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Land from the Sea: The Mangrove Afforestation Program of Bangladesh

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ABSTRACT

The coastal areas of Bangladesh have a high cyclone frequency, and the protection from cyclone damage afforded by the natural mangrove forests of the Sundarbans, led the Forest Department in 1966 to initiate a mangrove afforestation program. These initial plantings proved highly successful in protecting and stabilizing coastal areas, and led to a large-scale mangrove afforestation initiative. To date, approximately 120,000 ha of mangroves have been planted. Nursery and planting techniques have been developed for the major species, while additional species are still being investigated. As a result of the extensive monospecific plantations, however, outbreaks of two major insect pest species have been observed. In addition, a number of other problems were also encountered but in

terms of coastal protection and stabilization, wood production and land reclamation, large-scale mangrove afforestation appears to be both technically possible and socio-economically beneficial.

1 INTRODUCTION

The coastal areas of Bangladesh have suffered severe cyclone damage almost annually since cyclone recordings began in 1584. During the period from 1960 to 1970, eight severe cyclones were recorded, with the intense cyclone and associated storm surge of November 1970 reported[1] to have caused the deaths of about 300,000 people; current estimates of the April 1991 cyclone yield a similar figure.

The protection from cyclone damage afforded by the Bangladesh Sundarbans mangrove forests, a continuous natural mangrove forest of 5,800 km^2 in the south-west of Bangladesh, led the Forest Department in 1966 to commence a programme of planting mangroves outside the protective coastal embankments in order to provide greater protection for inhabited coastal areas. These initial mangrove plantings were highly successful and led to the development of a large-scale mangrove afforestation program. With the interest in mangrove afforestation around the tropics,[2,3,4,5,6,7] we review the development of the Bangladesh mangrove afforestation program, its implementation and the benefits and experience gained from it.

2 THE BANGLADESH COASTAL ENVIRONMENT

The coastal area of Bangladesh lies within the tropical zone between 21-23°N and 89-93°E. The mean annual rainfall varies from about 1500 mm in the west to over 3800 mm in the south-eastern region. The heaviest rainfall occurs during the monsoon period (July and August) while there is practically no rainfall during the dry winter months of December to February. Mean coastal temperature during January is 19.5°C while during July, the mean temperature is 27.2°C. Cyclones are most common during the pre- and post-monsoon period, with May and October having the highest frequency.

Most of the 710 km coastline is dominated by the deltaic deposits of the Ganges-Brahmaputra-Meghna Rivers. Originating in the Himalayas, this river complex carries an estimated annual sediment load of 2.4 x 10^9 tons.[8] These sediments are transported and sorted by river flow and reworked by tidal and wind action, leading to extensive areas of accretion and erosion in the coastal area. With the fall in mean sealevel after the monsoon, these newly formed deltaic deposits - locally known as 'char' lands - become increasingly exposed, often drying completely during the winter months.

Because of the nature of these 'char' lands, their partial submergence during subsequent monsoons, and their high interstitial salinity, these areas are not suitable for agriculture until salts have been leached out and soil ripening has occurred.[9,10] Consequently, this new land remains bare until natural successional changes lead to a grass cover, usually dominated by halophytic uri-grass, *Oryza coarctata.*[11] Protection of these lands from subsequent erosion and acceleration of their vertical accretion are prime objectives of the coastal afforestation program.

3 BACKGROUND TO THE PROJECT

From its limited beginnings in 1966, annual plantings of approximately 320 ha (800 acres) of mangroves were undertaken on newly accreted land in the Patuakhali, Barisal, Noakhali and Chittagong coastal districts. These plantations were established by the respective district coastal afforestation staff with assistance from the local villagers. Techniques to raise suitable seedlings and to establish the plantations were developed by 'trial and error'.

As the coastal afforestation programme proceeded, it became apparent that the plantations contributed both to the acceleration of land accretion, and to the stabilization of the 'char' lands. These plantations and the sedimentary processes they induced apparently had the ultimate potential of providing land sufficiently raised and stabilized to be used for agricultural purposes - thus, meeting the prime objectives of the afforestation programme.

While the initial objective of the afforestation program was to create a shelter belt to protect the lives and properties of the coastal communities, the early success of the plantations resulted in the setting of additional objectives for coastal afforestation,[12] including to: (a) provide forest products for a range of uses; (b) develop forest shelter-belts to protect life and property inland from tidal surges; (c) inject urgently needed resources into the national economy (i.e. timber and land); (d) create employment opportunities in rural communities; and (e) create an environment for wildlife, fishes, and other estuarine and marine fauna.

With these additional objectives and the more stable conditions after political independence on 16 December 1971, the afforestation programme was given added impetus in 1973. From July 1980 to December 1985, the 'World Bank'-funded Mangrove Afforestation Project I aimed to plant approximately 8,100 ha (20,000 acres) of mangroves annually while the Mangrove Afforestation Project II was designed to create a further 8,100 ha (20,000 acres) of new plantations annually from 1986 to 1990. By 1990, 120,000 ha of mangroves had been planted (Fig. 1) although accurate area determinations are still being collated by the Space Research and Remote Sensing Organization (SPARRSO).

In conjunction with the increased funding for, and acceleration of the planting program, a more systematic investigation of techniques was initiated to refine the raising of seedlings, determine the optimal planting season, develop an appropriate spacing of seedlings, and determine the optimal harvesting strategy. Responsibility for these investigations were given to the Plantation Trials Unit, established as part of the Bangladesh Forest Department in 1980 and transferred to the Forest Research Institute in 1985. As part of the evaluation of the Mangrove Afforestation Project I and II, the need for an intensive management-orientated research program was also identified in relation to the mangrove plantations. Objectives for such a research programme included, *inter alia,* the improvement of nursery and plantation techniques, and the more effective management of mangrove plantations. For existing plantations, such management included the control of pest outbreaks, the development of thinning schedules and optimal rotation times, underplanting trials, site/species matching studies as well as growth trials for a range of indigenous and exotic species. For future plantations, management capabilities were needed to identify the most favorable locations for plantations and to develop techniques, using additional mangrove species, to establish successful multi-specific plantations.

4 SPECIES SELECTION

Although roughly 27 species of mangroves and a similar number of mangrove associates occur in Bangladesh[13,14] most are rare, or of little economic importance.[11] Only 10 or so species occur frequently enough to sustain silviculture (Table 1).

As a result of the early 'trial and error' approach to plantations, only two species - *Sonneratia apetala* and *Avicennia officinalis* - showed encouraging survival rates, and as a consequence, these two species dominate the mangrove plantations generally as monospecific stands.[15] These species are medium quality timbers used for fuel wood, constructions and furniture.[16,17] About 80% by area of the early plantations consisted of monospecific stands of *Sonneratia apetala,* about 15% consisted of stands of *Avicennia officinalis* with the remaining areas consisting of *Excoecaria agallocha, Bruguiera* spp. and *Ceriops decandra,* more valuable species for timber or paper pulp production. Polybag culture of a range of other mangrove species (Table 2) has been experimentally developed although field assessments of the performance of these species are as yet incomplete.[18,19]

5 NURSERY AND PLANTING TECHNIQUES

Nursery and planting techniques vary considerably among the various species, and a summary of the techniques employed for each of the major species is provided below:

Sonneratia apetala: Mature green fruits of keora *(Sonneratia apetala)* are generally collected during September and they are heaped for 20 days to allow the pericarps to decay. They are then rubbed and washed in water to separate the small seeds from the rotted fleshy portion of the fruits. About 1 kg of green fruit will yield about 275 g or 7,500 seeds.[20] These seeds maintain their viability for about one month. Approximately 7-8 kg of these seeds are broadcast onto intertidal nursery beds 1.2 m wide and 12 m long, slightly raised above the surrounding sediment. The beds are usually encircled by low (15 cm) earthen walls which retain water pumped into the enclosures during unusually dry periods.

Germination onset and success is largely controlled by salinity which needs to be maintained below 20ppt; above 20ppt germination performance declines rapidly.[21]

The seedlings are allowed to grow for about 10 months and from each nursery bed about 2,350 seedlings of the desired height (30-60 cm) become available for the next suitable planting season i.e. from July to August. At this time, the seedlings are gently pulled out of the ground and packed for transport to selected afforestation sites. Generally, one such nursery bed provides sufficient seedlings to plant an area of 0.4 ha at the usual spacing of 1.2 x 1.2 m.[20] The uprooted seedlings can be stored in the shade for up to six days without any significant losses.[22] As discussed later, this approach results in adequate survival rates for a species that has not been cultivated elsewhere.

Excoecaria agallocha: Seeds of this species ripen in August. The seeds retain their viability for about one month and can either be sown directly onto sheltered intertidal areas, or may be raised in nurseries. Although nursery raising is not used for large plantings, some polybag seedlings are allowed to grow for about 12 months and seedlings of the desired height (30-50 cm) become available for planting from July to August. At this time, the seedlings are packed for transport to afforestation sites where they are usually planted out at a spacing of 1.0 x 1.0 m. One-year old seedlings may also be collected from the floor of natural forests of the Sundarbans and rapidly transported to planting sites where they are usually planted on relatively raised lands. Because this species is mostly planted onto more raised lands, survival rates using these planting techniques are around 80% after 12-months.

Avicennia officinalis: The crypto-viviparous[23] propagules of species of *Avicennia* are usually collected from around the base of mother trees in August to September. When kept in air, these propagules lose their viability within a few days. These propagules may be directly planted into sheltered areas by 'dibbling' - where the propagule is gently pushed into the soft sediment until firmly wedged. 'Dibbling' is usually undertaken during neap tide periods to allow the seedling to develop roots. Pre-treatment of the propagules has also been used to decrease the establishment time. Such treatment consists of placing the propagules in small nets and exposing them to daily tidal inundation to hasten the decay of the pericarp. Removal of the pericarp by pre-treatment reduces the establishment time to 2-3 days compared with the 5-6 days required where no pre-treatment is used. Alternately, propagules may be raised in nursery beds that are exposed to daily tidal inundation. Seedlings are raised for about 1-2 months after which they are gently pulled out of the ground and packed for transport to afforestation sites where they are usually planted out into holes of 3 cm diameter at a spacing of 1.0 x 1.0 m. Recent experiments using one-year old seedlings (ranging in height from 70-90 cm) raised in nursery beds and planted out at Chittagong and Barisal, showed high survival rates, and may prove to be more suitable for areas where larger seedlings are required.

6 SURVIVAL AND GROWTH OF THE PLANTATIONS

Survival: Because of the highly dynamic nature of the Bangladesh coastline, survival of mangroves is generally poor and replacement planting often needs to be undertaken for up to 3 years. In sheltered localities, however, survival is usually around 70% (see next section). Long-term survival (i.e. between 5 and 15 years) is also highly variable but in experimental plots at Barisal,[24] survival in 5-year old *Sonneratia apetala* ranged from 29-52%. Quantitative data for *Avicennia officinalis* is still being collated but initial analyses suggest approximately 30-60% survival rates after five years in the Chittagong coastal district.

Optimal Planting Season: Planting during June to August appears to result in maximum survival of newly planted seedlings of *Sonneratia apetala* based on replicate plots where fixed numbers of seedlings were planted out from nurseries every month over a 24-month period (Fig. 2). Cyclical regression analysis of these data[25] shows that not only the time of planting but the age of seedlings is a contributing factor, and that seedlings older than 12 months generally result in lower survival rates for equivalent months (e.g. compare July/August in 1988 with July/August in 1989 in fig. 2).

While quantitative field trials have not yet been carried out with *Avicennia officinalis,* maximal survival of this species also appears to occur during June to August. In some areas such as the Chittagong and Noakhali Divisions, winter planting is considered to result in higher survival rates but, to date, no experimental data support this view.

Optimal Initial Spacing and Thinning Schedules: At 1.2 m x 1.2 m spacing, the trees become congested within 4 or 5 years (Table 2). In such dense *Sonneratia* and *Avicennia* plantations, thinning is carried out after 9-10 years when up to 50% of the stems may be removed.[26] Thinning of these plantations largely consists of removing stunted trees and cutting smaller stems from multi-stemmed trees, and results in slightly reduced natural mortality together with marginal annual increases in height and girth. In more widely spaced plantations, thinning is generally not required because of the relatively slow rate of tree growth and the loss of some trees in plantations due to stem borer attack (see below); the products of thinning yield low economic returns.

Mean Annual Increment/Height increases: Increases in height and girth, and thus volume, depends on the initial spacing of the particular plantation (Table 2). In 5-year old plantations of *Sonneratia apetala,* maximal heights are attained at a spacing of 0.85 x 0.85 m while maximal girth is found in plantations where the initial spacing was 2.4 x 2.4 m. Maximal wood production for this species of 18.5 m^3/ha/yr occurs at an initial spacing of 1.2 x 1.2 m.[24] The heights, girths and volumes together with their mean annual increments (MAI) for variously aged plantations for all species used in afforestation, have been summarized in (Table 3). These data show that with an initial spacing of 1.2 x 1.2 m, acceptable volume increments are found in some species throughout the coastal regions. For other genera such as *Bruguiera, Ceriops and Xylocarpus,* poor growth performance occurs throughout the coastal regions, and is attributable to poor species-to-site matching, particularly in relation to interstitial salinity and tidal inundation.[10,23]

7 PROBLEMS ENCOUNTERED

The mangrove afforestation project in Bangladesh is being carried out in one of the most dynamic natural environments on earth and as such, some problems associated with land stability must be expected and can never be completely eliminated. Four types of land stability problems have been recognized[27] including: burial of mangrove seedlings when and where sediment accretion rates are particularly high; smothering of seedlings by sand in areas where wave action reworks large volumes of sand shorewards; the winnowing of fine sediment (clay and silt) from the plantation site during prolonged stormy periods, leaving a mobile sandy lag deposit; and the erosion of plantation margins through bank slumping by migrating tidal and river channels. All four types of coastal change have caused the loss of mangroves from existing plantations. However, the increasingly systematic identification of areas with land stability problems is being used to avoid planting sites where the risk of crop losses between planting and harvesting is high. In this way, mangrove losses due to adverse coastal changes should be progressively minimized.[28]

Other problems in relation to mangrove plantations have been identified.[29,30] Over and above the generally difficult communication and logistic conditions in the coastal areas, these problems include unauthorised cattle and buffalo grazing and the illegal occupation of newly raised land by the local villagers for cultivation of rice.

In the mangrove nurseries, one of the initial problems encountered was that heavy rains during the early nursery period caused low seedling production, usually because the seeds are light and easily floated away.

In addition, early planting trials of other mangrove species using the technique where seedlings are pulled out of the ground, did not provide acceptable levels of survival - presumably due to root damage during seedling extraction. The high proportion (about 80% by area) of *Sonneratia apetala* in early plantations is partly due to the tolerance which this species shows toward this transplanting procedure. Polybag culture is now used to raise seedlings of at least 10 different mangrove species (Table 1) for growth trials, and these show much better performance in terms of survival and growth after out-planting. Nevertheless, the extent of the early monospecific plantations has led to outbreaks of two major pest organisms:

Keora stem borers: *Zeuzera conferta* (Cossidae: Lepidoptera)

Stem borer infestations of *Sonneratia apetala* plantations have increased markedly over the last five years apparently with the increased area of monospecific stands of this species. In 1988, a mean of 52% of the trees were affected with 22%, 17% and 13% respectively showing severe, moderate or slight infestations.[31]

Although stem borer attacks generally do not kill the trees, they reduce their timber value, and the Protection Division of the Forest Research Institute is presently trying to develop control measures. At the same time, the PTU is evaluating the silvicultural control of this insect through multi-specific plantations, particularly mixtures of *Sonneratia* and *Avicennia.*

Leaf defoliators: *Streblote siva* (Lasiocampidae: Lepidoptera)

The numbers of this insect have also increased in apparent response to large monospecific stands of *Sonneratia apetala.* As with the stem borer, this species generally does not kill the trees but severe infestations may cause growth deformities and a marked decline in growth generally and wood production specifically. The silvicultural control of this insect through multi-specific plantations, particularly mixtures of *Sonneratia* and *Avicennia* is currently under investigation by the PTU.

Economics of thinning

In 1985, the mean yield of wood from 10-year old plantations was estimated at 200m^3/ha, providing a mean annual increment (MAI) of 20m^3/ha.

Because of purchaser preference, the price of *Sonneratia* as fuel wood is approximately 2 Taka per cu.ft. while other popular fuelwoods are generally priced at 15 Taka per cu.ft. even though *Sonneratia* has a slightly higher calorific value (8236 Btu/lb) when compared with mango (7886 Btu/lb) and raintree (8191 Btu/lb).[32] Thus, from a purely economic perspective, while the price of *Sonneratia* as fuel wood remains low, the cost of thinning is barely recoverable.[26] One of the options currently being evaluated is to design the plantations so as to optimize timber productions without the need for thinning.

On the basis of experimental trials it was found[33] that an adjustment of density so that in 5- or 6-year old plantations, densities of 1100-1600 trees/hectare occurred, would result in a marginally increased diameter increment - and hence, volume. Such an adjustment of density may be achieved either by thinning when plantations are 5- or 6-years old, or by adjusting the initial spacing so that this density is attained by natural attrition around 5 or 6 years after planting.

If the products of thinning are an important outcome from the coastal plantations, and if these can be harvested economically, then it seems that the current spacing of 1.2 m x 1.2 m should be retained, with thinning carried out when the plantations are 5 or 6 years old. However, as there is some doubt on the economics of thinning,[26] it may be preferable to adjust the initial spacing to achieve the desired density 5 or 6 years after planting out. An initial spacing of 1.75 m x 1.75 m will result in the desired densities after 5 or 6 years through natural losses and, would thus reduce the initial labour involved in establishing the new plantations. On the other hand, such wider initial spacings would require monitoring to ensure that unforeseen physical events, for example, have not caused major departures from the predicted survival rates. In addition, some infilling may also still be required as mortality may occur in patches rather than randomly through newly established plantations.

8 BENEFITS GAINED

On current estimates, there are some 96,000 ha of suitable coastal lands presently available for further plantations. Despite this, it is estimated that a total of 150,000 ha has been reclaimed and stabilized since the inception of this program. Considerable areas (60,000 ha) have now become raised to the level where they are no longer suitable for further mangrove plantations and these are currently planted with salt-tolerant upland trees (e.g. *Acacia nilotica, Albizia procera, Samanea saman, Casuarina equisetifolia)* or have been transferred from the Forest Department to the local people for grazing of cattle, goats and buffalo.

More importantly, the protection and stabilization provided has 60,000 ha of stabilized land which at current land values ($US 800/ha), suggests that the real success of the coastal plantations has been to generate 1.44 x 10^9 takas from new agricultural lands.

In addition, it is estimated that the plantations have provided more than 600,000 m^3 of wood (Ishtiaq Uddin Ahmed, Assistant Conservator of Forests, pers. comm.) and other forest products, and have provided in excess of 5 x 10^6 man days employment for local villagers over the last 25 years - considerably adding to the economies of coastal villages.

During the intense cyclone of April 1991, many of the mangrove plantations were damaged. The intensity of damage was higher along the Chittagong coast than in the western part of the coastal belt but none of the mangrove nurseries sustained any significant damage. Young plantations (1-5 years old) seemed to have suffered most damage through wave action, with leaf loss ranging from 10-80%. By July 1991, however, most of the plantations showed clear signs of recovery (Siddiqi, unpublished data), and it is expected that full recovery will occur with the exception of those areas where excessive silt deposition resulted. Damage to non-mangrove species raised on the coastal embankments (such as *Acacia nilotica)* was significantly higher than that to mangroves, and less developed root systems in non-mangrove species may have contributed to their susceptibility to 'wind-throw'.

Consequently, it may be argued that the most significant benefit provided by the mangrove plantations was the provision of a self-repairing system which facilitated the stabilization and protection of the coast during intense cyclonic conditions.

9 LESSONS LEARNED

While resource decision-making is always easier with the benefit of hindsight, there are several important lessons emanating from this program which have wider application. From an ecological management perspective, the major lesson to date has been that monospecific mangrove cultures may develop problems which are difficult and costly to remedy. Where the economic conditions are as they are in Bangladesh, then silvicultural control measures need to be investigated rather than to rely on chemical control measures. More importantly, plantations need to be designed as multispecific systems to minimize or avoid some of the identified problems. In that sense, silvicultural research should precede any intensive planting program.

In some instances, mangrove plantations have had a sacrificial value i.e. they have caused such rapid accretion that the land no longer supports mangroves. Because using mangrove plantations to accelerate the accretion of new land is not necessarily compatible with optimal timber production, the objectives for afforestation need to be reviewed and clearly prioritized.[27]

Finally, the changing soil salinities as well as soil maturation of the newly accreted lands require an integrated program of sequential planting of suitable species which are able to adapt to the changing conditions. In contrast to the existing situation, such an integrated program requires the long-term control and tenure of the land by the Forest Department.

Despite the improvements that could have been made to this program at its inception, it has nevertheless proved successful in most respects and illustrated that large-scale mangrove afforestation is both technically possible and socio-economically beneficial.

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