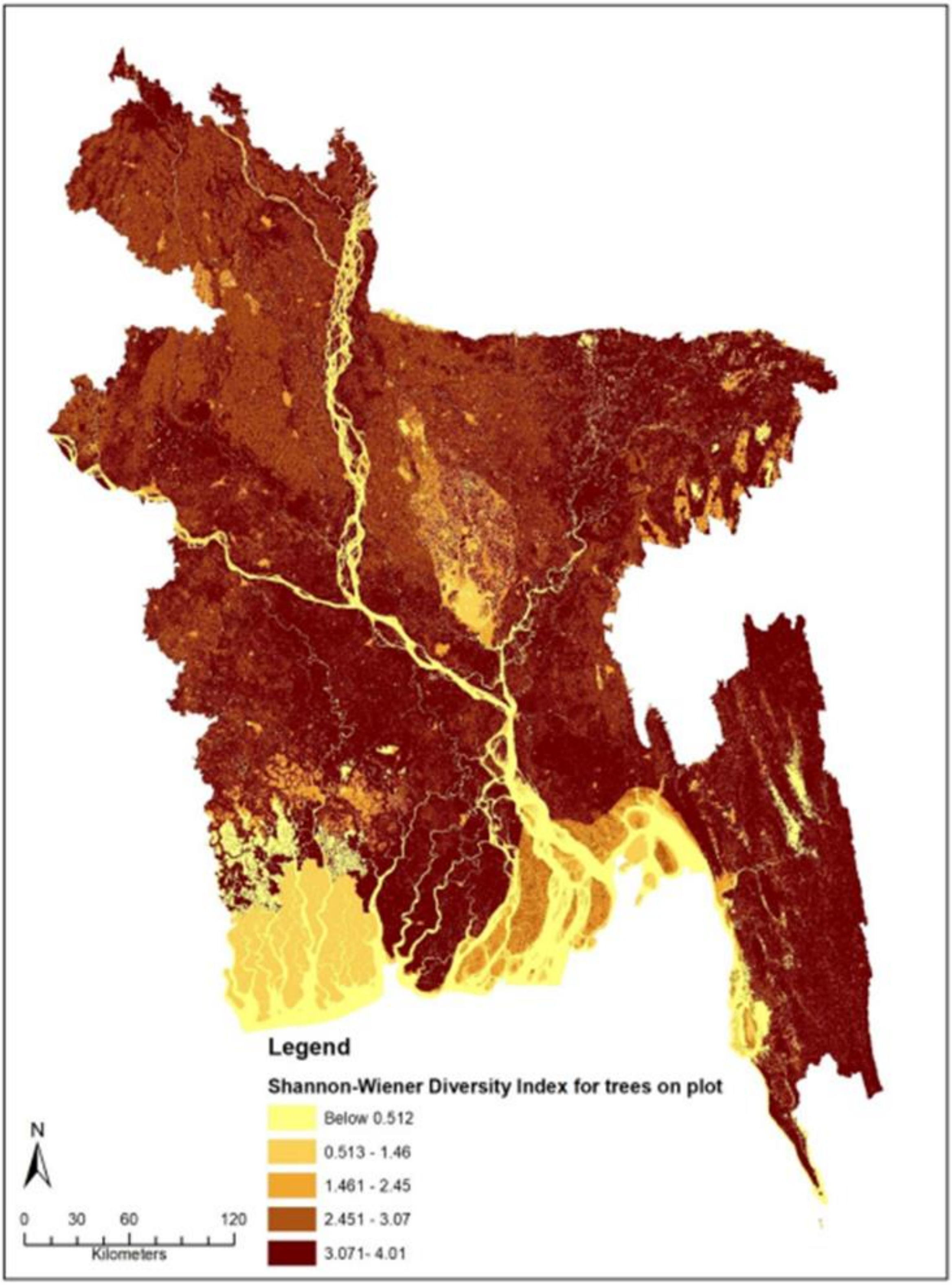

Fig. 1. Map of the spatial distribution of Shannon-Weiner Diversity Index for trees adopted from BFI plots

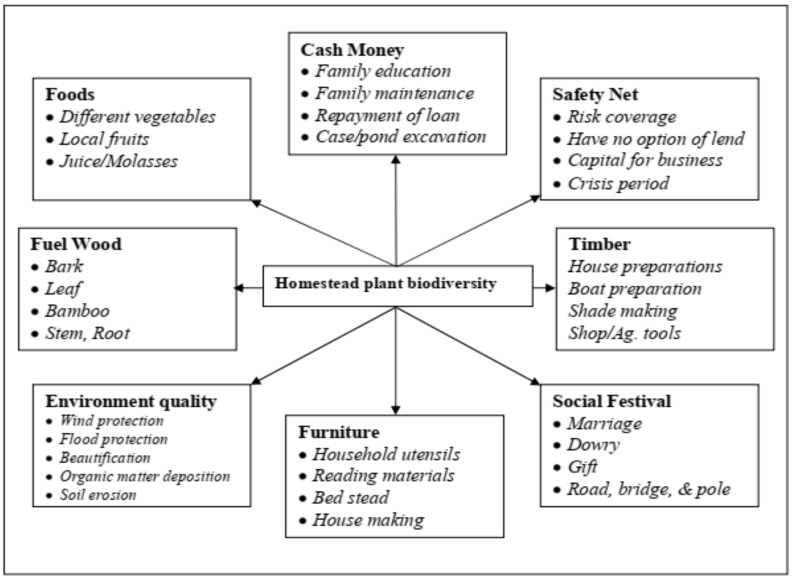

Fig. 2. Impact of homestead plant in the income generation and livelihood supports.

2. Coastal Forest's Role in Mitigating the Effects of Climate Change

Climate change is likely to increase the frequency of cyclones, storm surges, flood, salinity level, soil erosion, and sedimentation in Bangladesh (Siddiqi, 2008a). As natural disasters strike coastal areas annually, the need for greenbelts has been recognized for a long time.

For the purpose of protecting coastal areas and offshore islands from cyclones and storm surges, afforestation along the coastal belt is the cheapest and ecologically most beneficial method (Siddiqi, 2008b). Mangrove forests are the most productive ecosystem on earth, and they provide multiple benefits to coastal populations through their ecological, biophysical, and socioeconomic functions (Siddiqi 2001). Mangroves and other coastal forests can mitigate the effects of wind, storm waves, and current velocities (Fritz and Blount, 2007). Thick and dense vegetation reduces the height of the tides, thereby reducing the extent of the devastation (Siddiqi 2002). The dense forests along the coast can shield human settlements, lives, properties, and agricultural crops from climate change-induced extreme weather events (Islam et al. 2015). According to Silori (2010), coastal protection is an important function of mangrove forests, as they serve as a natural barrier against storms, typhoons, and tsunami, thereby protecting coastal residents. Recent tsunami and major storm experiences in Southeast Asia and other parts of the world have demonstrated that mangroves can and have played crucial roles in absorbing and weakening wave energy and preventing damage from debris movement (Latief and Hadi, 2007).

Some mangrove species can survive natural disasters and variable inundation of coastal habitats in order to adapt to various scenarios of sea level rise (Nandy and Ahammad, 2012). The intertwined roots of mangrove forests contribute to the stabilization of coastal areas by capturing sediment and bio-filtering nutrients and some pollutants from the water (Prasetya, 2007). In estuaries and coastal waters, the aerial roots of mangroves hold back sediments and reduce pollution from sewage and aquaculture (Silori, 2010). Islam et al. (2015) noted that mangrove plantations trap soil particles and sediments with their root system, thereby accelerating accretion and stabilizing newly accreted land along the Bangladeshi coastline. The root system can also prevent soil erosion along river and canal banks. Mangrove forests play a crucial role in providing breeding grounds and habitats for numerous commercially valuable marine species, including mud crabs, mollusks, and prawns. Thus, mangrove forests provide a novel and highly effective method for mitigating and adapting to climate change.

The coastal embankments are intended to protect against salt intrusion from the Bay of Bengal. An embankment plantation with suitable non-mangrove species not only serves as a shelterbelt but also helps to reduce embankment damage from cyclonic floods and storm surges.

3. Coastal Plantation and Its Diversity

Since the 1960s, the Bangladesh Forest Department (BFD) has implemented programs of coastal afforestation along the 710 kilometers of coastline by planting mangroves on coastal embankments, newly accreted coastal char lands, and offshore islands. Compared to unplanted areas, mangrove plantations in coastal Bangladesh have promoted accretion and reduced erosion, according to Chow (2017). Between 1973 and 1989, plantation areas experienced 37,2 times more accretion than erosion, whereas non-planted areas experienced only 1.6 times more accretion than erosion. Man-made mangrove forests cover more than 170,000 hectares of embankments, chars, and islands and constitute a unique coastal greenbelt (Table 1).

Afforestation of foreshore and tidal areas outside embankments proved to be a cost-effective method of dissipating wave energy and reducing embankment flooding during storm surges. Cyclone Sidr in 2007 and Cyclone Aila in 2009, for example, caused less property damage and fewer fatalities in Chokoria and surrounding areas than the devastating cyclone in 1991. This was due to foreshore afforestation on embankments, which significantly reduced storm surge velocity (GoB 2008).

Table 1. List of coastal afforestation projects implemented by the Bangladesh Forest Department until 2014

Sl. no.	Name of the project	Starting year	Completion year
1.	Afforestation in the coastal belt and offshore islands	1960–61 1965–66	1964–65 1969–70
2.	Afforestation Project in the coastal regions of Chittagong, Noakhali, Barishal and Potuakhali	1974–75	1979–80
3.	Mangrove Afforestation Project	1980–81	1984–85
4.	Second Forestry Project	1985–86	1991–92
5.	Forest Resources Management Project-FRMP	1992–93	2001–2002
6.	Extended Forest Resources Management Project	2002–03	2003–04
7.	Coastal Embankment Rehabilitation Project (CERP)	1997	2003
8.	Coastal Green Belt Project-CGP	1995–96	2001–02
9.	Forestry Sector Project	1997-98	2005-06
10.	Sundarbans Biodiversity Conservation Project (SBCP)	1999-2000	2004-05
11.	Char Development and Settlement Project (CDSP)	2000-05	2005-10
12.	Coastal Char Land Afforestation Project	2005–06	2009–10
13.	Management Support Project for Sundarbans Reserve Forest	2005–06	2009–10
14.	Plantation of BWDB's Embankment in the Coastal Belt and its adjacent Char Areas	2009-10	2011-12
15.	Afforestation in the Coastal Areas to Mitigate Adverse Effect of Climate Change Project	Nov. 2010	June 2013
16.	Community Based Adaptation to Climate Change Through Coastal Afforestation Project in Bangladesh	July-2009	June-2014

Source: Bangladesh Forest Department (BFD), 2012

In the coastal areas, a total of 1,92,395 ha mangrove, 8,690 ha non-mangrove, 2,873 ha Nypa, and 12,127 km strip plantations were planted as of 2013 (Hasan, 2013). Among the early mangrove plantations, about 80% of the area was *S. apetala*, 15% was *A. officinalis*, and the remaining percentage was *E. agallocha*, *Bruguiera sexangula* (kankra), *Ceriops dacandra* (goran), *H. forms*, and *X. mekongensis*, which are more valuable species for timber, fuel wood, and paper pulp production. The most successful planting species, *S. apetala*, demonstrated promising survival and growth performance all along the coastal belt. *A. officinalis* is the eastern coastal belt's second most successful species. These two species dominate the overall mangrove plantations along the coast. Other valuable mangrove species, on the other hand, did not survive in the accreted lands, most likely due to a lack of planting experience and scientific knowledge. However, a few trees of other mangrove species can be found sporadically along the coastline, in addition to the existing *S. apetala* and *A. officinalis* plantations. As a result, *S. apetala* has been widely planted in almost all development projects due to its success in newly accreted char lands. However, due to continuous siltation on the forest floor, a lack of seed sources from other mangrove species, and grazing by cows and buffalos, no regeneration has been found in *S. apetala* forests. Plantations of 37 different non-mangrove species have been established, primarily on the slop of a coastal embankment, along roadsides, and on raised coastal lands (Nandy et al., 2002).

Nonetheless, all BFD coastal afforestation projects are expected to create sustainable buffer zones that create shelterbelts, prevent erosion, trap sediment, and reduce potential loss of life and property during natural disasters. From 1960 to 2014, many projects were implemented, and some are still being implemented, to develop a coastal forest ecosystem (Table 1). The main goals of all of the projects were to increase forest coverage, halt resource depletion, and improve mangrove forest conservation.

3.1 Trees species richness of this region

This area was home to 189 different species (manily Barguna and Patuakhali). There were 189 species in moderately saline areas, 152 in highly saline areas, and 147 in less saline areas. The most species were found in moderately saline areas, including fruit yielding 44, timber and fuel wood 36, medicine and spices 17, ornamental plants 18, naturally growing plants 14 and woody-non-woody (herbs/shrubs/climbers) 60 (Table 2). Out of 189 plant species, 68.25% were trees (timber, fruits, medicinal, ornamental, and naturally growing) and 31.75 % were woody, non-woody (herbs/shrubs/climbers).

The reason for the abundance of plant species in these areas is the presence of floodplain and tidal saline ecosystems. On the other hand, some alien tree species, such as Acacia and Eucalyptus, have been found introduced in southern homesteads in recent years, which is detrimental to homestead plant biodiversity. It is critical to exercise caution and prevent the spread of alien species in the homestead.

Chambol, Mahogany, and Rain Tree were the most common and highest ranked timber-yielding species; fruits-yielding species were Mango, Coconut, and Khejur; medicinal and spices species were Deshi neem, Arjun, and Akon; ornamental species were Mehedi, Krishnachura, and Jabaphul; and naturally growing species were Shewra, Balgach, and Dumur. Existence of some species in one or more homesteads reduced to a handful of plants unable to demonstrate its relative frequency value in number in the table is a pressing concern in terms of genetic diversity. In terms of their prevalence, it is understood that a large number of local and indigenous species have been steadily declining in the southwestern homesteads, despite their apparent species richness. The top prevalent species were Chambol, Mahogany, and Raintree, all of which were favored by the locals for their rapid growth and high timber value.

However, these are not beneficial to the existence of other plants on homesteads. Other species, aside from the most prevalent species of various categories, were ranked very poorly, indicating a decreasing trend in homestead plant biodiversity.

Table 2. Higher relative prevalent species in different categories.

Species	Relative Prevalence				Total		
	Landless	Small	Medium	Large	Average trees	% Of Homestead with the species	RP all farm
Timber-yielding							
Chambal	17.409	23.243	36.458	44.933	31.56	0.88	27.880
Mahogany	14.910	26.474	31.129	38.670	32.33	0.83	26.672
Rain tree	16.571	22.434	24.525	29.322	24.41	0.93	22.679
Fruit-yielding							
Aam	9.121	9.771	11.642	16.100	11.92	0.91	10.878
Khejur	3.278	6.198	8.840	12.960	8.92	0.78	6.985
Medicinal							
Arjun	0.007	0.010	0.046	0.004	0.16	0.10	0.015
Deshi Neem	0.635	0.777	1.242	1.489	1.91	0.49	0.938
Akon	0.000	0.002	0.008	0.073	0.10	0.06	0.006
Ornamental							
Jabaful/rakta	0.043	0.031	0.062	0.033	0.23	0.18	0.041
Mehedi	0.011	0.014	0.028	0.004	0.12	0.12	0.015
Naturally growing							
Harra	0.086	0.165	0.090	0.249	0.61	0.23	0.138
Dumur	0.026	0.037	0.021	0.002	0.23	0.11	0.025

3.2 Species diversity indices of different categories of species

According to various categories of respondents, the Shannon-Wiener diversity index (H), which takes into account both the abundance pattern and diversity, has been presented as the simplest indicator of the character of a community (Table 3). In all categories, the species diversity indices were higher in the southern region of Bangladesh. The diversity (H) was greatest for large farms (2.36), and gradually decreased as farm categories decreased, with landless farms having the lowest diversity (2.21). On the other hand, there is a positive relationship between plant diversity and farm categories, in that plant diversity increased proportionally as farm size increased. The population of fruit-bearing species followed a negative correlation with farm size, in which the diversity of fruit trees increased as farm size decreased. The table also revealed that the diversity and abundance of timber-producing species were greater than those of fruit-producing, medicinal, ornamental, and naturally occurring species.

Table 3. Species diversity indices of different farm categories.

Class	Pi^2					H*
	Timber yielding	Fruit yielding	Medicinal	Ornamental	Naturally Growing	
Landless	0.1112	0.0495	0.001	0.0001	0.0004	2.21
Small	0.1117	0.0517	0.0005	0.0001	0.0003	2.22
Medium	0.1066	0.0433	0.0014	0.0001	0.0003	2.27
Large	0.0983	0.0396	0.0004	0.0001	0.0003	2.36

*H = Shannon-Wiener index, Pi = population of total individuals in the ith species.

3.3 Principal economic and lucrative timber-bearing species

In less saline to highly saline regions, eleven timber-bearing species have been designated as economically and commercially viable species. Raintree, Chambol, and Mahogony were prioritized as the most economic and profitable timber-yielding trees in the study areas among the identified species (Fig. 3). Similar trends were observed in the relative prevalence of previously discussed species. Considering the economic return, this species is considered a "poverty reduction" species. These species provide the poor with a rapid economic return. Common in moderately to strongly saline regions were Indan buch, Jilapi, Telikadam, Kadam, Indian alamond, and Indian laburnum, which were adopted for their rapid growth and high economic return. These were also used as poles, agricultural implements, handicrafts, boat building materials, and animal feed. In moderately to highly saline regions, Telikodom was favored in the homesteads. It is utilized as economic species compliance to preserve for future use. Jilapi provides indigenous fruits to rural children in the southwestern region of Bangladesh, serving as an alternative source of nutrition.

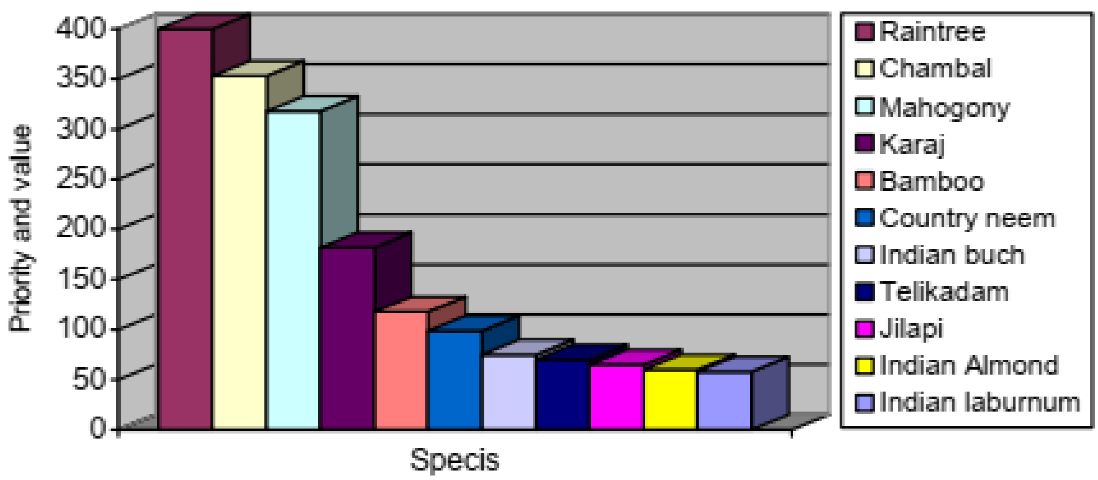

Fig. 3. Economic and profitable timber-yielding species in less saline to strongly saline areas of this region

3.4 Principal economic and lucrative fruit-bearing species

A total of 14 fruit-bearing species were identified and ranked according to their economic value and profitability in areas of varying salinity. These were: i) *Mangifera indica*, ii) *Cocos nucifera*, iii) *Zizyphus mauritiana*, iv) *Borasus flabellifer* v) *Artocarpus heterophyllus*, vi) *Psidium guajava*, vii) *Tamarindus indica*, viii) *Areca catechu*, ix) *Musa sp.*, x) *Citrus sp.* xi) *Sygygium cumini*, xi) *Spondias pinnata*, xiii) *Diospyros phillipensis*, xiv) *Citrus grandis*.

The species with the highest priority were Mango, Coconut, Banana, Betel Nut, Bilati gab, and Hog palm in less saline areas, and Mango, Jujube, Coconut, Palmyra palm, Pummelo, Tamaring, and Banana in moderately to heavily saline areas. The aforementioned fruit species play a significant role as the primary fruit source for households. Previously, it was mentioned that poor and small households cultivated fruit-bearing plants to obtain fruits and cash income. The findings of this study indicate that Mango, Coconut, Palmyra palm, Banana, Tamarind, and Jujube are economically and commercially viable species (Fig. 4). These fruit-bearing species can provide a marginal family with their primary annual income and subsistence. According to reports, the leaves and fruits of some of these species are used for multiple purposes, including molasses, juice, handicrafts, shade, mat, and business. These have provided rural poor with employment opportunities.

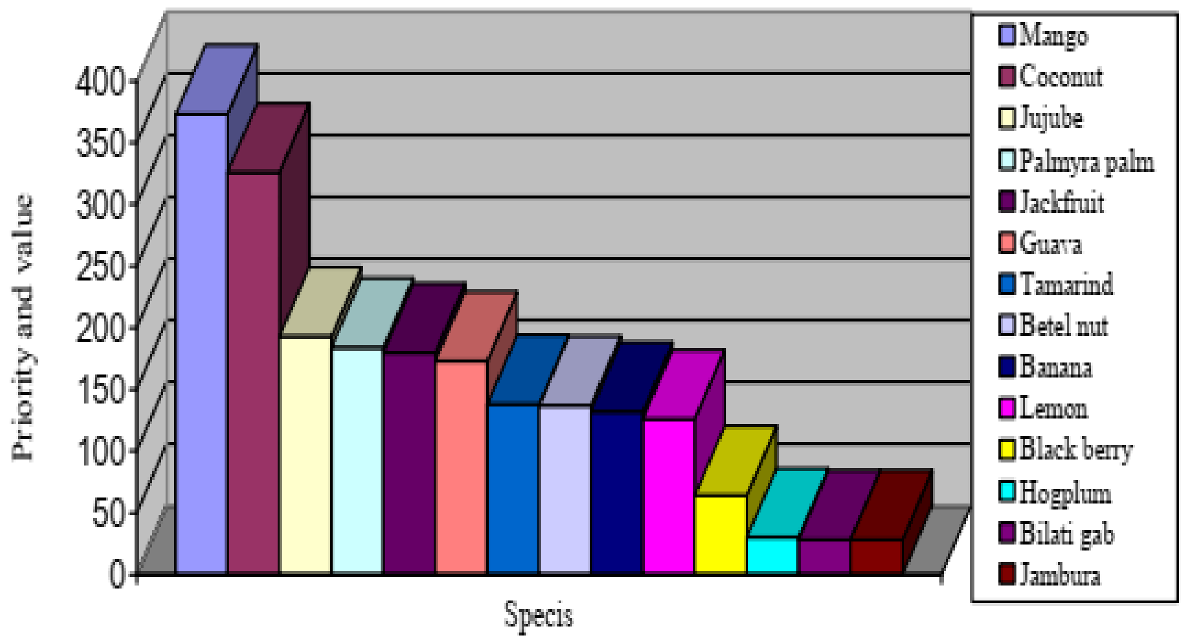

Fig. 4. Economic and profitable fruit species in less saline to strongly saline areas.

In these study areas, endangered and rare species require conservation and immediate action (Table 4). In the southwestern region of Bangladesh, species must be nurtured and the necessary steps taken to restore their former status.

Table 4. Threatened and rare species need to be conserved and immediate action in this region

Local name	**English name**	**Scientific name**
Abeti	Cane	*Calamus rotung*
Atafal	Custard apple	*Annona reticulate*
Bantula	----	*Hibicus moschatus*
Buno Karol	Teasle gourd	*Momordica cochinchinensis*
Cawaphal	Cowa	*Garcinia cowa*
Chatian	Devils tree	*Alstonia scholaris*
Hijal	Indian oak	*barringtonia acutangula*
Kamranga sheem	Winged bean	*Psophocarpus tetragonolobus*
Mewa kathal/Ata	*Annona muricata*	
Mouseem	Sword bean	*Canavalia gladiata*
Nagmani	----	*Wissadula periploci folia*
Pechigab	----	*Diospyros embryopteris*
Royna	Rohina	*Aphamixis polystachya*
Urigab/Bangab	----	*Diospyros Montana*

A total of total of 21 species have been identified as saline tolerant and 33 species as less saline and medium saline tolerant (Table 5).

Table 5. Saline tolerant and less saline tolerant species.

Local name	Scientific name	Local name	Scientific name
Aam[1]	*Mangifera indica*	Kadam[2]	*Anthocephalus cadamba*
Akashmoni[1]	*Acacia auriculiformis*	Kailla lata[1]	*Derris trifoliate*
Amra[2]	*Spondias pinnata*	Kola[2]	*Musa sapientum*
Amrul[2]	*Oxalis corniculata*	Kamranga[1]	*Averrhoa carambola*
Atafal[2]	*Annona reticulate*	Kathal[2]	*Artocarpus heterophyllus*
Babla	*Acacia nilotica*	Kaufal[3]	*Garcinia cowa*
Bahai[1]	*Zizyphus mauritiana*	Kewra[1]	*Sonneratia apetala*
Barai[3]	*Zizyphus mauritiana*	Keya pata[1]	*Pandanus foetidus*
Bash[1]	*Bambusa vulgaris*	Khejur[1]	*Phoenix sylvestris*
Bel[1]	*Aegle marmelos*	Khoia Babala [1]	*Pithecellobium dulce*
Bilati gab[3]	*Diospyros phillipensis*	Lebu[2]	*Artocarpus heterophyllus*
Chaila[1]	*Sonneratia caseoloris*	Lichi[2]	*Litchi chinenss*
Chambol[1]	*Artocarpus chaplasha*	Mahogany[1]	*Swietena mahagoni*
Chatian[2]	*Alstonia scholaris*	Mama kala[1]	
Choto Jam[1]	*Syzygium sp.*	Narikel[1]	*Cocos nucifera*
Dalim[2]	*Punica granatum*	Nim[1]	*Azadirachta indica*
Deshi Nim[1]	*Azadirachta indica*	Nona Jhau[1]	*Tamarix indica*
Golgach[1]	*Nypa fruticum*	Papaya[2]	*Carica papaya*
Harguji[1]	*Acanthus illicifolius*	Pechi gab[1]	*Diospyros embrayopteris*
Jambura[2]	*Citrulus grandis*	Peyara[2]	*Psidium guajava*
Safeda[2]	*Manilkara sapota*	Rain tree [1]	*Samanea saman*
Sundri[1]	*Heritiera foemes*	Sarbat lemon[2]	*Citrus limettoides*
Supari[2]	*Areca catechu*	Sarifa[2]	*Annona squamosa*
Tal[1]	*Borasus flabellifer*	Sisoo[1]	*Dalbergia sissoo*
Tetul	*Tamarindus indica*		

[1] saline tolerant, [2] saline non-tolerant and [3] medium tolerant.

4. Mangrove Trial Plantations

The sustainability of the established *S. apetala* plantations in the coastal belt is threatened by rapid sedimentation at plantation sites, species succession, and insect infestation under the traditional management practices (Siddiqi et al., 1992). Thus, the sites become unsuitable for the optimal development of *S. apetala* and *A. officinalis*. In coastal regions, the mortality rate of these species' seedlings is high. Consequently, gaps are created within plantations. In addition, there was no regeneration under these plantations because the forest floor was rising, the soil was compact, and there was no seed source for other mangrove species. After the harvest of mature *S. apetala* trees, there will be no second rotation crops in this forest to ensure its sustainability. In order to maintain a continuous forest cover in the coastal belt and increase the production of coastal forest, the Bangladesh Forest Research Institute has been under planting with other valuable mangrove species in the coastal belt since 1990. Eleven commercially significant mangrove species were experimentally planted. Multiple trial plots were established on Rangabali island in the Patuakhali district and Char Kukri-Mukri island in the Bhola district. All mangrove species (Table 6) were grown in polybags with the exception of *N. frutican*s, which was sown in muddy soil. The trial plots were grown beneath 9–12-year-old *S. apetala* plantations with a 1.5 m x 1.5 m spacing. In the selected sites, ten-month-old seedlings were planted, with the exception of *N. fruiticans* seedlings, which were planted when they were three months old.

Table 6: Growth performance of mangrove species from 16-21 years old experimental stands at Rangabali and Char Kukri-Mukri islands of Bangladesh

Common name	**Scientific name**	**Rangabali Island**			**Char Kukri-Mukri Island**		
		Mean Survival (%)	**Mean Height (m)**	**Mean DBH (cm)**	**Mean Survival (%)**	**Mean Height (m)**	**Mean DBH (cm)**
Sundri	*Heritiera fomes*	51.34	6.19	5.87	39.21	5.65	5.34
Gewa	*Excoecaria agallocha*	61.76	9.31	9.83	58.64	9.29	9.49
Passur	*Xylocarpus mekongensis*	47.87	6.84	7.97	26.18	6.84	7.34
Dhundul	*Xylocarpus granatum*	30.32	4.70	5.24	-	-	-
Kankra	*Bruguiera sexanula*	13.90	5.04	5.46	-	-	-
Khalshi	*Aegiceras corniculatum*	62.84	5.90	6.13	46.02	6.61	7.96
Shingra	*Cynometra ramiflora*	35.85	6.54	5.24	18.38	4.96	4.27
Goran	*Ceriops decandra*	23.38	4.98	5.04	-	-	-
Kirpa	*Lumnitzera racemosa*	43.95	5.24	6.31	11.66	5.30	7.51
Golpata	*Nypa fruticans*	40.06	4.59	-	56.00	3.43	-

Source: Islam et al., 2013

On both Rangabali and Char Kukri-Mukri, the growth performance of particular mangrove species was encouraging. *H. fomes, E. agallocha, X. mekongensis, A. corniculatum, Cynometra ramiflora* (shingra), *Phoenix paludosa* (hantal), and *N. fruticans* were deemed promising at 16-21 years of age in the western coastal belt based on their survival, height, and diameter growth (Table 6). Therefore, these promising mangrove species are suitable for the cultivation of second rotation crops within *S. apetala* plantations for the management of coastal forests in a sustainable manner. A successful under planting will also produce mixed and multi-story forests.

5. Non-mangrove Trial Plantations

As a result of the coastal environment's high degree of dynamism, sedimentation is quite high in certain areas of the coastline. As the forest floor gradually rises, the land becomes unsuitable for *S. apetala* and *A. officinalis*. Other mangrove species cannot thrive in this environment. Consequently, 13 important mainland species were used to examine the viability of non-mangrove species on the raised but empty land (Table 7). The trial plots were established on the islands of Rangabali and Char Kukri-Mukri. All species of seedlings were maintained in polybags for five to six months. The test plots were grown on 60 cm x 60 cm x 40 cm heaps with a 2.0 m x 2.0 m spacing. Six-and-a-half-month-old seedlings were planted in the designated areas.

Table 7. Growth performance of mainland tree species at the age of 17 years planted at Rangabali island

Common name	Scientific name	Survival (%)	Mean height (m)	Mean DBH (cm)
Payra	*Pithecellobium dulce*	81	10.49 ± 0.24	12.94 ± 0.29
Rain tree	*Samanea saman*	80	13.21 ± 0.30	24.34 ± 1.25
Jhao	*Casuarina equisetifolia*	69	15.26 ± 0.38	19.45 ± 0.33
Babla	*Acacia nilotica*	32	11.69 ± 0.19	11.66 ± 0.18
Kala koroi	*Albizia lebbeck*	73	9.90 ± 0.22	13.97 ± 0.46
Sada koroi	*Albizia procera*	59	11.28 ± 0.44	16.52 ± 0.68
Sonboloi	*Thespesia populnea*	52	7.19 ± 0.29	13.77 ± 0.35

Source: Islam *et al*., 2014

Six non-mangrove species, including *S. saman, C. equesetifolia, P. dulce, A. nilotica, Albizia lebbeck* (kalo koroi), and *A. procera*, were deemed suitable for planting on elevated coastal lands based on their survival, height, and diameter growth (Table 7 and 8). Other palm species, such as *Cocos nucifera* (coconut), *Phoenix sylvestris* (date palm), and *Borassus flabellifer* (palmyra palm), were discovered to be suitable in the foreshore coastal regions of Bangladesh (Islam et al., 2014).

Table 8. Growth performance of mainland tree species at the age of 17 years planted at Char Kukri-Mukri Island

Common name	Scientific name	Survival (%)	Mean height (m)	Mean DBH (cm)
Babla	*Acacia nilotica*	66	7.87 ± 0.18	14.02 ± 0.26
Jhao	*Casuarina equisetifolia*	25	11.64 ± 0.61	15.23 ± 0.80
Kala koroi	*Albizia lebbeck*	14	8.48 ± 0.59	14.75 ± 0.98
Payra	*Pithecellobium dulce*	63	9.99 ± 0.26	17.24 ± 0.73
Rain tree	*Samanea saman*	32	11.11 ± 0.40	19.74 ± 0.98
Sada koroi	*Albizia procera*	14	11.27 ± 0.80	14.13 ± 1.54

Source: Islam *et al*., 2014

6. Coastal Embankment Plantations

Under the Green Belt Project in 1995 and the Coastal Embankment Rehabilitation Project in 1997, non-mangrove species were planted on the embankment slopes and roadside as part of the coastal afforestation. On the inner and outer slope of the embankment, 37 species other than mangroves were planted. Species of timber, fuel wood, and fruit trees were included in this program. Nandy et al. (2002) conducted a survey to evaluate the growth performance and adaptability of the planted species on the coastal embankment.

In the eastern portion of the coastal belt, *Leucaena leucocephala* (ipil ipil), *Acacia auriculiformis* (akashmoni), *C. equisetifolia, S. saman,* and *Cocos nucifera* stood out among the 14 species planted. In the central coastal belt, twenty different species were planted. Good performance was demonstrated by *A. auriculiformis*, *Acacia mangium* (mangium), *Embelica officinalis* (amloki), *C. equsetifolia*, *P. sylvestris,* and *C. nucifera*. The western coastal belt was planted with 31 species. The most successful were *C. equsetifolia, A. auriculiformis, Terminalia arjuna* (arjun), *A. nilotica, S. saman, P. dulce,* and *C. nucifera*. Significant portions of the desolate coastal belt are being greened by the plantations on embankments.

7. Performance of Coastal and Village Plantations in Comparison to Other Tree Species of Different Forest Sites

According to BFI, coastal regions have the second-highest tree stem density after Sundarbans. Despite having the lowest stem density per hectare, the village has the greatest total basal area per million square meters (Table 9 and 10).

Table 9. Number of tree species, tree and sapling stem densities and tree and sapling basal area by zone.

Zone	Number of species[1]	Tree stem density (stem/ha)	Total number of stem (stem/ha)	Basal area (m^2/ha)	Total basal area (million m^2)
Coastal	103	229	969	8.82	4.50
Hill	284	146	630	6.23	10.34
Sal	113	169	268	5.89	3.08
Sundarbans	28	661	6,861	22.29	8.99
Village	232	98	184	3.28	33.93
National	392	129	472	4.52	60.84

[1]Excludes unknown tree species

Table 10. Gross tree volume by zone

Zone	Volume (m^3/ha)	Total volume (million m^3)	Sampling error (±%)
Coastal	50.08	25.55	22.80
Hill	47.69	79.12	18.75
Sal	34.17	17.84	17.03
Sundarbans	97.75	39.44	12.36
Village	21.44	221.98	10.85
National	28.54	383.92	7.67

Moreover, the gross volume in coastal zone is also found to be the 2nd top ranked position keeping the village zone at least point.

The variation in diameters and heights between zones is indicative of the dominant tree growth forms in each zone. The average DBH (cm) is greater in the village zone, whereas the average height is greater in the coastal zone. The stem density is greater in the lower height and DBH classes than in the larger size classes (Fig. 5). Specifically, height classes greater than 20 m in all zones have the lowest density (1 stem/ha), indicating fewer trees in the larger size classes.

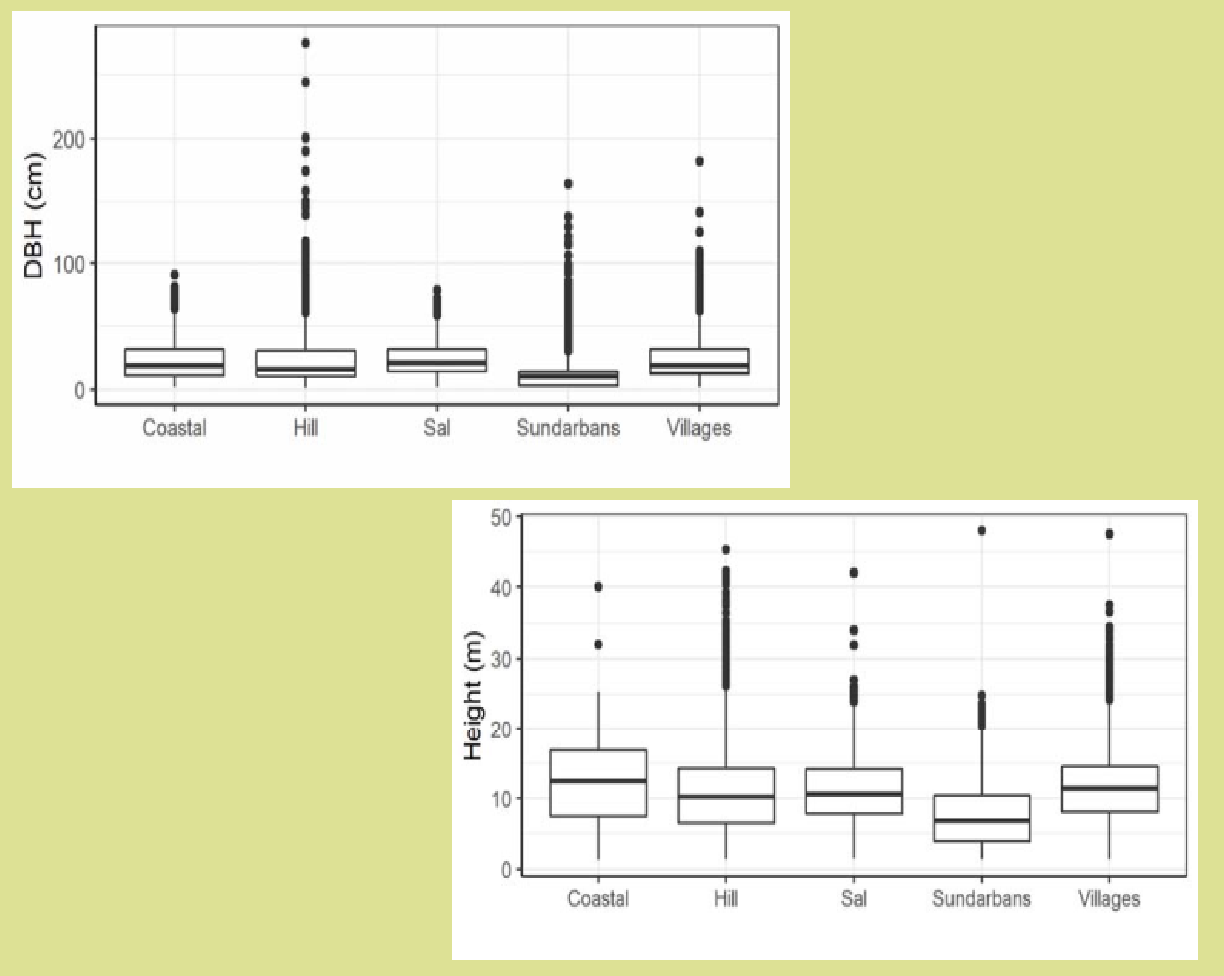

Fig. 5. Ranges and medians of diameters (top) and heights (bottom) for all tree individuals by zone (Source: BFI Report).

The coastal zone has the second-highest stem density per hectare based on diameter at breast height (cm) and height (m) (Fig. 6 and 7), while the village zone has the lowest stem density, which is comparable when the growing stock is considered (Fig. 8).

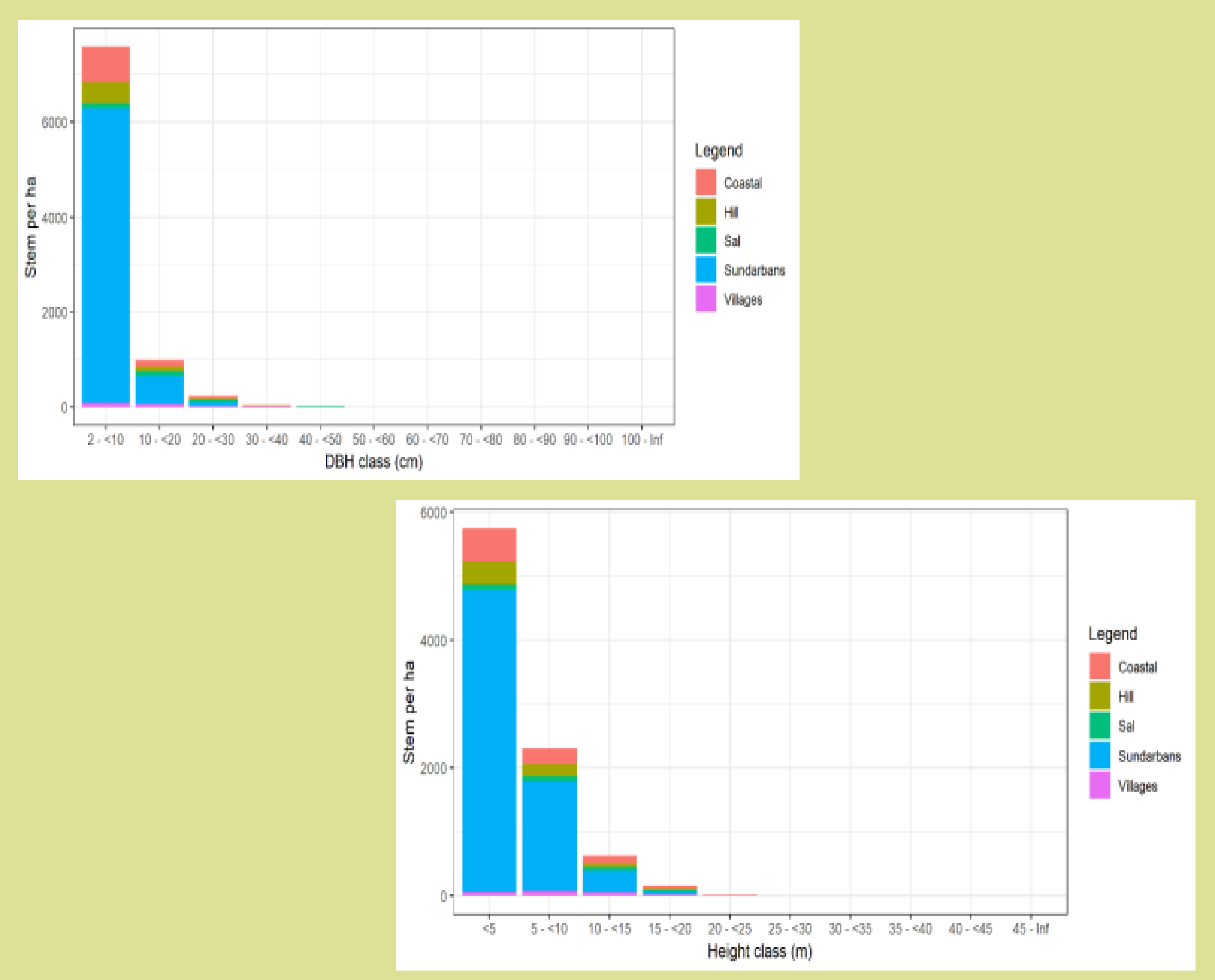

Fig. 6. The distribution of stem density for each diameter class (top) and height class (bottom) by zone.

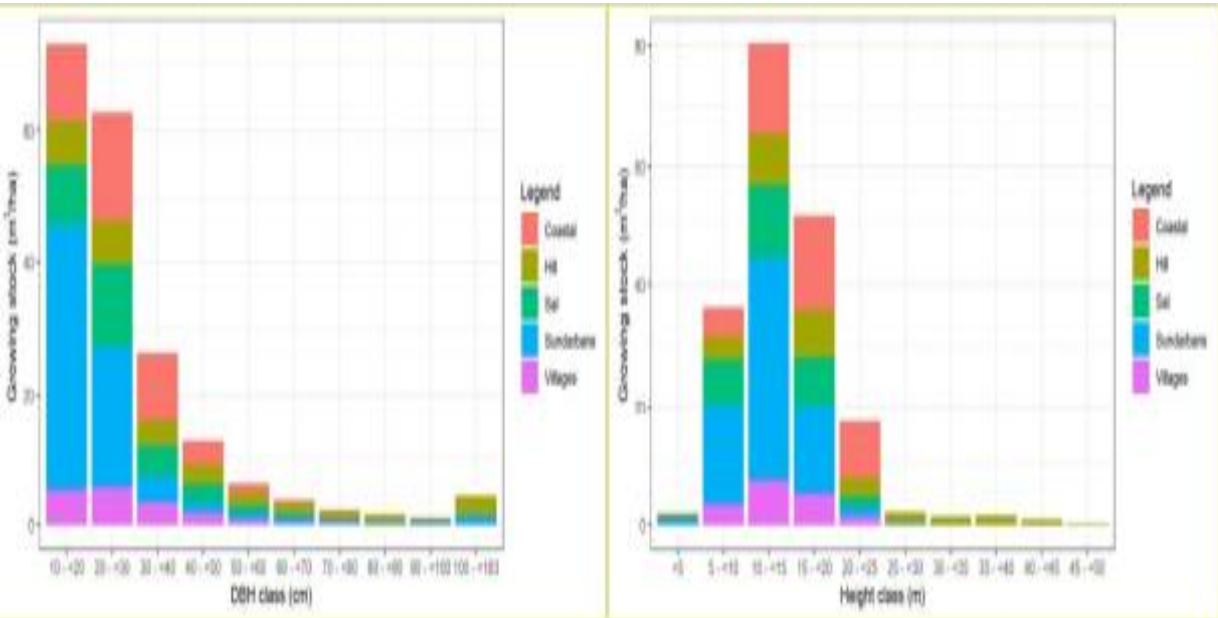

Fig. 7. The distribution of growing stock for each diameter class (top) and height class (bottom) by zone.

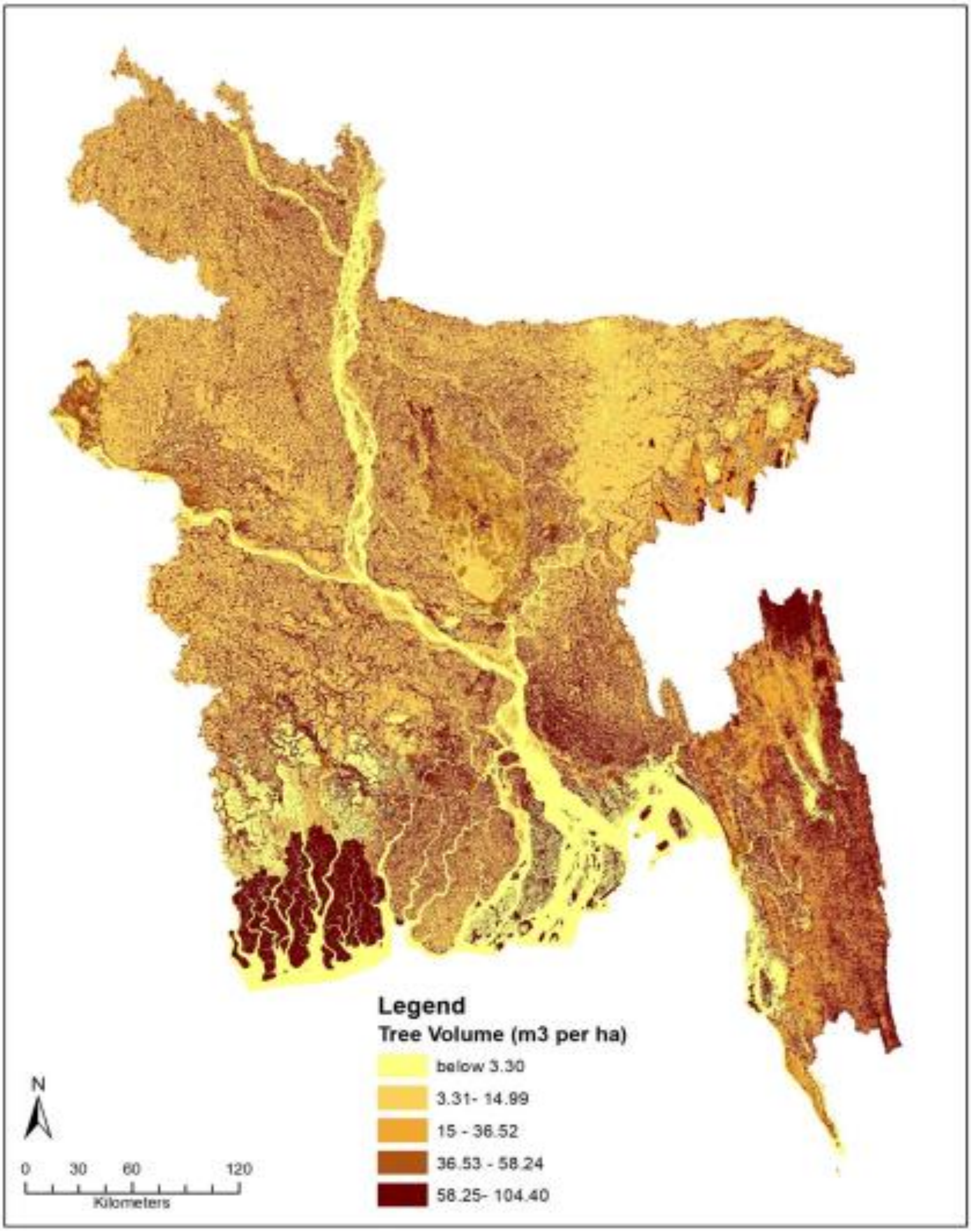

Fig. 8. Spatial distribution of gross growing stock volume

In addition, astonishingly coastal areas have a smaller number of introduced tree species and thereby playing a vital role in conserving our natural flora and fauna (Fig. 9).

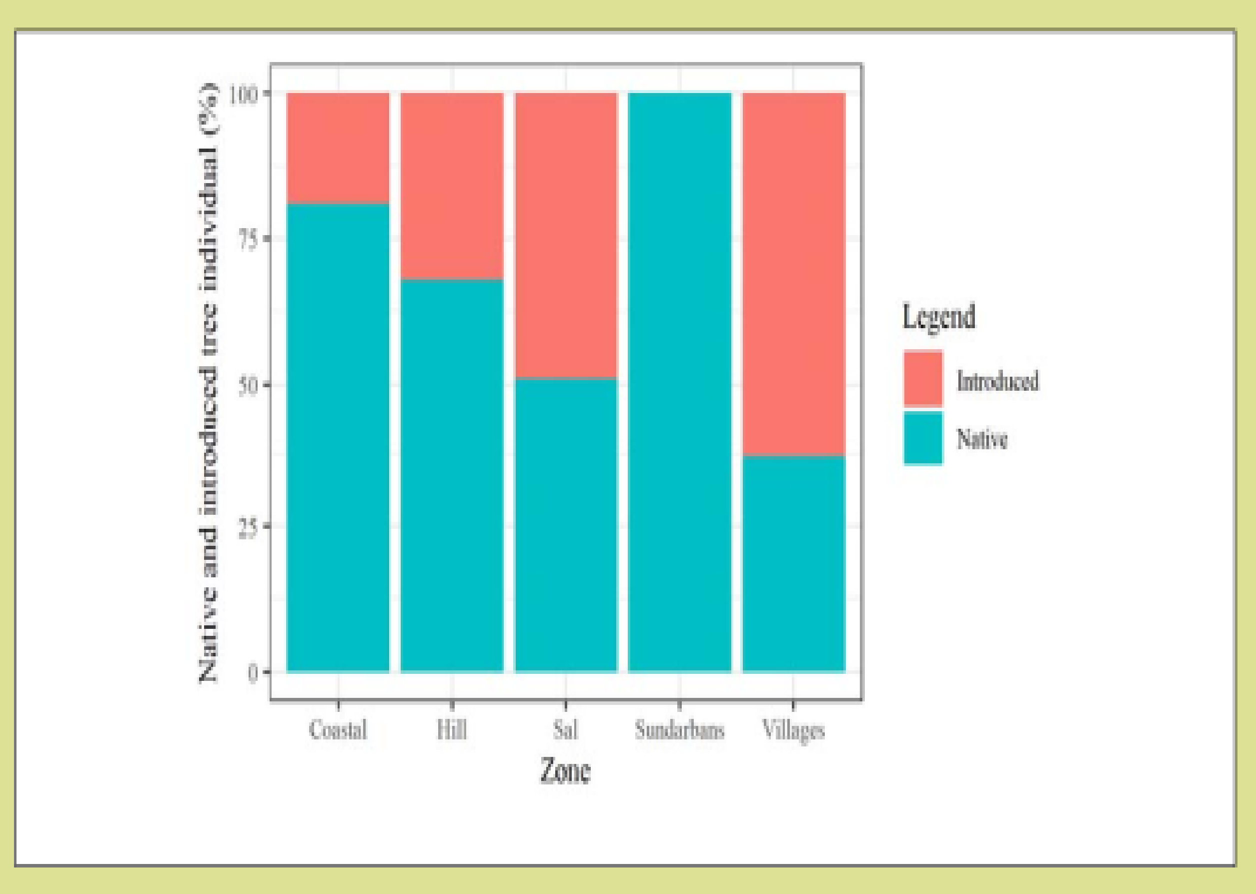

Fig. 9. Percentage of native and exotic tree individuals in different zones

C. decandra, *E. agallocha*, and *H. fomes* are the three species with the highest stem density in the country, although they are found almost exclusively in the Sundarbans zone. *T. grandis* predominated in the Hill zone, whereas *E. agallocha* predominated in the Coastal zone (Table 11 and 12). The Village zone has the highest concentration of *S. mahagoni*.

Table 11. Stem densities, Diameter at Breast Height (DBH), and height statistics of the most dominant tree species of coastal and village zone of Bangladesh including its contribution to national level.

Tree Scientific Name	**Local Name**	**Tree stem density (stem/ha)**	**Tree and sapling stem density (stem/ha)**	**DBH (cm)**			**Height (m)**		
				Mean	Max	Min	Mean	Max	Min
Coastal Zone									
Excoecaria agallocha	Gewa	10	523	2	9.6	46.7	1.5	7.0	22.4
Sonneratia apetala	Keora	86	104	2	78.7	130	1.8	16.8	24.8
Areca catechu	Supari	59	100	3	11.8	69.6	1.7	11.3	22.1
Memecylon edule	Anjan	35	2	3.5	7.8	2.1	3.7	7.21	
Samanea saman	Siris	14	24	2	35.7	110.8	1.7	14.8	37.5
Village Zone									
Swietenia mahagoni	Mehogoni	13	31	2	18.9	86.1	1.4	11.4	32
Areca catechu	Supari	23	30	3	11.8	69.6	1.7	11.3	22.1
Mangifera indica	Aam	10	18	2	27.8	125.7	1.5	10.0	36.5
Eucalyptus camaldulensis	Eucalyptus	5	11	2	18.0	55.5	1.5	14.2	34.5
Acacia auriculiformis	Akashmoni	3	10	2	15.2	61.4	1.6	11.6	32.5
National level									
Excoecaria agallocha	Gewa	9	83	2	9.6	46.7	1.5	7.0	22.4
Ceriops decandra	Goran	76	2	2.8	9.8	1.4	3.1	11.2	
Heritiera fomes	Sundri	10	53	2	13.0	117	1.4	9.5	24.8
Areca catechu	Supari	20	27	3	11.8	69.6	1.7	11.3	22.1
Swietenia mahagoni	Mehogoni	11	26	2	18.9	86.1	1.4	11.4	32

Table 12. Top five species by zone and ranked by growing stock

Scientific name	Local name	Growing stock (m3/ha)	Origin
Coastal Zone			
Sonneratia apetala	Keora	25.60	Native
Areca catechu	Supari	5.14	Introduced
Samanea saman	Siris	4.90	Introduced
Cocos nucifera	Narikel	3.33	Introduced
Sonneratia caseolaris	Ora	1.61	Native
Village Zone			
Swietenia mahagoni	Mehogoni	3.13	Introduced
Cocos nucifera	Narikel	2.19	Introduced
Areca catechu	Supari	2.11	Introduced
Mangifera indica	Aam	2.04	Native
Samanea saman	Siris	1.27	Introduced

8. Conclusions and Suggestions

Bangladesh is highly susceptible to climate change due to its geographical location, population density, and socioeconomic status. Coastal afforestation is one of the coping strategies that can be utilized to mitigate the negative effects of climate change. Along the coastal belt, the Bangladesh Forest Department has already established extensive plantations of *S. apetala*, creating a healthy environment. Historically, these established plantations protected the lives and property of coastal residents from natural disasters such as cyclones and tidal surges.

Mangrove plantations have accelerated the sedimentation process, and a significant amount of landmass has been created on various chars lands and offshore islands. In contrast, mangrove trial plantations serve as seed sources in coastal regions. Large seedlings, primarily of *E. agallocha* and *H. fomes*, have been regenerated within the *S. apetala* forest in the western coastal belt, thereby creating dense, sustainable mangrove forests of the second generation in certain regions.

Due to high mortality, monospecific plantations of *S. apetala* are confronted with a serious problem that has produced enormous voids within the forests. There is an immediate need to restore these gaps through reforestation, establishing a second rotation mangrove plantation by introducing recommended mangrove species with adaptive capabilities for a long-term, sustainable coastal shelterbelt. Over the past two decades, the Bangladesh Forest Research

Institute has selected suitable mangrove species for coastal areas in order to address the stated issues. BFRI, on the other hand, has chosen non-mangrove species suitable for planting on coastal raised lands and embankments. Therefore, urgent large-scale plantations can be initiated with promising mangrove species using the acquired knowledge, experience, technology, and expertise to develop a second generation forest in the voids left by *S. apetala* plantations. On the raised coastal lands, foreshore lands, and coastal embankment, a plantation program with other site-appropriate non-mangrove and palm species can be initiated to enhance the coastal ecosystem.

- At the age of 16-21 years, *H. fomes, E. agallocha, X. mekongensis, A. corniculatum, Cynometra ramiflora* (shingra), *Phoenix paludosa* (hantal), and *N. fruticans* were found to be promising for coastal zone plantation and the monoculture should be reduced by introducing some of these at the later phase and thereby increase diversity.
- On the elevated coastal lands, the plant species *S. saman, C. equesetifolia, P. dulce, A. nilotica, Albizia lebbeck*, and *A. procera* were discovered to be suitable for planting.
- Palm plantations can provide a strong shelterbelt; only the palmyra palm can withstand winds of up to 300 miles per hour and is the best windbreak against cyclonic storms (Islam et al. 2014). Therefore, palm species, such as *Cocos nucifera* (coconut), *Phoenix sylvestris* (date palm), and *Borassus flabellifer* (palmyra palm), can be planted to suitable foreshore coastal regions of Bangladesh (Islam et al. 2014).
- Non-mangrove species that can withstand flooding like *A. mangium, A. auriculiformis, S. saman, Mangifera indica* (mango), *T. arjuna, Lagerstroemia speciosa* (jarul) can be planted into salinity threatened home gardens to increase household income and ensure food security at least during crisis time. Other tree species that can grow well and tolerate moderate to strong saline conditions can be planted to increase indigenous species diversity include *P. dulce, C. equisetifolia, A. nilotica, A. procera, C. nucifera, P. sylvestris, B. flabellifer,* and *Areca catechu* (betel nut) (Islam et al. 2014).

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