HUMAN-INDUCED SUCCESSION OF VEGETATION ON NEW ACCRETIONS IN THE COASTAL AREAS OF BANGLADESH

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SIDDIQI, N. A. & KHAN, M. A. S. 2004. Human-induced succession of vegetation on new accretions in the coastal areas of Bangladesh. Coastal afforestation in Bangladesh was initiated in 1996 with pioneer species *Sonneratia apetala* and *Avicennia officinalis.* Tree species, *Excoecaria agallocha, Heritiera fomes* and *Xylocarpus mekongensis*; shrub species, *Cynometra ramiflora* and *Lumnitzera racemosa*; and palm species, *Phoenix paludosa* and *Nypa fruticans* were suitable for second rotation crops. A survival of 90.3% for *E. agallocha,* 84.7% for *H. fomes* and 58.3% for *X. mekongensis* was recorded. Mean annual height increments of these species were 1.03, 0.59 and 0.14 m and diameter increments 0.92, 0.39 and 0.15 cm respectively. Survivals for *C. ramiflora, L. racemosa, P. paludosa* and *N. fruticans* were 59.0, 51.3, 84.7 and 97.3% respectively. On relatively raised lands, non-mangrove species, namely *Acacia nilotica, Casuarina equisetifolia, Pithecellobium dulce, Samanea saman, Albizia lebbeck* and *A. procera* were promising. After eight years, these species had a survival of 69, 65, 85, 61, 60 and 19% respectively with good height and diameter increments. Thus, a sustainable forest cover in the coastal areas of Bangladesh can be ensured.

Key words: Coastline – mangrove planting – non-mangrove species – forest creation

SIDDIQI, N. A. & KHAN, M. A. S. 2004. Sesaran tumbuhan di tokokan baharu di kawasan berpantai Bangladesh akibat campurtangan manusia. Perhutanan pantai di Bangladesh dimulakan pada tahun 1996 menggunakan spesies primer *Sonneratia apetala* dan *Avicennia officinalis.* Spesies pokok iaitu *Excoecaria agallocha, Heritiera fomes* dan *Xylocarpus mekongensis;* spesies pokok renek iaitu *Cynometra ramiflora* dan *Lumnitzera racemosa* serta species palma iaitu *Phoenix paludosa* dan *Nypa fruticans* sesuai sebagai tanaman giliran kedua. *Excoecaria agallocha, H. fomes* dan *X. mekongensis* masing-masing merekodkan kemandirian 90.3%, 84.7% dan 58.3%. Purata pertambahan tinggi tahunan untuk ketiga-tiga spesies tersebut masing-masing 1.03 m, 0.59 m dan 0.14 m manakala pertambahan diameter masing-masing 0.92 cm, 0.39 cm dan 0.15 cm. Kemandirian untuk *C. ramiflora, L. racemosa, P. paludosa* dan *N. fruticans* masing-masing 59.0%, 51.3%, 84.7% dan 97.3%. Penanaman spesies bukan bakau seperti *Acacia nilotica, Casuarina equisetifolia, Pithecellobium dulce, Samanea saman, Albizia lebbeck* dan *A. procera* di tanah yang lebih tinggi adalah menggalakkan. Selepas lapan tahun, spesies tersebut masing-masing merekodkan kemandirian 69%, 65%, 85%, 61%, 60% dan 19% serta mempunyai pertambahan ketinggian dan pertambahan diameter yang baik. Justeru, litupan hutan yang mapan di kawasan pantai Bangladesh boleh dijamin.

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Introduction

The coastline of Bangladesh extends over 710 km on the Bay of Bengal. Of this, natural mangrove forest covers about 100 km. The Sundarbans in the western part and the Chokoria Sundarbans in the east are natural mangrove forests. The greater part of the coastline was without tree vegetation until the initiation of mangrove afforestation programmes in the late 1960s. Until 1999, approximately 170 000 ha of land have been planted (Figure 1). However, plantation failures occur over considerable areas due to rapid geomorphic changes and biotic stresses.

Natural succession occurs in various ways in different mangrove forests of the world. Usually, members of the family Rhizophoraceae are the climax species. However, in the Sundarbans, the climax species are *Heritiera fomes* (Sterculiaceae) in low saline areas, *Excoecaria agallocha* (Euphorbiaceae) in moderately saline areas and *Ceriops decandra* (Rhizophoraceae) in high saline areas (Das & Siddiqi 1985, Karim 1994). The Chokoria Sundarbans has been under tremendous human stress and biotic interference and the natural process of succession was interrupted which resulted in non-existence of a clear successional pathway. However, the forest consisted mainly of an association of *C. decandra* and *Avicennia officinalis*. It had moderately dense forest cover with many mangrove species only a few decades ago (Siddiqi *et al.* 1994).

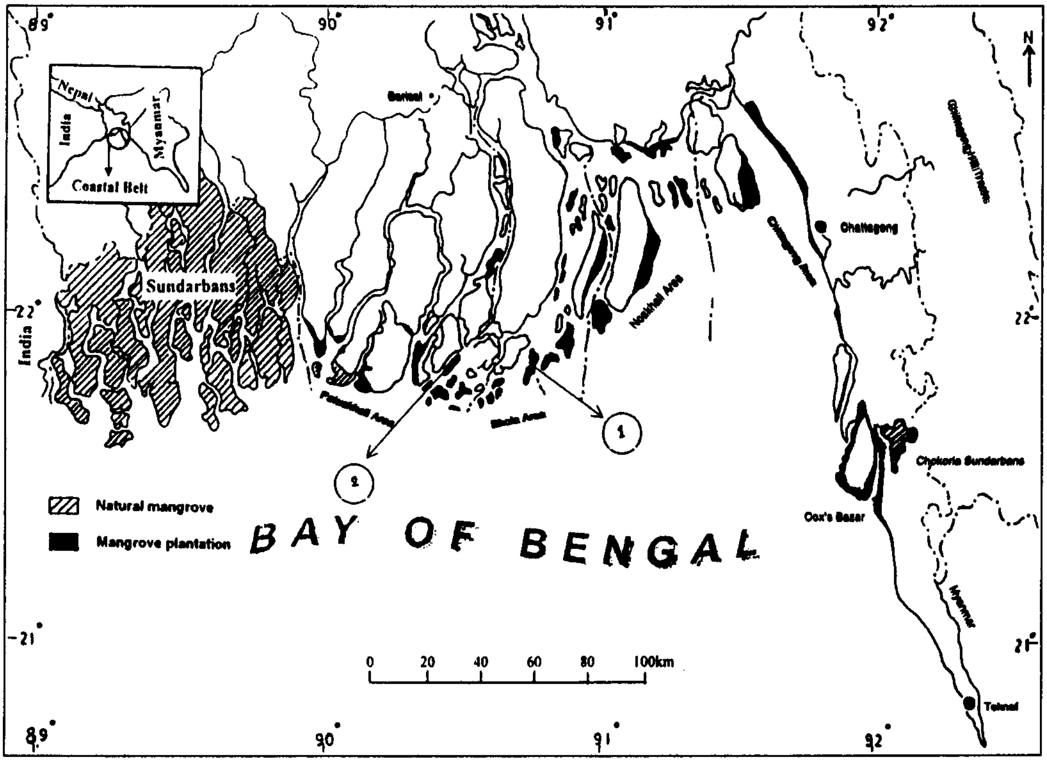

Figure 1 Coastline of Bangladesh showing the locations of natural and planted mangroves, and study areas

There could be several reasons for the absence of natural mangrove vegetation along the shoreline. These include the non-availability of propagules, tidal current behaviour, frequent tidal surges and a dynamic coastal geomorphology. However, most factors responsible for mangrove development were favourable. Repeated devastating cyclones and tidal surges led foresters to initiate in 1966 the raising of mangrove trees on barren coastal areas with the primary objective of minimising the loss of human life and property (Saenger & Siddiqi 1993). *Sonneratia apetala* and *A. officinalis*, being the pioneer tree species in the ecological succession, were highly successful and most of the mangrove plantations consisted of these two species. However, geomorphology change (i.e. heavy sedimentation) in the coastal region is very rapid and therefore replacement of these species by other later successional species is necessary in order to maintain continuous forest cover. Moreover, raised lands, above the reach of normal tides as a result of further deposition of silts, are available in coastal areas. These lands are no longer suitable for mangrove species and need to be brought under vegetation cover with mesophytes. The Bangladesh Forest Research Institute (BFRI) undertook studies in the coastal areas to select species and develop methods of raising plantations in a highly dynamic and constantly changing environment. This paper is aimed at showing how humans can induce ecological succession for sustainable management of coastal plantations.

Materials and methods

The coastal areas of Bangladesh lie between latitude 21°–23° N and longitude 89°–93° E. The climate is humid. Temperatures range between 18 and 32 °C. The amount of rainfall varies from about 3000 mm in the west to 2000 mm in the centre, and as high as 4000 mm in the east. Tides are semi-diurnal and depending on location, mean tidal range varies from 2.2 to 4.0 m (Anonymous 1994). Erosion and sedimentation are greatly influenced by tides. The water salinity also varies in different locations and seasons and is generally lower in the east than in the west. In monsoon, water salinity ranges from 3 to 27 ppt while in the dry season from 10 to 33 ppt (Siddiqi & Khan 1990).

Soil texture is silt clay loam. Silt is the dominant fraction followed by clay and sand. Soils are, however, coarser towards the southeast. Soil pH is slightly or moderately alkaline with a mean of 7.9. Mean organic carbon in the soil is 1.4% and mean nitrogen content 0.09%. Soil salinity ranges from 0.3 to 4.2 dSm^{-1} in the month of December (Khan *et al.* 1998), two months after the monsoon. Soil salinity reaches its peak from April till May when average salinity as high as 9 dSm^{-1} was recorded (Hassan 1987). Daily tidal inundation during the monsoon, moderate salinity and poor drainage are characteristic features of coastal soils. Erosion and accretion are common phenomena in the coastal areas. The accretion rate is higher, being 13.5 km^2 per year (BUET/BIDS 1993). Total volume of sediments carried by the Ganges, the Brahmaputra and other rivers is about 2.5 billion tons per year, although there are differences in estimates with regard to the quantity of sediment load. A small portion is deposited inland or along the immediate coast and most of the sediment drift off the continental shelf and is transported into the deep sea (Nishat & Haque 1984).

In all, 28 experimental plots of mangrove and non-mangrove species were established since 1990 on different places along the coastline by the BFRI. This paper is, however, mainly based on the analysis of data collected from the research plots established at Char Kukri Island. Char Kukri is located at latitude 21° 55' N and longitude 90° 40' E (Figure 1) and covers an area of 2500 ha. The elevation of the island is 1 m above mean sea level. Mean maximum and minimum temperatures are 32 and 19 °C. Annual rainfall is about 2800 mm.

The experiments for an under-planting trial with mangrove species were laid out in complete randomised design (CRD) with three replications. A total of 11 species, namely *H. fomes, E. agallocha, Xylocarpus mekongensis, X. granatum, Aegiceras corniculatum, Cynometra ramiflora, C. decandra, Lumnitzera racemosa, Bruguiera sexangula, Phoenix paludosa* and *Nypa fruticans*, were studied. Thus, the total number of plots was 33 (3 × 11) for mangrove species trial. These plots were fenced to prevent biotic interference, particularly grazing animals. Ten-month-old seedlings, raised in pots, were planted, except for *N. fruticans* seedlings, which were planted when three months old. In each plot, 100 mangrove seedlings were planted at a spacing of 1.5 × 1.5 m after mechanical thinning of a nine-year-old established *S. apetala* plantation. The size of each plot was about 0.35 ha. Only *N. fruticans* was planted on gentle slope along the canal bank at a spacing of 1 × 1 m. The size of each plot was 0.01 ha covering an area of 0.03 (0.01 × 3) ha. The data in relation to seedling survival and growth over time were collected from the plots. The performance of the tree species was assessed by analysis of variance (ANOVA) and LSD test. Shrubs and palms were not included in the statistical analyses.

Trials with non-mangrove (mesophyte) species were also conducted in CRD with three replications. Nine species, namely *Albizia lebbeck, A. procera, A. chinensis, Samanea saman, Acacia nilotica, Thespesia populnea, Dalbergia sissoo, Calophyllum inophyllum* and *Diospyros peregrina*, were planted in flat land following weeding of grasses and climbers. These species were planted at 2 × 2 m spacing on relatively raised areas that are only inundated in the monsoon during spring tides. The number of plots was 27 (3 × 9) covering an area of 0.48 ha. Each plot was planted with 49 seedlings, 10–12 months old and raised in pots. However, seedling performance on flat land was unsatisfactory as the seedlings were susceptible to even short-term inundation. Subsequently after clearing the sites, 13 species were planted on earth-made heaps (each 0.6 × 0.6 m wide and 0.4 m high) to reduce the influence of inundation. These species included *A. lebbeck, A. procera, S. saman, A. nilotica, T. populnea, Swietenia macrophylla, Leucaena leucocephala, Melia azederach, Pithecellobium dulce, Syzygium cumini, Casuarina equisetifolia, D. sissoo* and *Lagerstroemia speciosa*. Each plot was planted with 81 polybags of 10- to 12-month-old raised seedlings at a spacing of 2 × 2 m. The number of plots was 39 (3 × 13) covering an area of 1.1 ha.

With regard to species composition of natural vegetation on the barren shoreline, information was not available due to lack of studies in the past. Appearance and occurrence of plants on newly-formed lands were noted through continuous observation from 1988 to 1998. A variation in occurrence of natural vegetation was noticed between the western and eastern parts along the shoreline.

Accordingly, the natural vegetation has been discussed separately for the western shoreline and eastern shoreline.

Results and discussion

Natural occurrence of vegetation

Western shoreline

Geomorphic change in coastal Bangladesh is highly dynamic. There is heavy sedimentation in different areas. Sedimentation up to 1 m deep was recorded in a few years (McConchie 1990a). In general, a grass (*Myriostachya wightiana*) colonises the land within two years following exposure to water. Germinated seeds of this species are commonly found floating in the water during the rainy season and colonisation occurs. It first appears where salinity is low. A daily five to seven hours exposure of newly accreted land above water in the monsoon is ideal for colonisation. Within a year after anchorage of these seeds the ground becomes covered with a dense mat of *M. wightiana*. In two years, the species grows to a height of 1–1.5 m.

In areas with heavy silt deposition, ranging from 0.25 to 0.5 m per year, *Imperata cylindrica* is found. This species grows vigorously and establishes itself by complete removal of *M. wightiana* cover when the level of tidal inundation is low. On very fine soils with regular inundation or waterlogged conditions, species diversity is higher. In these situations, *Typha elephantina, Phragmites karka* and *Cyperus javanicus* colonise by replacing *M. wightiana*. With the maturity of lands, *Acanthus ilicifolius*, a mangrove thorny herb growing to a height of 1.5 m, is seen occupying huge basin type areas in addition to the existing species. With time, *Derris trifoliata*, a climber appears scattered. *Pandanus foetidus*, a prickly succulent herb, is observed by the sides of creeks. At this stage, tree species struggle to establish themselves. Seedlings in small number such as *Sonneratia caseolaris* and *S. apetala* are noticed. On suitable sites along the sides of canal or river, *S. caseolaris* establishes. However, the seedlings of *S. apetala* hardly reach the sapling stage. Grazing by cattle is one of the causes for the disappearance of *S. apetala*. A few seedlings of *E. agallocha* are noticed to establish in the coastal areas of Noakhali. With further maturation of soils and rising of sites, *Hibiscus tiliaceous*, a mangrove associated shrub and the mesophyte, *Tamarix indica*, establish sporadically together with *Cynodon dactylon, Calotropis procera, Ipomoea pes-caprae, Dalbergia spinosa* and *Finlaysonia maritima.*

Eastern shoreline

On the eastern part (Chittagong and part of Noakhali coastline), salinity is higher and *Porteresia coarctata* represents the only pioneer grass community on new accretions. *Cyperus javanicus, T. elephantina* and *P. karka* never appeared. *Acanthus ilicifolius* occurs like the western part. *Aegialitis rotundifolia* is commonly noticed in the form of shrub in association with *A. ilicifolius. Derris trifoliata* is seldom observed. Subsequently, *T. indica* appears. Sometimes, the species attains a height of up to 5 m with a diameter of 20 cm. At this time, *Mallotus repandus, D. trifoliata* and *C. procera* are also found scattered. *Hibiscus tiliaceous* is not seen. Seedlings and saplings of *Avicennia* sp. and *E. agallocha* are occasionally noticed. On many places, there is sand dune movement where pioneer species is *I. pes-caprae,* a prostrate herb. Other species found in the western part do not appear here.

Raising mangrove plantations

The shrub and tree vegetation was scanty and scattered along the coastline. Even naturally occurring lightly dense vegetation did not exist in any part of the coastal belt except for areas with the natural mangrove forests. The long shoreline was virtually barren and exposed to wind and waves. There was a need to bring the area under tree cover by artificial regeneration. So, the Bangladesh Forest Department had to undertake a massive coastal afforestation programme.

Most of the commercial mangrove species, namely *S. apetala, A. officinalis, Avicennia marina, Avicennia alba, Amoora cucullata, B. sexangula, E. agallocha, X. mekongensis, H. fomes, C. decandra* and *N. fruticans* have been planted on the newly accreted lands periodically inundated by tidal water (Choudhury 1971). Of these, *S. apetala* was the most successful along the coastline, while *A. officinalis* was most successful in the eastern part. *Sonneratia apetala* accounted for 94.4% and *A. officinalis* 4.8% of the successful mangrove plantations in Bangladesh (Table 1). Being strongly light demanding with a preference for newly accreted soft mud, they are pioneer tree species in ecological succession. Interestingly, pnuematophores that help in respiration and anchorage of trees were found to appear only within a year for *S. apetala* and two years for *A. officinalis,* after planting of seedlings/propagules. For other species, such as *H. fomes, X. mekongensis, B. sexangula, C. decandra, A. cucullata, C. ramiflora* and *L. racemosa,* it took about five years for the development of aerial roots. Early pneumatophore development could be one of the causes for the successful establishment of *S. apetala* and *A. officinalis* on unstable and anaerobic soils.

Table 1 Species-wise distribution of mangrove and non-mangrove plantations in the coastal areas of Bangladesh

Species	% of species-wise plantations in four coastal Divisions				% of total mangrove plantations	% of total mangrove and non-mangrove plantations
	Chittagong	Noakhali	Bhola	Patuakhali		
Sonneratia apetala	74.57	98.82	97.99	94.99	94.42	92.70
Avicennia officinalis	21.42	0.11	–	–	4.80	4.71
Excoecaria agallocha	–	–	1.66	0.37	0.40	0.39
Bruguiera sexangula	1.10	–	–	0.79	0.38	0.37
Non-mangrove	2.91	1.07	0.46	3.85	NA	1.83
Total	100	100	100	100	100	100

Source: Siddiqi and Shahjalal (1997); NA = not applicable

Nursery and planting techniques for *S. apetala* and *A. officinalis* are well developed (Siddiqi *et al.* 1993a). Seedlings of *S. apetala* were raised on nursery beds and uprooted naked seedlings from the beds were planted in suitable sites. Maximum survival was recorded when the seedlings were planted in the monsoon on sites not exposed to strong wind or waves (Islam *et al.* 1990). The appearance of *M. wightiana* or *P. coarctata* indicates that the site is suitable for supporting *S. apetala.* Initially, up to 85% seedling survival was recorded in an experimental plot at Char Kukri. More than 70% survival was noticed five years after planting (Siddiqi 1987). *Avicennia officinalis* is raised from dibbling propagules in the soft soil or planting naked rooted seedlings. Survival is lower than that of *S. apetala.* Thus the intensity of vacancy filling or replanting is usually higher to create plantations of *A. officinalis* (Siddiqi & Khan 1996).

Raising second rotation crop

The massive development of pneumatophores causes an increase in silt deposition and ultimately a rise of the forest floor. In a short period, lands tend to stabilise and the rate of tidal inundation is lowered. As a result, sites become unsuitable for optimal growth of pioneer species requiring regular submersion. The species find themselves in environmentally stressed conditions. Large-scale bee-hole (*Zeuzera conferta*; Cossidae) infestation in *S. apetala* trees has already posed a serious threat to the sustainability of the plantation (Islam *et al.* 1989, Baksha 1996). The establishment of natural regeneration under the canopy of existing crop or nearby areas is seldom observed (Siddiqi *et al.* 1995). There is no alternative to planting for the creation of a second rotation crop after exploitation of the available growing stock. Species that appear at later stages of succession are shade tolerant at least during their early stages. In addition, they require lower level of inundation. Before harvesting the pioneer species, a second rotation crop under the canopy of existing plantations should to be created in order to maintain a continuous forest cover.

Mangrove trees as upper storey

Six tree species, namely *E. agallocha, H. fomes, X. mekongensis, X. granatum, B. sexangula* and *A. corniculatum,* raised in pots were under planted in the vacant space of thinned plantations of *S. apetala* in different islands including Char Kukri (Siddiqi *et al.* 1992). Data collected and analysed (Table 2) after eight years showed differences in survival ($F_{5, 12} = 5.8$; $p < 0.01$) as well as height ($F_{5, 12} = 44.4$; $p < 0.001$) and diameter increments ($F_{5, 12} = 45.8$; $p < 0.001$). Higher survival was recorded for *E. agallocha* (90.3%), *H. fomes* (84.7%), *B. sexangula* (61.3%) and *X. mekongensis* (58.3%). The maximum mean total height was 9.23 m for *E. agallocha,* followed by *H. fomes* (5.3 m). The highest mean total diameter was recorded for *E. agallocha* (7.3 cm), followed by *H. fomes* (3.1 cm). The performance of *E. agallocha* and *H. fomes* appeared to be significantly better. The introduced spotted deer (*Axis axis*) in the island browsed on seedlings of other species. This is apparent from the fact that the survival of *X. mekongensis, A. corniculatum* and *B. sexangula* was 81, 80 and 75% respectively in the nearby

Table 2 Performance of mangrove trees planted under the *Sonneratia apetala* plantations after eight years at Char Kukri Island

Species	Mean survival (%)	Mean total height (m)	Mean annual height increment (m)	Mean total diameter (cm)	Mean annual diameter increment (cm)
Excoecaria agallocha	90.3 a	9.23 ± 0.33	1.03 a	7.33 ± 0.17	0.92 a
Heritiera fomes	84.7 a	5.33 ± 0.61	0.59 b	3.13 ± 0.95	0.39 b
Xylocarpus mekongensis	58.3 ab	1.64 ± 0.12	0.14 c	0.92 ± 0.42	0.15 c
Bruguiera sexangula	61.3 ab	0.94 ± 0.02	0.09 d	0.0	0.0 c
Xylocarpus granatum	25.7 b	1.22 ± 0.09	0.07 d	0.0	0.0 c
Aegiceras corniculatum	31.3 b	1.52 ± 0.69	0.17 c	1.09 ± 0.45	0.14 c

Diameter was not attained at breast height (1.3 m from the ground).
Means in the same column followed by the same letter do not differ significantly at the 0.05 probability level.

Rangbali Island, which was free from deer. Survival and growth of *H. fomes* and *E. agallocha* were also high at Rangabali. Generally, the performance of *H. fomes*, *E. agallocha* and *X. mekongensis* was satisfactory. A second rotation crop can be created with these species, although in the eastern coastline further studies are necessary to observe the feasibility of under planting (Siddiqi & Shahjalal 1997).

Mangrove shrubs and palms as understorey

With regard to shrubs and palms, five species, namely *C. ramiflora*, *C. decandra*, *L. racemosa*, *P. paludosa* and *N. fruticans*, were tried. Survival of both the palm species was high, *N. fruticans* with 97.3% and *P. paludosa* with 84.7% (Table 3). Annual harvesting of nipa leaves was undertaken after four years; 2–3 fronds from each plant. The fronds gradually increased in size over time. With regard to *P. paludosa*, the main stem attained an average height of 2.9 m with a diameter of 5.1 cm in eight years. A clump was found to contain between 4 and 14 stems during this period. The stems did not attain harvesting size and it is likely to take 10 years for the first harvest of stems. With regard to shrubs, the survival values for *C. ramiflora*, *L. racemosa* and *C. decandra* were 59.0, 51.3 and 35.0% respectively. The average heights of these species were 2.5, 2.6 and 0.7 m respectively (Table 3). Thus, all the planted palms and shrubs except *C. decandra* were promising species as understorey vegetation. However, at Rangabali Island, *C. decandra* had 66% survival with an average height of 1.5 m after eight years. Thus, development of multi-storied, mixed plantations is possible by harvesting the existing *S. apetala* plantations.

Table 3 Performance of mangrove shrubs and palms planted under the *Sonneratia apetala* plantations after eight years at Char Kukri Island

Species	Mean survival (%)	Mean total height (m)	Mean annual height increment (m)	Mean total diameter (cm)
Cynometra ramiflora	59.0	2.49 ± 1.04	0.26	1.43 ± 0.66
Ceriops decandra	35.0	0.67 ± 0.12	0.08	0.0
Lumnitzera racemosa	51.3	2.60 ± 0.07	0.32	1.73 ± 0.06
Phoenix paludosa	84.7	2.93 ± 0.19	0.33	5.06 ± 0.13
Nypa fruticans	97.3	NA	0.32	

NA = Not applicable due to annual harvesting after four years following out planting.

Establishment of non-mangrove plantations

Performance on flat land

Sedimentation in some areas of the shoreline is quite high. Rapid accretion causes complete or partial burial of the planted seedlings and saplings. Failure of mangrove plantations due to high deposition of silt is not uncommon (McConchie 1990b). On raised areas, seldom inundated by tidal water, mangroves cannot be grown. Therefore, the feasibility of non-mangrove species in raised but vacant lands was studied. Inundation affects the non-mangrove seedlings in the coastal environment (Siddiqi 1986). So, planting was undertaken in the late monsoon allowing the seedlings to avoid the actual impact of tidal inundation and wave action. Nine species included in the trials were well distributed in the coastal region of southern Bengal. Only four species, namely *A. lebbeck, A. procera, S. saman* and *A. nilotica,* survived, generally with poor performance. The difference in survival was significant ($F_{3,8} = 9.20$; $p < 0.01$). *Acacia nilotica* had an average survival of 36.3% at eight years with annual height and diameter increments of 0.7 m and 0.9 cm respectively (Table 4). A significant difference for height and diameter increment was not obtained due to complete mortality of trees in some plots.

Table 4 Performance of mesophytes on plain ground eight years after planting in areas only inundated during monsoon spring tides at Char Kukri Island

Species	Average survival (%)	Mean annual height increment (m)	Mean annual diameter increment (cm)
Albizia lebbeck	9.43 b	0.55	0.95
Samanea saman	5.33 b	0.62	1.28
Albizia procera	3.70 b	0.59	0.98
Acacia nilotica	36.33 a	0.74	0.91

Means followed by the same letter do not differ significantly at the 0.05 probability level.

Performance on heaps

Thirteen well distributed species of the coastal region were subsequently chosen and planted on heaps following unsatisfactory experience on flat land. Data recorded after six years on the performance of various species of plants on heaps showed complete absence of three species, namely *S. macrophylla, L. leucocephala* and *M. azederach,* which died within two years after planting. Probably the species disappeared due to unfavourable environmental conditions except for *L. leucocephala,* which died due to heavy browsing by deer. Survival was significantly different ($F_{9,20} = 5.83$; $p < 0.01$) and was higher for *A. lebbeck, S. saman, A. nilotica, P. dulce, C. equisetifolia, T. populnea* and *D. sissoo.* All these species had survival above 60% (Table 5). Lesser bandicoot rats (*Bandicota begalensis*) caused substantial damage to the root system of some species, particularly *A. lebbeck* and *S. saman.* Reducing the activities of rodents could have ensured higher survival of these species. Increasing the size of the heap possibly could do this. It is not clear why survival of *A. procera* was low (19%), although it

Table 5 Performance of mesophytes on heaps six years after planting in areas only inundated by spring tides at Char Kukri Island

Species	Mean survival (%)	Mean total height (m)	Mean annual height increment (m)	Mean total diameter (cm)	Mean annual diameter increment (cm)
Albizia lebbeck	60.0 a	4.14 ± 0.57	0.52 b	5.41 ± 0.50	0.90 bc
Samanea saman	60.7 a	6.74 ± 0.85	0.94 a	9.71 ± 1.07	1.62 a
Albizia procera	18.7 b	4.85 ± 0.37	0.62 b	6.40 ± 0.40	1.06 b
Acacia nilotica	69.0 a	7.90 ± 0.21	1.17 a	6.92 ± 0.10	1.16 b
Pithecellobium dulce	85.3 a	6.71 ± 0.84	0.96 a	10.63 ± 1.03	1.78 a
Syzygium cumini	36.0 b	3.85 ± 0.23	0.49 b	4.47 ± 0.75	0.74 c
Casuarina equisetifolia	65.0 a	6.54 ± 0.21	0.93 a	6.60 ± 0.34	1.10 b
Lagerstroemia speciosa	10.3 b	2.12 ± 0.21	0.35 b	2.03 ± 0.26	0.34 c
Thespesia populnea	91.0 a	2.54 ± 0.18	0.27 b	4.67 ± 0.19	0.93 bc
Dalbergia sissoo	62.7 a	3.18 ± 0.36	0.42 b	2.73 ± 0.36	0.55 c

Means followed by the same letter do not differ significantly at the 0.05 probability level.

showed satisfactory performance in the eastern part (Siddiqi *et al.* 1993b) and Rangabali Island. With regard to height, mean annual increment was significantly different ($F_{9, 20} = 9.52$; $p < 0.001$) and higher in *S. saman, A. nilotica, P. dulce* and *C. equisetifolia.* Their height increment was around 1.0 m per year. Diameter increment was also significantly different ($F_{9, 20} = 12.93$; $p < 0.001$) and higher in *P. dulce* and *S. saman,* followed by *A. nilotica, C. equisetifolia, A. procera, T. populnea* and *A. lebbeck.* The annual diameter increment of these species varied from 0.9 to 1.8 cm (Table 5). It is, therefore, apparent that plantations with species, namely *A. nilotica, C. equisetifolia, P. dulce, S. saman* and *A. lebbeck* can be established on coastal lands provided that planting is done on slightly raised heaps. It has to be taken into account that slight difference in the depth, duration and frequency of inundation will play a vital role in the selection of mangrove or non-mangrove species for planting in the area. *Albizia procera* may also be included in the planting programme.

Conclusions

There is little chance for the development of tree cover in the exposed shoreline of Bangladesh by natural process of ecological succession. However, the succession process can be moved forward artificially through proper application of research based knowledge.

Naturally occurring species along the coastline do not lead to dense vegetation or forest crop on newly formed land through the process of sedimentation.

Massive plantations with *S. apetala* and *A. officinalis* have been raised followed by evolving methods of their nursery and planting techniques. However, coastal geomorphology is highly dynamic and abrupt or gradual rise of the forest floor causes uncertainty in sustainable management of these two pioneer species.

A second rotation crop in the existing *S. apetala* plantations can be replaced by more valuable mangrove species, namely *H. fomes, E. agallocha, X. mekongensis, C. ramiflora, L. racemosa, P. paludosa* and *N. fruticans.*

Vacant lands that are further raised and only inundated in spring tides during the monsoon can be brought under plantations with non-mangrove species, namely *A. nilotica, C. equisetifolia, P. dulce, S. saman, A. lebbeck* and *A. procera*.

It is possible to maintain a continuous forest cover by appropriate human intervention along the open shoreline and off-shore islands of Bangladesh. Sustainable management of the man-made forests can ensure the protective and production role of plantations for coastal population.

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