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Eucalypts in Bangladesh – Does Research Findings Support the Environmental Issues of Eucalypts Planting?

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Abstract

Eucalyptus citriodora was introduced for the first time in Bangladesh probably in the 1930's in the eastern part by the tea planters as ornamental trees. The first trial of *Eucalyptus* was initiated by Bangladesh Forest Research Institute (BFRI) in 1965, and seedlings were raised and planted in Rasulpur (Mymensingh) and Hathazari (Chittagong). But the trial was closed down with inadequate information. In eighties, *E. camaldulensis, E. tereticornis,* and *E. brassiana* were found suitable in the climatic and edaphic conditions of Bangladesh from the trials of 84 seedlots of 12 species of *Eucalyptus* imported through CSIRO from different parts of Australia. Following some other trials, *E. camaldulensis* -Petford provenance was found suitable and promising for large scale plantation programs in the country. But, the issues of environmental degradation due to *Eucalyptus* planting that arose from different sources remain an unanswered question. The Government has a ban on further planting of Eucalypts in Forest Department's land. However, people are still planting eucalypts in their homesteads, marginal and fallow lands for immediate return from plantations. The present paper briefly discusses the research findings of different trials of *Eucalyptus* and analyses the prospects and problems for future eucalypt plantations in Bangladesh.

Key word: Allelopathic effect Coppice, Elimination trial, *Eucalyptus*, Homesteads, Provenance trial

Eucalypts in Forest Plantations of Bangladesh

Selection of Eucalypts through elimination and provenance trials by BFRI

In Bangladesh, like many other developing countries, Eucalypts were introduced in the 19th century as ornamental plants to decorate parks, road sides, or for collection in botanical gardens. Probably in the 1930's, *Eucalyptus citriodora* was introduced in the eastern part of Bangladesh by the tea planters as ornamental trees (Davidson and Das, 1985). Later on, it spread throughout the country in haphazard manner by botanists, foresters, gardeners and tree planters (Hassan, 1994). The first trial of *Eucalyptus* was initiated by Bangladesh Forest Research Institute (BFRI) in 1965, and seedlings were raised and planted in Rasulpur (Mymensingh) and Hathazari (Chittagong). But of the trial was closed down with incomplete results and inadequate information (Rashid, 1969).

Bangladesh Forest Research Institute imported 84 seedlots (provenances) of 12 species of *Eucalyptus* from different parts of Australia through CSIRO in 1977-78. Among those, only three species of *Eucalyptus,* viz. *E. camaldulensis, E. tereticornis,* and *E. brassiana* were found suitable in the climatic and edaphic conditions of Bangladesh (Davidson and Das, 1985; Hossain *et al.*, 1989) through elimination trials. From the view point of coppicing ability of different provenances, *E. camaldulences, E. tereticornis* and *E. brassiana* showed high coppicing ability and *E. camaldulensis* produced the highest coppice yield (Hossain *et al.*, 1994). Some other provenance trials of *E. brassiana* (12 provenances) and E. *urophylla* (12 provenances) were laid out during 1983 to select the superior provenances for Bangladesh (Islam *et al.*, 1997). However, the seeds of a total of 218 provenances of 37 species of *Eucalyptus* were introduced in Bangladesh (Table 1) from which finally *E. camaldulensis*-Petford-1 was found suitable, promising and recommended for large scale plantation programs (Davidson and Das, 1985).

Table 1. Eucalyptus species/ provenances introduced in Bangladesh for experimental plantations

Species	Provenances No.	Species	Provenances No.
Eucalyptus acmenioides	8	*Eucalyptus moluccana*	4
Eucalyptus botryoides	5	*Eucalyptus obliqua*	1
Eucalyptus brassiana	18	*Eucalyptus occidentalis*	1
Eucalyptus camaldulensis	25	*Eucalyptus pellita*	3
Eucalyptus citriodora	10	*Eucalyptus pilularis*	5
Eucalyptus cloeziana	16	*Eucalyptus polybractea*	1
Eucalyptus crebra	3	*Eucalyptus propinqua*	1
Eucalyptus deglupta	1	*Eucalyptus radiata*	1
Eucalyptus delegatensis	1	*Eucalyptus resinifera*	7
Eucalyptus dives	1	*Eucalyptus robusta*	15
Eucalyptus drepanophylla	1	*Eucalyptus saligna*	18
Eucalyptus exserta	5	*Eucalyptus smithii*	1
Eucalyptus fibrosa	1	*Eucalyptus tereticornis*	12
Eucalyptus globulus	9	*Eucalyptus tesselaris*	1
Eucalyptus grandis	11	*Eucalyptus tetrodonta*	1
Eucalyptus macrorhyncha	1	*Eucalyptus torelliana*	2
Eucalyptus maculata	9	*Eucalyptus urophylla*	12
Eucalyptus microcorys	3	*Eucalyptus youmanii*	1
Eucalyptus microtheca	3	*Total- 37 species*	218 prov.

Eucalypt planting by Forest Department and Individuals

The suitability of *Eucalyptus* was described by Banik and Alam (1995) at Sitakunda hilly regions of Chittagong Forest Division. Bhuiyan (1995) reported the potential of *Eucalyptus* grown in hilly regions of Chittagong as well as North Bengal agroforestry plantation and the degraded sal forest areas of central zone. The expected yield from eucalypt plantations in Bangladesh was 19.00 m^3 $ha^{-1}yr^{-1}$, though the performance at the silvicultural research station was comparatively higher (Davidson and Das, 1985). Recent study showed that the actual yield per ha per year was only half of the expectations (Hassan, 1994). However, Davidson *et al.* (1985a, b, c and d) determined the volume table, biomass production for young Eucalypts in Bangladesh. Some plants, particularly in the hill forest areas of Chittagong and Cox's Bazar looked poor and erratic even within the same plantations throughout the rotation cycle. Origin of quality seed sources was probably the reason of this poor performance, is considered essential for the optimum growth of the species.

In Bangladesh, *Eucalyptus camaldulensis* were planted by the Forest Department and are being planted by private sectors owing to its proven capacity to supply fast grown timber for a wide variety of end uses. By 1995, some 12,000 ha eucalypt plantations were raised in the forest land besides scattered plantings of unknown hectare in the farm lands, homegardens, strip plantations and ornamental plantings throughout the country (Bhuiyan, 1995).

Growth of Eucalypts in Plantation Forests of Bangladesh

Three species of *Eucalyptus*, e.g., *E. camaldulensis, E. tereticornis* and *E. brassiana* proved superior to over 36 other Eucalypt species tried in Bangladesh (Davidson and Das, 1985). With these species, Petford, Mt. Garnet and Coen provenances respectively are the best ones. After 5 years of growth, mean annual increment per ha ranged from 11.7 to 95.6 m^3 for Petford, 4.9 to 66.6 m^3 for Mt. Garnet and 7.3 to 34.2 m^3 for Coen. Latif (1988), Latif and Islam (2004), Latif *et al.* (1983, 1985a, 1985b, 1999) determined the biomass, volume and height diameter relations of Eucalypts in Bangladesh. MAI in m^3 h^{-1} yr^{-1} of three superior *Eucalyptus* species at different research stations at the age of 5-6 years are shown in Table 2, which was exceptionally promising in early growth and development.

Table 2. Growth performance of 3 major *Eucalyptus* species (5 - 6 year old) in different experiment stations of Bangladesh Forest Research Institute, Bangladesh (Davidson and Das, 1985)

Locality	Species	Survival %	ht (m)	dbh (cm)	MAI ($m^3 h^{-1} y^{-1}$)
Lawachara	*E.camaldulensis*	56	8.8	4.8	17.1
Charaljani	*E.camaldulensis*	66	13.2	11.9	95.6
Charkai	*E.camaldulensis*	84	7.9	5.6	23.4
Hathazari	*E.camaldulensis*	89	9.5	5.9	28.9
Keochia	*E.camaldulensis*	60	7.5	5.7	13.9
Lawachara	*E. tereticornis*	59	5.7	4.0	9.1
Charaljani	*E. tereticornis*	60	13.0	10.1	67.3
Charkai	*E. tereticornis*	57	8.0	5.7	18.4
Hathazari	*E. tereticornis*	59	9.8	6.9	24.7
Lawachara	*E. brassiana*	61	8.7	4.9	15.3
Charaljani	*E. brassiana*	56	10.6	7.6	34.2
Charkai	*E. brassiana*	76	8.1	6.0	16.3
Hathazari	*E. brassiana*	76	9.7	5.9	23.9
Keochia	*E. brassiana*	81	6.2	4.5	11.7

Similarly trial plantation in Madhupur in Tangail showed the superiority (Table 3) of eucalypts in comparison to some other species (Hossain et al., 1995).

Table 3. Survival percentage, mean height (m) and mean dbh (cm) in a species trial at the age of 5.5 years

Name of the species	Survival %	Mean ht. (m)	Mean dbh (cm)
Acacia auriculiformis	82a	9.41a	9.1b
A. mangium	52bc	10.40a	11.5a
Albizia procera	-	-	-
Eucalyptus camaldulensis	83a	9.58a	7.0c
Prosopis juliflora	-	-	-
Artocarpus chaplasha	-	-	-
Chukrasia tabularis	06b	6.74b	6.8c
Dipterocarpus turbinatus	37c	3.72c	4.1b
Xylia kerrii	57b	7.09b	7.2c
Syzygium grande	59b	3.96c	4.1b

Another trial of 12 provenances of 4 *Eucalyptus* species at Chittagong University campus showed the initial growth of 4 Eucalyptus species (Hossain et al., 1996) where *Eucalyptus camaldulensis*, *E. tereticornis* and *E. urophylla* appeared as promising species (Table 4).

Table 4. *Eucalyptus* species-provenances seed lot number, origin, survival %, height and collar diameter at 1.5 years after out planting at Chittagong University campus (Hossain *et al.,* 1996).

Species, Seed lot No. and Origin	Survival %	Height (cm)	Collar diameter (cm)
E. *camaldulensis*- 12355, Western Australia	81ab*	194.8 c	2.66 ab
E.*camaldulensis*- 15026, Victoria	56 c	197.0 bc	1.86 d
E. *camaldulensis*- 18604, Queensland	87 a	218.1 ab	2.73 ab
E. *tereticornis*- 14846, Queensland	65 c	175.0 e	2.17 c
E. *tereticornis*- 17864, Queensland	84 a	219.6 a	2.69 ab
E. *tereticornis*- 18760, Queensland	37 d	175.4d	2.15 c
E. *Pellita*- 18149, Queensland	81 ab	195.1 c	2.40 bc
E. *pellita*- 18749, Queensland	69 bc	146.6 f	2.16 c
E. *pellita*- 18759, Northern territory	75 ab	187.5 c	2.47 bc
E. *urophylla*- 13828, Indonesia	76 ab	175.2 de	2.91 a
E.*urophylla*- 17836, Indonesia	69 bc	182.4 cd	2.64 ab
E. *urophylla*- 18095, Indonesia	75 ab	156.1 ef	2.61 ab

* Means denoted by the same letter(s) are not significantly different, Duncans Multiple Range Test (DMRT)

Similarly, another trial plantation was established with 15 multipurpose tree species of both exotic and indigenous (*Acacia auriculiformis, Alstonia scholaris, Anthocephalus chinensis, Cassia nodusa, Casuarina equisetifolia, Chickrasia tabularis, Dalbergia sissoo, Eucalyptus camaldulensis, Gmelina arborea, Melaleuca leucadendron, Melia azedarach, Mesua ferrea, Pinus caribaea, Polyalthea longifolia* and *Terminalia arjuna*) in 1994 with a view to find out suitable species for degraded hill areas of this region.These plantation species were assessed for survival and growth (Table 5) at the age of 7 years (Hossain and Khan, 2005).

Analysis of data showed that the survival percentage was highest (100%) for Melaleuca leucadendron, followed by Eucalyptus camaldulensis (98%), Acacia auriculiformis (97%) and Gmelina arborea (96%). Similarly, considering the growth parameters (dbh, merchantable height, total height), A. auriculiformis, E. camaldulensis and M. leucadendron were superior in comparison to other species (Table 5). The height and diameter growth of A. auriculiformis (13.2 m and 16.6 cm respectively) and E. camaldulensis (14.1 m and 14.6cm respectively) of this study closely support the findings of Ahmed (1990) and Ara et al. (1989). It was found that some exotic species grow better than the tested indigenous species. A. auriculiformis and E. camaldulensis were also found promising in the same area (Osman et al., 1992) and in Tangail (Hossain et al., 1995). These MPTS may be exploited to rejuvenate the degraded sites in the south-eastern hilly areas of Bangladesh.

Table 5. Comparative growth performance of 15 multipurpose tree species in the degraded hill areas of Chittagong University campus

Species	Growth parameters			
	Dbh (cm)	Merchantable ht. (m)	Total height (m)	Survival (%)
Acacia auriculiformis	16.6 a*	9.5 ab	13.2 ab	97 ± 2
Alstonia scholaris	9.5 c	5.4 bcd	6.5 cd	78 ± 13

Anthocephalus chinensis	14.2 ab	4.6 cd	7.5 bcd	73 ± 14
Cassia nodusa	12.1 abc	6.3 abcd	9.8 abcd	91 ± 7
Casuarina equisetifolia	15.3 ab	9.6 ab	13.6 ab	92 ± 6
Chickrasia tabularis	12.5 abc	7.2 abc	11.3 abc	86 ± 9
Dalbergia sissoo	11.8 bc	7.8 abc	11.2 abc	64 ± 18
Eucalyptus camaldulensis	**14.6 ab**	**10.2 a**	**14.1 a**	**98 ± 2**
Gmelina arborea	15.4 ab	8.5 ab	12.2 abc	96 ± 3
Melaleuca leucadendron	15.6 a	10.4 a	14.7 a	100 ± 0
Melia azedarach	12.7 abc	5.6 bcd	9.4 abcd	84 ± 12
Mesua ferrea	8.8 c	3.5 d	5.5	80 ± 14
Pinus caribaea	11.7 bc	5.4 bcd	7.2 bcd	82 ± 12
Polyalthea longifolia	13.5 abc	3.2 d	5.8 d	74 ± 17
Terminalia arjuna	11.2 bc	6.7 abcd	9.2 bcd	87 ± 10

* Means followed by the same letter (s) are not significantly different at $P<0.05$, Duncan's Multiple Range Test (DMRT)

Coppicing ability of Eucalypts

Eucalypts possesses excellent coppicing ability, and first few generations are more productive than the seedling crops (Latif *et al.,* 1985c). A comparative study of the coppicing ability of different provenances of *E. camaldulensis, E. tereticornis* and *E. brassiana* in Charaljani Silvicultural Research Station at Madhpur in Tangail showed that their coppicing ability was very high (Table 6) and *E. camaldulensis* produces highest coppice yield (Hossain *et al.,* 1994).

Table 6. *Eucalyptus* coppice crops at Charaljani Silvicultural Research Station at Madhupur in Tangail at the age of four year (Hossain *et al.,* 1994)

Species	Stumps Coppicing (%)	Coppice stocks (stems ha^{-1})	Height (m)	DBH (cm)	Stem volume over bark ($m^3 ha^{-1} yr^{-1}$
E.camaldulensis	95	6733	11.5	11	86.0
E. tereticornis	95	5371	10.9	10.2	59.5
E. brassiana	*95*	5432	8.7	7.5	30.8

Controversy and Criticisms of *Eucalypts* Grown as Plantation Species

Though eucalypts have become an important industrial species in many countries, debate still remains about their effect on the environment (Shiva and Bandyopadhyay, 1983; Karanth and Singh, 1983). However, the current expansion rate of eucalypt around the world shows not all countries embarking in large scale plantations are convinced by concerns raised in India.

This controversy has resulted in confusion about the suitability of eucalypt plantations in Bangladesh. Research results suggest that some provenances of several species of the genus are suitable for the country in terms of growth and site adaptability. As a result, the country has undertaken large scale eucalypt planting program and to date about 12,500 ha have been brought under plantations to supply domestic fuelwood. Research projects have under-taken to verify objections under Bangladesh conditions revealed that the effects in Bangladesh are the same as those in India. However, confusion and negative attitude towards eucalypt planting has developed among policy makers, politicians and elites. The news media and environmentalists publish articles on the possible bad effect of these species in Bangladesh and neighboring countries. There is a directive from the government not to plant these species further. Some established plantations were also felled or cleared off.

Eucalyptus is blamed for more water absorption than other species, to reduce soil fertility, leading to soil erosion, harmful for wildlife and reduces native understorey vegetation diversity. But, the criticisms and blames are not supported by sufficient scientific research findings. Contrary, the leading forestry, agroforestry experts and scientists concluded that eucalypts may be a suitable species for afforestation and reforestation in denuded areas, marginal lands, roadside plantations and agroforestry programs (Amin *et al.*, 1995; Hossain *et al.,* 1997).

However, the mass of rural people, who plant eucalypt on their homesteads have not shown any negative reaction to these environmental whims. These people participate in tree planting in small rural woodlots, agroforests and marginal land in rural areas (Ahmed *et al.*, 2007b). An early return of a handsome volume of wood is very important to them. They are in crucial need of fuelwood, poles and posts for domestic uses (Ahmed and Akhter, 1995). So, a sharp divergence of opinion exists between different groups of people in society. Therefore there are some findings both in favor and against of *Eucalyptus* plantings in Bangladesh. Some of the controversies are discussed below:

Excessive water consumption

It is claimed that Eucalypts consume more water in comparison with other species, which results into drying of site and converting the site as unsuitable for the growth of other crops. Eucalypts are known to be highly water demanding mainly because of their rapid growth (Davidson, 1995). Though the water consumption efficiency of eucalypts is much higher in comparison to many native species, t Eucalypts consume less water based on unit weight of dry matter produced (Chaturvedi, 1983; Tiwari and Mathur 1983). On the contrary, Eucalypts actually economise soil water storage because of having minimum evapo-transpiration surface, waxy leaves, stems and fewer lenticels (Karschon and Heth, 1967; Banerjee, 1972). Dabral (1970) conducted a study on potted seedlings of several forest species (*Eucalyptus citriodora, Dalbergia* sp., *Pinus* sp., and *Populus* sp.) and concluded that Eucalypt was producing more biomass per unit weight of water consumed, though its total water consumption was greater than other genera. A nursery experiment in Chittagong University also supports the same findings.

Depletion of Soil Nutrients

Eucalyptus is frequently blamed for its adverse ecological effects in contribution to depletion of soil nutrients. However, the fact is that it is impossible to provide a full introduction of Eucalypt's contribution to soils and the nutrient cycle before getting experimental results on the effects of *Eucalyptus* to the soils. A substantial enrichment of nutrients in the *Eucalyptus* litters is reported (George 1978, 1979, 1982; Sharma *et al.,* 1984). Davidson (1973) reported that *Eucalyptus* can accumulate nutrients in top soil from the deeper horizons through nutrient pumping mechanism.

Aryal *et al.,* (1999) studied the effect of mixed planting of *Eucalyptus camaldulensis* and *Albizia procera* on the soil fertility compared to their mono-plantation in Bangladesh. It wasfound that both the species performed well in mixed condition compared to the mono-plantations. Soil in mixed plantation showed better nutrient contents compared to that in single plantations. The authors suggested mixed plantation for improving soil properties. However, based on propaganda excluding a high yielding species from plantation program would not be a wise decision for any government while doing large scale mono-plantation with Eucalypt will also be a symbol of unwise vision.

Depletion of Ground Gegetation

Study on the undergrowth of *Eucalyptus* plantations in comparison with some non-eucalypts (*Acacia*, chapalish, mahgony, mixed plantation) did not reflect any allelopathic effects of eucalypts in Chittagong University Campus and Madhupur sal forest area (Hossain *et al.*, 1998). Undergrowth vegetation however, depends on the previous vegetation and cultural practices of the plantation management. Increase or decrease of biodiversity in Eucalypt plantation is a controversial issue, and this is also applicable for any other plantation species, as the plantations starts with slash and burning of sites that accelerates the erosion of genetic resources. However, occasionally nesting and honey comb are seen in Eucalypt plantations. The number and oven-dry weight of ground vegetation in some eucalypt and non-eucalypt plantations in Bangladesh showed that eucalypt plantations support luxurious ground vegetation in comparison to other species (Table 7).

Table **7**. The number of undergrowth species and oven dry weight (kg/ha) in different *E. camaldulensis* plantations at Madhupur sal forest area

Plantation species	Plantation year	Age (year)	No of species represents	Oven-dry weight (kg ha^{-1})
Eucalyptus camaldulensis	1978	16	18	398
E. camaldulensis	1982	12	16	305
Acacia auriculiformis	1985	9	18	439
E. camaldulensis	1988	6	19	617
E. camaldulensis	1989	5	9	189
Cassia siamea	1989	5	15	275
Xylia dolabriformis	1989	5	18	395

Allelopathic Effects of Eucalypts

All species of *Eucalyptus* have foliar oil glands that are rich in essential oils, principally terpeneoids; typically 1 to 5 percent of the fresh weight is essential oils (Baker and Smith, 1920; Guenther, 1950). The leaves contain diverse phenolic compounds (Hillis, 1967; Hillis and Brown, 1984). Several researchers (Ahmed *et al.*, 1984; Igoanugo 1986, 1987; Bowman and Kirkaptric, 1986 and Lovett *et al.*, 1989) have contributed to studies of allelopathy in *Eucalyptus* species. From an experiment in plantation mixed stands of *Eucalyptus citridora*, *E. camaldulensis*, and *E. grandifolia* in Nigeria, Igoanugo (1988) found that beans can be incompatible with *Eucalyptus*, while maize and sorghum may be compatible with eucalypts for agro-silvicultural practices. May and Ash (1990) noted that various *Eucalyptus* species could yield allelopathic chemicals that may be effective in suppressing under-story vegetation.

Allelopathic implications of *Eucalyptus* on other crops

Considering the issues and debate of allelopathic effects of Eucalypts on associate crops, a series of experiments were carried out in the laboratory and nursery of the Institute of Forestry and Environmental Sciences, Chittagong University to assess and confirm the allelopathic effects of *Eucalyptus camaldulensis* on agricultural crops and forest crops (Ahmed *et al.*, 2004). The series of experiments along with their outcomes was compared with control treatments (Ahmed *et al.*, 2007a; 2008).

In all the experiments, allelopathic effects of eucalypts were seen but the effects were diminished in field conditions rather than in controlled laboratory and nursery trials. Receptor crops also respond variably which may conclude that the effect in field conditions depends on many environmental factors.

Social Implications of Planting Eucalypts in Bangladesh

The future of eucalypts in Bangladesh depends on the acceptability of the species in society among different groups of people. To indicate the degree of acceptability, it is relevant to understand how people react with participatory forestry practices especially in woodlot and agroforestry plantations, where eucalypts are a major component of the systems. Peoples' participation is so far, encouraging in such plantation activity. In a social study, it was found that the average participants in woodlot and agroforestry plantations are about one hectare per family and peoples' participation is increasing day by day. In

Northern Bangladesh, agroforestry practice has got momentum with mass people's active participation (Bhuiyan, 1995; Ahmed, 2001).

Social surveys can be an indicator of social acceptance of eucalypts. Chowdhury (1993) interviewed people living in and near the forest and plantation areas to understand their preference in choosing species. Among the interviewee, 80% favoured short rotation species, 15% favoured combination of short and medium rotation species, whereas less than 2% respondents favoured long rotation species; the rest did not have any choice or they did not understand about the choice. However, none mentioned fuelwood as the first priority but the majority advocated for cash returns. It was found that the majority prefer *E. camaldulensis* and *A. auriculiformis* for immediate returns from plantations. These species are significantly contributing to the forest products in the society.

In Bangladesh trees are planted around homesteads as a part of whole farm systems to produce food, fodder, fuel, timber and organic matter and supports other functions like wind break and shade. Agroforestry practices in both encroached forestland and homestead areas have, therefore, emerged as a pressing national land use, demanding for tree production along with crop and other areas (Bhuiya *et al.,* 2001). In the present context of Bangladesh, agroforestry practices are appropriate for long-term benefits. A unique combination of different species of fruits, timber and biomass yielding trees can generate high amount of earnings for the farmers of Bangladesh (Abedin *et al.,* 1990; Chowdhury and Sattar, 1993). In both tropical and sub-tropical countries, *Eucalyptus* as an agroforestry component tree has been used for a long time. Not only in Bangladesh, are Eucalypts popularly grown in India and in China.

People's Attitude about Eucalypts in Sitakund Upazila

It was observed that *Eucalyptus* species have been extensively planted in the homesteads, roadsides, fallow lands and agricultural fields of Sitakunda upazilla, Chittagong (Ahmed *et al.*, 2007b), and a survey with the growers support the planting of eucalypts because of the need of less care and management of the crops and early return in comparison to other crops.

Mono-plantation of Eucalyptus

Mono-plantation of *Eucalyptus* species were raised on the homestead fallow lands. 100 % of the respondents informed that it is the abandoned part of the homestead where water logged exists for long time. But, the site is not harmful for *Eucalyptus* trees as the species are growing well.

Mixed Homestead Plantations including Eucalypts

Eucalyptus was seen randomly growing with other species in home gardens in the study area of Sitakunda upazilla, Chittagong. The result showed that 67% of the respondents planted it in the border of the homestead, while 18% planted it with other species in the bunds of the ponds and remaining 12 % of the respondents planted it in a mixed plantation with other species.

Effect of Eucalyptus on Associated Crops

Eucalyptus was raised as an agroforestry component in agricultural field and other fallow lands with an aim of getting more economic return. The main agricultural crops grown were bean and rice. Most farmers reported the depressing effect of *Eucalyptus* on rice yield. However, there was variation of its effect with ages as they observed (Table 8). Production of paddy progressively declined with the increasing age of *Eucalyptus* plantations. Plants of above 10-year old had the most adverse effect on the yield as it caused almost 15% reductions on an average under its canopy. The farmers also opined that this is also applicable for other tree species; even the situation is severe with *Albizia saman* (rain tree) because of its wide spreading canopy.

Table 8. Reduction of paddy yield by *Eucalyptus* in agroforestry system as stated by the respondents in the study area

Species with age	Reduction of yield in comparison to control
Eucalyptus (>10 yrs old)	15%
Eucalyptus (7-10 yrs old)	12%
Eucalyptus (5-7 yrs old)	8%
Eucalyptus (<5 yrs old)	negligible

In contrast, plants below 5 years old showed insignificant or very little effect on the crop yield. However, this is a rough estimate made by the farmers and they did not bother for the adverse effect, as they believed that the profit from the plant (Eucalypts) was more than the loss. In regard of bean and eucalyptus association, no negative effect was reported; rather the farmers viewed it as positive as the crops need support. In this case, they need not care for extra maintenance.

Farmers view on Allelopathic Effect of Eucalyptus

Regarding the investigation on allelopathic effect of *Eucalyptus,* most of the farmers (92%) said that they did not know any allelopathic effect of it on other crops. However, they opined that it had suppressive effect caused by shade and root system. The remaining 8% said that it might have poisonous effect, which is insignificant both in the field and homestead.

Reasons of Planting Eucalyptus

The farmers in the study area of Sitakunda upazilla, Chittagong of Sitakunda upazilla, Chittagong favor the planting of eucalyptus for the adaptability of the species as it grows well both in dry and wet sites, followed by its fast growing characteristics. The other reasons were that the species is not palatable, excellent fuelwood productivity, ornamental and less shade casting characteristics of the plant.

Conclusions

Eucalypts are the only species that were introduced in Bangladesh after elimination, provenance and growth trials. Though *Eucalyptus* is conspicuously successful in many countries, some governments, organizations and individuals have raised concerns about alleged adverse impacts of these species. The concerns about the impacts of *Eucalyptus* are depletion of water resources, deterioration of soil and wildlife, allelopathic effects, etc. However, some of the criticisms in Bangladesh have been caused by disappointed expectations rather than by ecological effects. *Eucalyptus* has often been heralded as wonder fast grown tree species which will bring immediate solutions to local wood fuel crisis and reduce erosion problems. When these ambitious expectations are followed by poor plantings, because of wrong species or seed sources or on the wrong species-site matching, than the local peoples or the Forest Department are disappointed with the poor field performances and returns.

Bangladesh has an immense scope and opportunity in extending plantation forests in barren, marginal and degraded forest areas. Whereas, Bangladesh is importing timber from more than 23 countries and the trend is increasing day by day with the hard earning foreign currencies. Huge population in Bangladesh is unemployed and if they are involved in plantation programs in available lands, the environment of the country will improve and the gap between demand and supply of forest produces shall be minimized. The controversies of environmental degradation by planting eucalypts are not strongly supported by scientific findings and professional experiences. Allelopathic effects pronounced in controlled laboratory conditions must not be projected in the fields, since field conditions are regulated by many environmental factors, that dilutes the inhibitory effects of phenolic compounds.

Social survey also supports the planting programs for immediate return from the plantations. However, native species must be given priority for plantation programs, but if there is no suitable alternative to meet the immediate requirements, exotics like eucalypts may be planted in limited areas. Instead of mono-plantation, mix plantations must be given priority, so that multiproduct may be available from the plantations. Mix plantations are able to solve many controversies of environmental issues of mono-plantations.

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State of Forest Genetic Resources Conservation and Management in Bangladesh

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Abstract

Genetic resources including forest genetic resources are among the most valuable assets that a country possesses. Assessment of forest genetic resources provides a basis for planning the conservation, sustainable use and development of forest genetic resources at the national level and contributes to regional and global actions. Preparation of the state of forest genetic resources provides an opportunity to engage and stimulate the interests of wide range of stakeholders to reflect on these immensely valuable resources of the country, on what has been accomplished and what remains to be done and to identify the needs required to achieve their conservation and sustainable use. It is apparent that about 50% of the forest area is covered by trees and only 22.9% of the forest area has more than 70% of tree cover. Large areas of forest have been deforested and degraded owing mainly to such reasons as illegal logging by organized gangsters, organised encroachments and conversion of forest lands for agriculture, industry, construction of roads and homestead purposes. High population pressure of the country and involvement of influential people of the society are liable to impose tremendous threats to government efforts to conserve public forests.

In this paper different forest types in Bangladesh are described . These are tropical wet evergreen forest, tropical semi-evergreen forest, tropical moist deciduous forest, tidal swamp forest, tropical fresh water swamp forest and littoral forest. The main plant species occurring in these forests are noted. Bangladesh possesses a good species diversity of both flora and fauna. Although rich in diversity the population size of most of the species has remarkably declined. High population pressure, clearing of forests, draining and filling up of wetlands, introduction of exotic species, and introduction of improved genotypes, pests and diseases , improper silvicultural techniques and management, and lack of public awareness are some of the major threats to Forest Genetic Resources (FGR). Poverty and the attitude of the people towards exploitation of natural resources as free goods also contribute to the loss of germplasm in the country. It was observed that 2% of labour force of the country is engaged in forestry activities. The paper has identified priority species in the Forest Department plantation program. In conclusion, the study emphasised on the critical need to develop coordinated efforts to conserve and manage FGR.

Key words: Bio-diversity, Conservation, Forest genetic resources, Management

Introduction

Bangladesh is situated in the north – eastern part of South Asia between 20°34′ and 26°38′ north latitude and 88°01′ and 92°41′ east longitude. Having border with India on the west, the north and the north-east and Myanmar on the south-east and the Bay of Bengal on the South, Bangladesh is one of the most populous countries in the globe. About 146.6 million people live within an area of 147.57 thousand km^2 in this country, the density of population per km^2 being 993 (BBS, 2009). Bangladesh has a subtropical monsoon climate with three prominent seasons in the year; summer monsoon and winter. In winter minimum temperature ranges from 7-13^{0}C to a maximum of 24-31^{0}C, while summer temperature various from 36^{0}C to 41^{0}C. The mean annual rainfall ranges from 1400 mm. to 4340 mm. (BBS, 2008) and the monsoon (June to October) accounts for 80% of the total rainfall. Except the hill ranges in the north-east and south - east, majority area of the country is low-lying floodplain.

Forest Genetic Resources can be defined as the economic, scientific of social values of the heritable materials contained within and between species. They are associated with different levels of natural diversity from ecosystem to species, populations, individuals and genes. Conservation of forest genetic resources means managing forest genetic resources for human use to yield the greatest sustainable benefits for present generations, while maintaining their potential to meet the needs and aspirations of future generations (FAO 1993).

Genetic resources including forest genetic resources are among the most valuable assets that a country possesses. Assessment of forest genetic resources provides a basis for planning the conservation, sustainable use and development of forest genetic resources at the national level and contributes to regional and global actions. Preparation of the state of forest genetic resources provides an opportunity to engage and stimulate the interests of wide range of stakeholders to reflect on these immensely valuable resources of the country, on what has been accomplished and what remains to be done and to identify the needs required to achieve their conservation and sustainable use. Hence it is necessary to carefully and comprehensively assess

- the state of forest genetic resources in the country and their role in production systems, including associated bio-diversity and the factors driving changes;
- the current contribution of genetic resources in forest development and food and agriculture;
- how the contribution of forest genetic resources to sustainable forest development and food and agriculture can be enhanced, identifying opportunities and obstacles, as well as strategies to realize the opportunities and overcome those obstacles;
- needs and priorities for capacity building to enable the conservation, sustainable use and development of forest genetic resources.

Forest Resources

Area and Distribution

The total area of Bangladesh is 14.757 million hectares of which 2.25 million hectares are forests which makes up 15.24% of the total land of the country. The forest area includes 1.52 million hectares of government forest managed by the Forest Department and 0.73 million hectares of Unclassified State Forest (USF). The Unclassified State Forests are controlled by the Deputy Commissioners and mainly situated in Chittagong Hill Tracts.

The Forest Department managed forests may be classified into Hill Forest, Natural Mangrove Forest, Mangrove Plantation Forest and Plain Land Sal Forest (Table 1; Fig.1.).

Table 1. Distribution of Forest Department Managed Forest

Category of Forest	Area (m.ha.)	% with respect ot country's area
Hill Forest	0.67	4.540
Natural Mangrove Forest	0.60	4.066
Mangrove Plantation Forest	0.13	0.881
Plain Land Sal Forest	0.12	0.813
Total	1.52	10.30

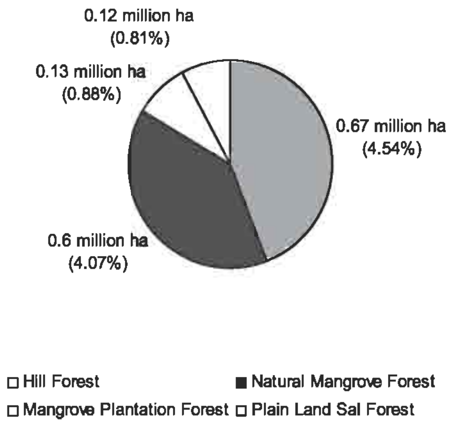

Fig. 1. Distribution of Forest Department Managed Forest

Hill Forests are mainly distributed in the north-eastern districts of Sylhet, Sunamgonj, Moulvi Bazar and Hobigonj and in the south-eastern districts of Chittagong, Cox's Bazar, Rangamati, Khagrachari and Bandarban. The major hill reserve forests are Kassalong (including Mainee Head Water Reserve), Rainkheong, Sitapahar, Sangu, Matamuhuri, Chittagong, Cox'Bazar and Sylhet reserve forests. Sitapahar was the first forest reserve in the hills and was declared as such in 1875. Hill forests make up 44% of the forest department managed forests of the country. The Unclassified State Forests (USF) are under the control of the Deputy Commissioners and are mainly situated in the hill districts of Rangamati, Khagrachari and Bandarban. A small portion of USF is also found in Sylhet. Tea garden is another category which needs mention where a substantial area is covered with forest. Approximately, 2800 hectares of land is covered with forest trees in the tea gardens and these are distributed in the districts of Moulvi Bazar, Sylhet, Hobigonj, Chittagong and Rangamati.

Sundarbans the world's largest contiguous tract of mangrove forest in the delta of the river Ganges and the Bramhaputra lies in the south-western corner of Bangladesh. Two-third portion of Sundarbans falls in Bangladesh and one-third in India. The area of Sundarbans that falls in Bangladesh measures 601,700 hectares situated in the districts of Khulna, Bagerhat and Satkhira. The Sundarbans represents nearly half (40%) of the remaining forests of Bangladesh and is dominated by halophytic tree species.

Forest Department started a coastal afforestation program in early nineteen-sixties and by far about 175,000 hectares of mangrove plantation has been raised which is strected from Cox'Bazar in the SE through Barguna in the SW in the coastline. Coastal Plantation Forests have been established in the districts of Cox's Bazar, Chittagong, Feni, Noakhali, Laximipur, Bhola, Barisal, Patuakhali, Perojpur and Borguna.

The Inland Sal Forests are mainly distributed in the districts of Gazipur, Mymensingh, and Tangail. Small patches of sal forest are also available in the districts of Sherpur, Netrakona, Dinajpur, Rangpur, Naogaon and Comilla. The total area of sal forest is 0.12 million hectares and accounts for 0.81% of total area of the country.

According to a most recent report (Altrell *et al.*, 2007) on National Forest and Tree Resources Assessment (NFA) conducted jointly by Food and Agriculture Organization (FAO), Bangladesh Space Research and Remote Sensing Organization (SPARRSO) and Bangladesh Forest Department during the period from 2005 to 2007 an area of 1.442 million hectares of the country is covered by forest which is 9.77 percent of the total area of the country and distributed (Table 2)

Table 2. Different Land Use Classes (LUC) designated as 'Forest' by NFA (2007) report

Land use classes			**Area (000')ha**
Level-1	**Level-2**	**Level-3**	
Forest 1,442	Natural Forest 1,204	Hill forest	551
		Sal forest	34
		Mangrove Forest	436
		Bamboo or Mixed Bamboo/ broad level forest	184
	Forest plantations 237	Long rotation forest plantation	131
		Short and Medium rotation forest plantation	54
		Mangrove plantation	45
		Rubber plantation	8

National Forest and Tree Resources Assessment 2005-07 report (Altrell *et al.,* 2007) provided some important indicators regarding Tree Cover in the land use class which is traditionally recognized as forest as well as other non-forest land use classes of the country. It shows almost 50% of the area of Bangladesh has some kind of tree cover. But only 2.3% of the area has a very high tree cover (> 70%) and roughly 20% has low tree cover (<5%). From the report it is evident that about 50% of the forest area is covered by trees and only 22.9% of the forest area has more than 70% of tree cover. Large areas of forest have been deforested and degraded owing mainly to such reasons as illegal logging by organized gangsters, organised encroachments and conversion of forest lands for agriculture, industry, construction of roads and homestead purposes. High population pressure of the country and involvement of influential people of the society are liable to impose tremendous threats to government efforts to conserve public forests.

NFA (2007) report also shows that a significant amount of tree resources are also available in villages and in cultivable lands apart from forest. According to this report, almost all the villages have got some tree cover. However, only a very small fraction of the village area has a very high tree cover. It may be predicted on the basis of the report that some 3.35 percent of the country's area is under village tree cover indicating a remarkable improvement than that of the Forestry Master Plan document where only 1.9% of the area of the country was reported to be under village forest. 1.75 percent area of the country were reported to be under the tree cover which is planted in cultivable lands by NFA which was not reflected by any authenticate previous report. Improvement of tree cover in the villages and cultivable lands is the testimony of brilliant success of tree planting movement in the country led by the government with enthusiastic participation of citizen. The area of tree cover by different land uses classes is given in Table 3 and tree cover under different land uses classes in Table 4a and Fig. 2.

Table 3. The area of Bangladesh under Tree Cover by different Land Use Classes (LUC)

Land Use Class	Area under Tree Cover (1000 ha)						
	No Tree Cover	<5%	5-10%	10-30%	30-70%	>70%	Total
Forest	0	68	30	440	574	330	1,442
Cultivated Area	5,552	1,866	460	197	227	25	8,327
Village	40	752	873	675	491	31	2,862
Built-up Area	13	72	19	0	0	0	104
Inland Water	1,910	100	12	0	0	0	2,022
Total	7,515	2,858	1,394	1,312	1,292	386	14,757

Table 4. Tree Cover shown as % of different Land Use Classes (LUC)

Land Use Class	Percentage of Area under Tree Cover						
	No Tree Cover	<5%	5-10%	10-30%	30-70%	>70%	**Total**
Forest	0.0	4.7	2.1	30.5	39.8	22.9	**100**
Cultivated Area	66.7	22.4	5.5	2.4	2.7	0.3	**100**
Village	1.4	26.3	30.5	23.6	17.1	1.1	**100**
Built-up Area	11.6	69.7	18.7	0.0	0.0	0.0	**100**
Inland Water	94.5	4.9	0.6	0.0	0.0	0.0	**100**
Total	51.5	19.5	9.7	8.6	8.3	2.3	**100**

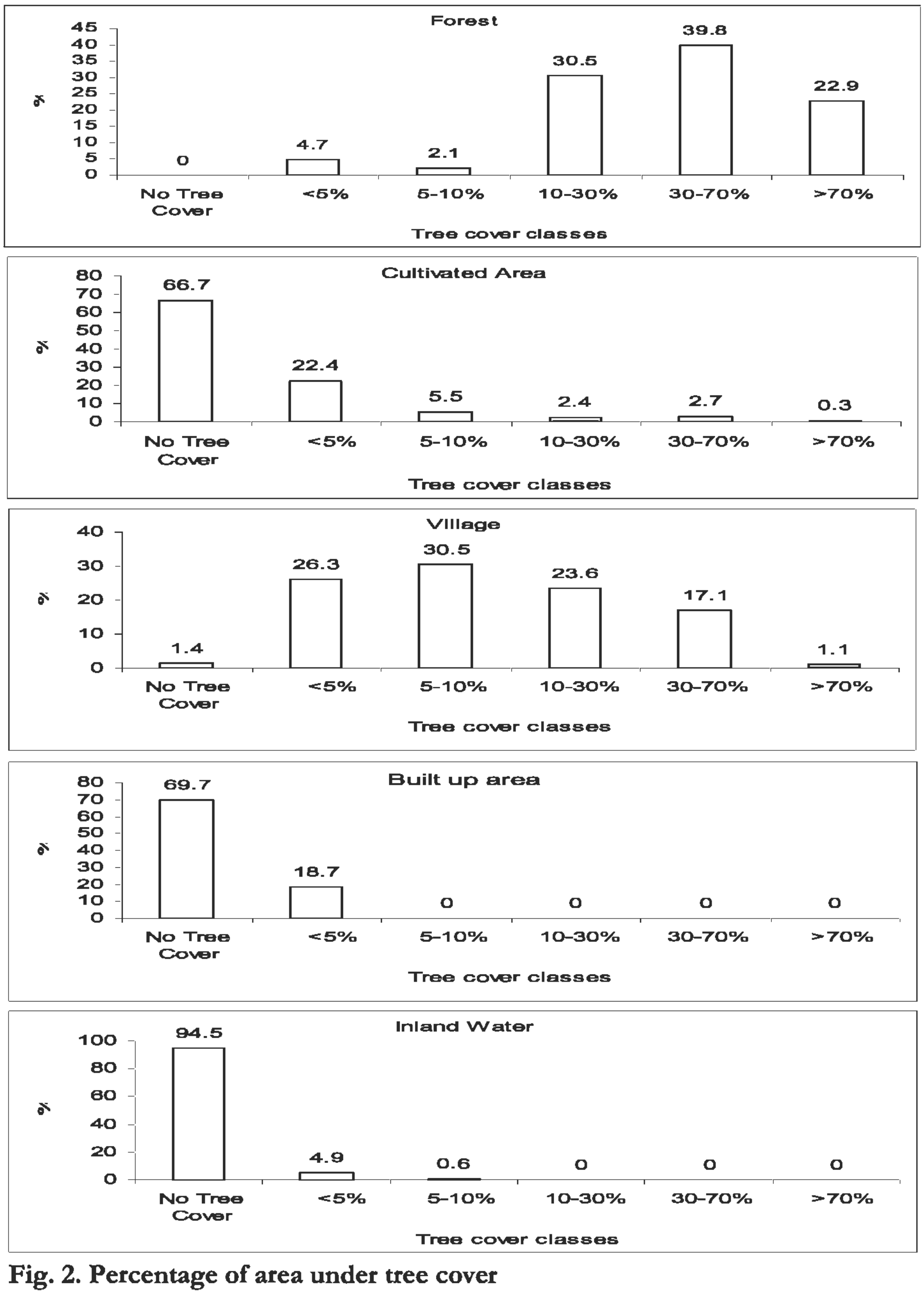

Fig. 2. Percentage of area under tree cover

Forest Types

The world is divided into 5 ecological domains and 20 global ecological zones. Bangladesh falls in two of these zones, namely Tropical Rain Forest (TAr) and Tropical Moist Deciduous Forest (TAwa). Maximum areas of South-eastern Chittagong Division and almost entire of north-eastern Sylhet Division falls in Tropical Rain Forest zone and rest of the country falls in Tropical Moist Deciduous Forest Zone (FAO, 2001). Not necessarily these ecological zones are forests. However, in early twentieth century, based on ecological characters the forests of Bangladesh divided into Tropical Wet Evergreen Forest, Tropical Semi- Evergreen Forest, Tropical Moist Deciduous Forest, Tidal Swamp Forest, Tropical Freshwater Swamp Forest and Littoral Forest. (Champion, 1935)

Tropical Wet-evergreen Forest: This type of forest is characterized by dominance of evergreen plants with rich bio-diversity; although a few semi-evergreen and deciduous species also occur but do not change or alter the evergreen nature of the forest. They occur in the hilly areas of Chittagong, Chittagong Hill Tracts, Cox's Bazar in the SE, and Moulvi Bazar, and Hobigonj in the NE. This type occurs commonly in the deep valley where the water is plentiful. It favours the slopes with a northern aspect where shade is prevalent. (Chawdhuri M. U., 1973) This is a magnificent dense evergreen forest with an irregular top storey of outstanding large and tall trees, characterized by rich flora. About 700 hundred species of flowering plants have been reported to grow in this type of forest (Banglapedia 2011). The canopy is irregular apart from the giant emergent trees projecting well above the main canopy, differentiation into definite canopy layers probably does not exist (Richards, 1952). Dipterocarps are characteristic of the emergent stratum and the *Anacardious Swintonia* (civit) often predominate. *Sterculiace, Anacardiaceae, Artocarpus* and *Syzygium* generally form an important part of the upper canopy, whilst *Lauraceae* and *Cupuliferae* more typical of the temperate forest are often present. *Mesua ferrea* and *Hopea* are generally found though not abundant. Some bamboos occur if the upper canopy is broken, but they are typically absent or inconspicuous in the undisturbed forests where canes and palms are the chief woody monocotyledons. Tree ferns occur but not commonly though epiphytes and ground ferns are abundant. *Rubiaceae* and *Acanthaceae* are frequent among the shrubby undergrowth.

Tropical Semi-evergreen Forest: Generally similar to wet-evergreen forest, the chief feature being the appreciable proportion of the upper canopy formed by the trees of deciduous species that also occur in the moist deciduous forest. Not only are more trees deciduous but the leafless period is longer and the canopy is correspondingly lighter during the period of minimum rainfall (November to March). This in turn is reflected by the somewhat greater prevalence of epiphytes and climbers, as well as bamboos which to some extent replace the canes and palms of the climax evergreen. They have more undergrowth than wet evergreen forests.

These forests occur in the hilly regions of Chittagong, Chittagong Hill Tracts, Cox's Bazar, Sylhet, Sunamgonj, Moulvi Bazar and Hobigonj and also in some parts of Dinajpur district in the NW. This type occupies the greater part of hill forests both on the hilly undulating ground and on the alluvial flats. Over 800 species of flowering plants have been recorded in these forests (Banglapedia, 2011). The emergent trees are mainly deciduous species and attain heights from 45 meters to 60 meters.

In the upper canopy *Dipterocarpus* spp. usually but not always a ssociated with evergreens such as *Mangifera, Lophopetalum, Amoora, Cinnamomum and Syzygium,* but also a fair proportion of deciduous forms such as but also a fair proportion of deciduous forms such as *Tetrameles, Artocarpus, Salmalia, Duabhanga, Garuga, Albizzia, Cedrella* and *Chikrassia.* The lower canopy is largely evergreen with various *Meliacea, Lauraceae, Myrtaceae* and *Cupuliferae.* The stratification of the tree canopy is more prominent in this type in comparison to wet evergreen forest. Bamboos of many species are typical and with them a few dwarf palms such as *Licula.* Monocotyledons such as *Phrynium, Alpina* and *Clinogyne* are locally abundant especially in wet places. *Rubiaceae* and *Acanthaceae* are also usually common in the shrub layer.

Tropical Moist Deciduous Forest : Closed Forest of 25 to 30 meters height, practically all the dominant species being deciduous though usually only briefly so in the drier months or only for a short period at the beginning of the hot weather. There is typically a mixture of several species in the top canopy but *Shorea robusta* (sal) grows markedly gregarious – a feature which has been intensified by biotic influences, hence this forest is commonly known as 'Sal Forest'. There may be a small proportion of evergreens even in the top canopy and their proportion increases in the middle canopy which is developed where the shade is not too dense. Bamboos often occur in this middle canopy whilst canes are rare and restricted to wet sites. Epiphytes are infrequent, but climbers numerous especially in the open. Shrubby undergrowth is present but is greatly influenced in density and composition by burning which is very prevalent in this type and grasses especially *Imperata* may replace the shrubs with repeated burning.

Shorea robusta is the principal species. *Terminalia* (*T. belerica* chiefly) and *Albizzia* are the commonest associates in the top canopy. *Dillenia pentagyna, Laegerstroemia* and *Salmalia, Lannea, Garuga* and *Sterculia* are also commonly present.

Tidal Swamp Forest: Sundarbans Mangrove Forest is the ideal example of this type of forest. Besides Sundarbans of Khulna, there was a small chunk of tidal swamp forest namely Chakoria Sunder bans in Cox's Bazar also. This was leased out and mostly deforested for shrimp culture and salt bed preparation. This type of forest is found on ground which is flooded at every high tide, and is evergreen closed high forest. The height of this forest is moderate, ranges from 5m to 25m. Usually a two storied forest, mainly *Heritiera* and less commonly *Bruguiera* occupying the top canopy. Younger trees of the same species or of other species such as *Ceriops,* with maximum height of only 10m occupy the under wood storey. At higher levels which flooded only at spring tides, there is more varied undergrowth of *Pandanus,* canes, ferns , etc. and if definitely saline, much *Phoenix peludosa.* Nearer the sea with definitely salt water, the *Heritiera* is replaced by the *Rhizophoraceae.* Species are relatively few there and most occur gregariously; all evergreen with simple coriaceous leaves. Grasses are rare. Climbers are usually few but epiphytes fairly numerous (notably the tuberous *Hydnophytum*).

Rhizophoraceae are most typical in the newly deposited mud banks submerged by the tides everyday. A few genera, each usually with several species, belonging to a considerable number of families such as *Sterculiceae (Heritiera), Meliaceae (Carapa), Lythraceae (Sonneratia), Verbenaceae (Avicennia), Euphorbiaceae (Excoecaria), Apocunaceae (Cerbera), Liguminosae (Cynometra)* are specially adapted to this type of unusual conditions. Shrubs are few, *Acanthus* being the commonest, whilst the fern *Achrostichum aureum* is very typical. Palms are limited to a few species notably *Phoenix peludosa* and *Nipa fruticans. Oryza coarctata* a grass species is an early colonizer where the water is fairly fresh. Sundarbans harbours 334 species of trees, shrubs, herbs, and epiphytes.

Tropical Fresh Water Swamp Forest: The determining factor for this type is a permanently moist soil, almost always subject to flooding during the rainy season. Swamp forest is adapted to monsoon flooding for three to four months, to depths 0.5 to 2.5 metres. The soil is typically deep and rich in humus and is usually fine textured. A fully developed canopy with mature trees standing 10 to12 meters tall *Barringtonia acutangula* and *Pongamia piñata* occur in varying proportions to form this vegetation type. *Crataeva nurvala, Trewia nudiflora* are frequently present, while *Salix tetrasperma* is rarely visible. These trees mostly produce their seeds in monsoon, and are dispersed through water, seedlings grow in great quantities. In addition, woody shrubs such as *Phyllanthus reticulate, Ficus heterophylla, Rosa involucrate* and *Sclepias* climbers are found. In stagnant shallow water, more or less pure consociations of *Typha* occur.

These forests are found mostly in Sylhet, Sunamgonj and Kishoregonj districts. Much of the area which currently remains under monsoon paddy would once have been occupied by swamp forest as well as reed lands and other aquatic vegetation. Remnant of swamp forest are now restricted to sloping away from village highlands down towards the haors helping to homesteads from wave erosion, and some recently replanted areas. These patches vary from a few plants to several hectares of more than a thousand trees. Depending on local conditions particularly the extent of human disturbance, the luxuriance of the vegetation varies, from sparse low trees with undergrowth grasses, as at Ranguchi and Rupnagar at *Tanguar Haor*, to dense close canopy with poor undergrowth, as was at *Pashua Beel* in *Gurmar Haor*, Tahirpur, Sunamgonj district.

Littoral Forest: This type of forest is best represented along the eastern shore of Bay of Bengal south of Chittagong and Cox's Bazar districts. Restricted development may be observed on sandy beaches on the seaward edge of Sundarbans and Patuakhali district. The determining factors are a loose sandy soil and full exposure to sea breezes, often with salt spray, depositing more soil whilst blowing some away. The soil is continuously wet below the surface; its lime content is quite high with shell fragments.
The vegetation is very sparse currently. *Casuarina equisetiolia* is the main species and occpies the top canopy having maximum height of 30 metres. *Pongamia pinata, Callophyllum inophyllum, Trewia nudiflora Terminalia catappa, Tamarix dioica, Erythrina variegata and Barringtonia* are the tree associates of *Casuarina. Pendanus foetidus, Vitex negundo, Hibiscus tiliaceaceus, Thespesia populina, Dolichandrone spathecea, Ixora arborea, Acanthus ilicifolius* are the important shrubs. *Ipomea pescaprae, Crinum spp* occur as trailing herbs. Grasses like *Cynodon dactylon, Saccharum spontaneum,* and *Oryza coarctata* also found in this type of forest.

Role of Forest in the Economy
Forest sub-sector contributed 81,660 million Taka (Equivalent to1,166.57 million US dollars) to the GDP in the year 2008- 09 which was1.75% of the GDP of Bangladesh. The growth of GDP in forest sub-sector exceeded 5% every year in previous five years (BBS, 2009). Labour force to the extent of 2% of the country is employed in forestry activities.

Forest Genetic Resources

Genetic Diversity
It is concerned with the variation in genes within a particular species and/ or between species. Genetic diversity occurs due to variability of genetic constitution within the species or between the species. Cross breeding also helps in occurring genetic diversity. Genes determines the ability of an organism to survive in a particular habitat under special conditions. They also increase the ability of species to with changing environment.
Comprehensive information on forest genetic resources (FGR) is not available in the country. Information on population diversity of species in terms of (i) chromosome numbers, (ii) morphological variation, (iii) flowering and seed production habit, (iv) flowering time and nature, and (v) seed morphology and viability etc. are available for a few agricultural species only. Forest species are neglected in this respect.

Species Diversity of Flora in Bangladesh

Bangladesh possesses a good species diversity of both flora and fauna. The tropical semi-evergreen forest is the richest in terms of species diversity. Although rich in diversity the population size of most of the species has remarkably declined. David Prain (1887-1944) was the pioneer to make a comprehensive study of flora of the then Bengal, Assam and Orissa and published his famous compilation 'Bengal Plants' in 1903. In this book he described about 2,700 species of angiosperm. Later it has been estimated by scientists that the total number of angiosperm species in Bangladesh would be nearly 5,000. Recently (2007) Encyclopaedia of Flora and Fauna of Bangladesh has been published. In this compilation it has been reported that there are a total of 3,611 species of angiosperms species available in Bangladesh. Out of which 2,623 species are dicotyledons belong to 158 families and 988 are monocotyledons under 41 families. These include indigenous as well as exotic species, either naturalized or commonly planted for economic or aesthetic purpose. D. K. Das and M. K. Alam (2001) documented 337 tree species of flowering plants, whether indigenous or introduced and naturalized in Bangladesh in their book *Trees of Bangladesh.* There are only 7 species of Gymnosperms reported to grow in the country but only five of them are found in the wild, and these are *Cycus pectinata*, *Podocarpus nerifolia, Gnetum latifolium* var. *funiculare, G. montanum,* and *G. oblongum.* Plant species in various groups are presented in Table 4.

Table 4. Number of Species in Various Groups of Plants

Plant group	Number of Species		
	World	Sub-continent	Bangladesh
Virus/Bacteria	8,050	850	470
Algae	40,000	7,175	1988+
Fungi	72,000	14,500	275
Lichen	13,500	2,223	*
Bryophytes	14,500	2,500	248
Pteridophytes	10,000	1,200	195
Gymnosperms	650	67	7
Angiosperms	250,000	17,527	3,611

Source: Encyclopaedia of Flora and Fauna of Bangladesh (2007) and Biodiversity National Assessment and Programme of Action (2010). * Published record not available

At least 1,000 species of forest plants are economically important; of these about 400 are considered tree species and about 450 as medicinally important. About 50 tree species and about 100 shrubs and herbs are viewed as commercially important (Banglapedia, 2011). The major forest tree species of the country are shown in appendix 1.

Siddiqui *et al.* (2007) reported that a total of 195 species of Pteridophytes have been identified and described in Bangladesh. However, according to M. K. Pasha (Banglapedia, 2007) there are about 250 species of Pteridophytes are there in Bangladesh, found mostly in the north-eastern hilly forests. *Selaginella,* and *Lycopodium* grows in moist and shady undisturbed places of hill forests. The most common ferns are *Pteris, Dryopteris etc.* grows commonly throughout the country. Tree fern species of *Cyathea gygantea, C. glauca, c. spinosa and Angiopteris evecta* grows in the eastern hilly region of Bangladesh. The tiger fern *Achrosticum aureum* is an integral part of vegetation of the Sundarbans forest.

Diversity of Species in Forest Ecosystems

Hill Forests: The Hill forests are the forests where the tropical wet evergreen forest ecosystem and the tropical semi evergreen forest ecosystem exist. This forests harbour tall canopy of wood trees and undergrowth of rattan, bamboo, medicinal herbs etc. Hossain and Khan (2010) reported that 2,260 species of angiosperm are available in the Chittagong Hill Tracts region. Heining (1925) discussed the annonated checklist of all the plant species known for the Chittagong Collectorate and Hill Tracts. Khan and Afza (1968) furnished the preliminary floristic report on Teknaf forest. Khan *et al.* (1994) reported the keystone species of plants of ecological and socio-economic value in the Teknaf Game Reserve, which comprises of 290 species belonging to 212 genera fewer than 65 families. Hossain *et al.* reported 85 tree species in the reserve forest of Bamu under Cox's Bazar forest division. Similarly, Hossain and Nath (1995) reported 85 tree species from a sample area of 2 ha in Sitapahar reserve block of Chittagong Hill Tracts (South) Forest Division representing 68 genera and 36 families.

Annonated Check List of Woody Flora of Sylhet Forests was prepared by Alam in 1988. In this list 795 species of 96 dicotyledonous families and 22 species of 2 monocotyledonous families has been included. 15 species of bamboos and 7 species of canes comprise monocotyledonous flora.

Moist Deciduous (Sal) Forest Ecosystem: In moist deciduous (sal) forest area, a record of woody taxa includes 260 species under 160 genera comprising of 56 families (Alam, 1995)
Mangrove Forest Ecosystems: The floristic composition of the mangrove forest ecosystem of Bangladesh is very rich in comparison many other mangrove forest of the world. Prain (1903) recorded 334 species of plants belonging to 245 genera under 75 families for the Sunder bans and adjoining areas. Heining (1892) reported 70 species from 34 families for the entire Sunder bans (Bangladesh and India). Chaffey and Sandom (1985) represented a list of 66 species in the Bangladesh Sundarbans from 37 families. *Heritiera fomes* and *Excoecaria agallocha* are the principal species of the forest. *H. fomes* constitutes about 65% of the total merchantable timber.

Diversity of Tree Species in the villages

Villages in Bangladesh are considered as the rich and diverse source of flora and fauna. Alam *et al.* (1996) reported 183 tree species comprising of 136 genera fewer than 48 families in the villages of Bangladesh. NFA 2005-06 report recorded 198 tree species in villages out of a total of 258 tree species in the country. 15 species represents over 80% of the total tree volume in the villages. The 4 most common species (*Cocos nucifera, Samanea saman, Mangifera indica* and *Areca catechu*) represent 50% of the gross volume in villages (Altrell *et al.,* 2007)

Forest Growing Stock

In Bangladesh the average gross volume of forest growing stock is 14 m^3 per ha. And the average commercial volume is 10 m^3 per ha. Forest is the Land Use Class (LUC) with the highest gross volume per ha. Of 48.3 m^3 and commercial volume of 29.7 m^3 followed by villages 36.1m^3 and 28.2 m^3 respectively.

Table 5. Total Gross and Commercial Volume of Growing Stock by LUC's (million m^3)

	Forest	Cultivated Land	Villages	Built-up Area	Inland Water	Total
Gross Volume	70	36	103	2.4	1.0	212
Commercial Volume	43	24	81	1.8	0.6	150

The total gross volume of forest growing stock in Bangladesh is 212 million m^3 and the total commercial is 150 million m^3 (Table5) .Almost 50% of the total gross volume can be found in the villages. Almost one third of the gross volume and less than 30% of the commercial volume is found in the forest. Out of the total gross volume 1/3rd can be found in the hill forests, 1/3rd in the bamboo forest and almost 1/3rd in the mangrove forest. Out of the total commercial volume 30% can be found in the in hill forests, almost 30% in bamboo forest and almost 40% in the mangrove forest. Plantations constitute only 3% commercial volume of the forest (NFA 2007).

Table 6. Total Gross and Commercial Volume of Growing Stock by Forest LUC's (million m^3)

	Hill Forest	Mangrove Forest	Bamboo Forest	Long Rot. Plantation	Short Rot. Plantation
Gross Volume	23	21	23	1.4	0.5
Commercial Volume	12	16	13	0.8	0.3

Bamboo forest has the highest gross and commercial volume per ha (Table 6, Table 7). Mangrove forest and Hill forest have significantly lower gross and commercial volume per hectare. The plantations in general have low tree volumes

Table 7. Average Gross and Commercial Volume per ha. of Growing Stock by Forest LUC's (million m³)

	Hill Forest	Mangrove Forest	Bamboo Forest	Long Rot. Plantation	Short Rot. Plantation
Gross Volume per ha.	42.2	48.0	127.6	11.1	9.7
Commercial Volume per ha.	21.8	37.7	72.2	6.4	6.3

Management of Forest

Hill Forests used to be managed under clear felling of naturally growing trees followed by artificial regeneration with commercially important species with a rotation of 60 years (long rotation) and 30 years (short rotation). Although initially this system appeared successful in creation of plantation in large areas of forest, deleterious effects of the system has been gradually visible and manifested in several ways such as, heavy erosion of soil, loss of productivity of the site, inadequate growth of trees in the plantation, serious and irrevocable loss of biodiversity and forest genetic resources, etc. This management system had been continued until a moratorium was imposed on the felling of trees in the natural forest by the government in1989. The bamboo growing in the hill forest either as pure stand or as under storey are managed under the culm selection system with a felling cycle of 3 to 4 years. The tidal forests had been managed under selection system followed by natural regeneration with a felling cycle of 20 years. This management system has al so been suspended. However, harvesting of non timber forest product gol pata (*Nypa fruticans)* is continuing. The inland moist deciduous (sal) forest had been managed under coppice system with a rotation of 25 years. Areas where *Shorea robusta* trees was comparatively less had been managed under clear felling followed by artificial regeneration system mostly with sal and other suitable species. All forests mentioned above had been managed as per prescription of the management plans. Apart from social forestry sites (mostly outside the forest) felling of trees from the forest are not the usual official practice now a days. Plantations in most of the occasions are currently being created in the forest in participatory method by involving local people. A considerable portion (261,891.50 ha.) of government managed forest has been declared and managed as protected areas in order to conserve flora and fauna.

NFA (2007) report shows that 46% of the country's total forests are under "Formal management plan" and 50% are under "Traditional management plan" (Table 8). Of the different forest types only Mangrove forest is totally covered by a "Formal management plan". Most of the areas in Hill forest and bamboo forest or mixed bamboo/ broad-leaved forest are under "Traditional management plan".

Table 8. Forest area by type of management and by forest LUCs (1,000 ha)

Forest type	Formal	Traditional	Not Known	Total
Hill Forest	63	453	35	551
Mangrove Forest	436	0	0	436
Bamboo Forest	7	162	14	184
Long Rotation Pltn	104	27	0	131
Short Rotation Pltn.	37	14	3	54
Mangrove Pltn.	0	45	0	45
Forest	648	700	52	1,400
Forest (%)	46%	50%	4%	100%

Identification of Threats

Forests in Bangladesh are declining at an alarming rate. Some species are disappearing fast and are considered threatened. A total of 19 tree species and 9 rattan species need immediate conservation measures (Khan, 1996). The ongoing loss of germplasm is a threat to FGR. High population pressure, clearing of forests, draining and filling up of wetlands, introduction of exotic species, introduction of improved genotypes, pests and diseases, improper silvicultural techniques and management, and lack of public awareness are some of the major threats to FGR. Poverty and the attitude of the people towards exploitation of natural resources as free goods also contribute to the loss of germplasm in the country.

The destruction of forest by shifting cultivation is another problem in Bangladesh. The forests are cut and cultivated for a short tome only, and when the residual nutrieants in the soil are leached as a result of erosion removing the top soil, the shifting cultivators move to some other places.

The country has four wild gymnosperms, viz., *Cycas pectinata, Gnetum scandens, G. funiculare* and *Podocarpus nerifolia. C. pectinata* is regionally threatened and the two *Gnetum* species have become very rare while the population of *P. nerifolia* are much depleted. Immediate appropriate conservation measures are needed to protect these species in the country. Khan (1996) reported that the number of plant species threatened in the country is 45. Among mammals, birds, reptiles and amphibians 15 species have become extinct and 33 species are endangered. According to the Government of Bangladesh (GOB,1992), there are 27 threatened and 39 endangered species of wildlife in Bangladesh at present.

Past and Present Activities in Conservation, Utilization and Management of FGR

Establishment of forest plantations in Bangladesh started in 1871 with teak *(Tectona grandis)* using seeds brought from Myanmar. Since then plantation forestry became a part of the overall clear felling silvicultural system. Teak was the main species planted because of its high value. Other species such as *Gmelina arborea, Artocarpus integrifolias, Dipterocarpus turbinatus, Swetenia mehagini, Lagerstroemia speciosa, Toona ciliate, Artocarpus chaplasha, Xylia kerri,* and *Syzygium grande* were introduced later. Most of the plantations were monocultures established with the assistance of shifting cultivators through taungia system. Since the plantations were established through clear felling followed by artificial regeneration, there was a severe loss of native vegetation. Moreover, with the development of mechanized logging for commercial purposes, the shifting cultivators could not cope with the extensive area cleared, which resulted in a rapid loss of FGR. The above mentioned species used for plantation establishment were slow growing and long rotation species. Plantations with these species were unable to meet the growing needs of the rapidly increasing population.

In 1974, the Forest Department (FD) began to establish plantations with fast growing species such as *Gmelina arborea, Albizia falcataria, Anthocephalus chinensis.* During this period, plantations of industrial species such as rubber, oil palm mulberry and cashew were established, but the overall results were not encouraging but rubber. Later, exotic species like *Eucalyptus camaldulensis, Acacia auriculiformis, Dalbergia sisoo* were planted with success. Now a days most of the plantations are developed by *Acacia auriculiformis* both within and outside the forest.

Forest plantations cannot be substitute to natural forests. The most important reason is that plantations are severely degraded in genetic resources compared to natural forests. In fact the forests of Bangladesh, particularly the plain land (sal) forest and the hill forests are severely degraded due to indiscriminate exploitation. Therefore, GOB has taken initiatives for the conservation of ecosystems and forest genetic resources in the remaining natural forests.

Conservation Strategies

Major international efforts to conserve FGR began in 1960s with the guidance and support of FAO. Conservation efforts of FGR have been implemented with the following strategies:

In situ conservation

Protected Areas : Protected Area is a common term used to designate the nature conservation areas established for different purposes in different names, such as national park, eco park, safari park, game sanctuary, wildlife sanctuary etc. Growth of population, demand for forest products and conversion of forest land for agriculture, housing, industries and for lot many other uses natural forests have been shrinking and degrading. In this context the environmental function and ecosystem services of natural forests have been increasingly recognized, both internationally and nationally. For the conservation of flora and fauna of natural forests human activities in certain tracts of forests are controlled, these tracts are protected areas. The first protected area of the country was Sundarbans Game Sanctuary established in 1960 at Kotka with an area of 121 square miles. 28 protected areas have so far been organized in the country with a total area of 261,891.5 hectares which covers more than 18% of the government forest and 1.77% of the area of the country. An up to date list of protected areas are given in appendix

Protected Area Management Strategies: With the advent of new millennium pressure on the protected areas have become greater through unauthorised felling of trees, collection of fuel wood and encroachments. It is in this context that in 2003 the Forest Department developed a new vision for Protected Area Management and launched a programme called Nishorgo Programme in 2003 to develop a model for collaboration with local stakeholders in protected areas. With the experience of the programme a new USAID supported project named Integrated Protected Area Co-management (IPAC) project has been taken where a system of co-management with the participation of local people has been undertaken for the conservation and management of protected areas.

World Heritage Site: The Sundarbans has been declared a world heritage site by UNESCO in 1998 for its vast expansion, diverse flora and fauna especially the famous Royal Bengal Tiger and unique array of natural mangrove forest, creeks, meandering streams, rivers and estuaries.

Nature Reserves: The objective of nature reserve is to protect communities and species and to maintain natural processes in order to have ecologically representative examples of the natural environment. In Chittagong Hill tracts tribal people maintain small and discrete chunks of natural forests which they call 'mouza reserves'

Ex situ Conservation

In contrast to *in situ* conservation, *ex situ* conservation includes practices that conserve genetic materials outside the natural habitat of the parent population. *Ex situ* conservation methods and materials include gene banks for seed or pollen as well as clone banks, arboreta, preservation plots, sample plots etc.

- Preservation Plots: BFRI has established five preservation plots at different hill forest areas and 27 at the Sundarbans mangrove forest.
- Clone Banks: BFRI has established two clone banks, one at Hyako, Chittagong (4 ha.) and another at Ukhia, Cox's Bazar (4 ha.). Seven tree species *(Tectona grandis, Gmelina arborea, Bombax ceiba, Dipterocarpus turbinatus, Syzygium grande, Swetenia mahagoni, Albizzia falcateria)* have been preserved in these two locations.
- BFRI Bamboo Arboretum: The BFRI Bambusetum (1.5ha.) has been established at the BFRI campus. This arboretum contains 27 bamboo species *(Bambusa balcooa, B. bambos var. spinosa, B. burmanica, B. cacharensis, B. comillensis, B. jaintiana, B. multiplex, B. nutans, B. polymorpha, B. salarkhanii, B. tulda, B. vulgaris, B ventricosa, Dendrocalamus giganteus, D. hamiltonii, D. longispathus, D. strictus, D. brandisii, Gigantochloa andamanica, G. atroviolacea, G. apus, Melocalamus compactiflorus, Melocanna baccifera, Schizostachyum dullua, Thyrsostachys oliveri, T. regis,* and *T. siamensis)* including six exotic species. One arboretum of medicinal plants,(1 ha.) has been established at the BFRI campus with a collection of 40 species. One cane arboretum (0.5 ha.) of seven species has also been established (Banik,1997). Three arboreta of tree species have been established at the BFRI HQ with 56 species, Keochia Forest Research Station with 56 species and Charaljani Silviculture Research Station with 52 species.

- Seed Storage: There is a National Forest Seed Centre {NFSC) at BFRI; however, the centre does not have any facility for long time storage of seeds.
- Tissue Culture: Tissue culture on forest tree species has been done only at the BFRI tissue culture laboratory. The BFRI has so far developed tissue culture techniques for six tree species and seven bamboo species.
- Botanical Gardens :
    - Mirpur Botanical Garden: area 85 ha, with 255 tree species (28,200 plants), 310 shrub species (8400 plants) and 385 herb species (10,400 plants). The total no. of families of trees, herbs, and shrubs is 114 (Ranjit, 1997).
    - Baldha Garden : area 1.15 ha, 18,000 trees, shrubs and herbs of 820 species and 92 families (Ranjit,1997)

Conservation of provenances

BFRI has established provenance trials of *Acacia mangium, Eucalyptus camaldulensis, E. brassiana, E. tereticornis, E. europhylla, Tectona grandis, Gmelina arborea, Pinus caribaea, P. oocarpa, Albizzia falcataria, Leucaena leucocephala, Melaleuca leucadendra, Gliricidia sepium* and *Populus deltoides* from 68 provenances.

Tree Planting Campaign

After independence , in 1970s government initiated tree planting drive throughout the country which has been gradually earned momentum. This drive has turned into tree planting movement as it is termed now a days with enthusiastic community participation. Started with a weeklong program, tree planting campaign are currently observed for three months every year. This campaign has a huge positive impact on FGR conservation and management.

Tree Fair

Tree fair, a very unique of its kind, has been observed in the country mainly in govt. initiative since 1994. The main event is arranged in the capital. Tree fairs are also arranged at all divisions and districts every year. At sub district level (upazila)also tree fairs are arranged. Tree fairs are arranged in private initiative, as well. In conservation and management of FGR role of tree fairs cannot be ignored.

Appendices 2-4 provide information on the conservation of important forest species in Bangladesh, their use and threats.

Institutional Framework

Role of different institutions are important for successful achievement of aims and objectives of any program. The Forestry Master Plan considered five interrelated institutions, i.e., policy, legislation, organizational structure, human resource development, research and extension.
Today, the forestry and forest institutions in Bangladesh are judged in much wider context than before. The interrelated and multiple roles of forests are vital for human welfare and sustained socio-economic development.
Since, Bangladesh is a signatory of the Convention on Biological Diversity held in Rio in 1992 and subsequently ratified it on 20 March 1994 the country has certain obligations under the convention.
Forest Department, Bangladesh Forest Research Institute, Bangladesh National Herbarium, Institute of Forestry and Environmental Science under Chittagong University, Department of Forestry and Wood Technology of Khulna University, Department of Forestry in Shahjalal University of Science and Technology, Botany Departments of Universities, Bangladesh Agriculture Research Council, etc., are the institutions involved in conservation, management and research on FGR. Recently Asiatic Society published a comprehensive compilation "Encyclopaedia of Flora and Fauna of Bangladesh" which may serve as baseline document on FGR.

National Forest Policy

In accordance with the National Forest Policy promulgated in October 1994, the following policy objectives are set in order to eliminate any uncertainty regarding the aims of the Government. These objectives have equal priority, since the successful fulfilment of one objective cannot compensate for the failure of another. The policy objectives are:

- To meet the basic needs of the present and future generations and also to ensure greater contribution of the forestry sector in the economic development, about 20% of the total area of the country will be afforested. Fallow lands, lands not useful for the purposes of the agriculture, hinterlands and in other possible areas, Government sponsored afforestation programs will be implemented.
- By creating employment opportunities, strengthening the rural and national economy, the scope for poverty alleviation and trees and forest based rural development sectors will be extended and consolidated.
- Biodiversity of the existing degraded forests will be enriched by conserving the remaining natural habitats of birds and other animals.
- Agriculture sector will be strengthened by extending assistance to the sectors related with forest development, especially by conserving the land and the water resources.
- National responsibilities and commitments will be fulfilled by implementing various international efforts and agreements ratified by the government relating to global warming, desertification and control of trade and commerce of wild birds and animals.
- Through the participation of the local people, illegal occupation of the forestlands, illegal tree felling and hunting of wild animals will be prevented.
- Effective use and utilization of the forest goods at various stages of processing will be encouraged; and
- Implementation of the afforestation programs – on both public and private lands will be provided with encouragement and assistance.

List of national priority species

The following species are the priority species in the Forest Department plantation program:

Long rotation plantation species

Tectona grandis, Dipterocarpus turbinatus, Syzygium grande, Swietenia macrophylla, Chukrasia tabularis, Michelia champaca, Hopea odorata, Xylia kerrii, Lagerstroemia flos-reginae, Shorea robusta and *Toona ciliata*

Medium rotation species

In addition to the long rotation plantation species *Pinus caribaea, Albizia falcataria, Bombax ceiba, Gmelina arborea, Anthocephalus chinensis and Eucalyptus camaldulensis, E. tereticornis, Dalbergia sissoo, Azadirachta indica, Samanea saman, Bombax ceiba, Acacia nilotica* and *A. catechu*

Short rotation species

Acacia auriculiformis, Acacia mangium, Eucalyptus camaldulensis, Melia azadirachta, Albizia chinensis, Leucaena leucocephala, Trewia nudiflora and Casuarina equisetifolia

Village groves

Artocarpus heterophyllus, Mangifera indica, Aegle mermelos, Litchi chinensis, Psidium guajava, Ziziphus spp., Syzygium, Albizia, Barringtonia, Eucalyptus, Erythea, Ficus, Albizia fuman, Anthocephalus, Tamarindus indica, Bombax ceiba, Swietenia macrophylla, Alstonia scholaris, Cocos nucifera, palmyra palm and bamboo.

On marginal lands such as roadsides

Tectona grandis, Mangifera indices, Artocarpus heterophyllus, Dalbergia sissoo, Butea frondosa, Polyanthina longifolia, Eucalyptus camaldulensis, Acacia auriculiformis, Swietenia, Albizia, Samanea, Syzygium and *Casuarina equisetifolia*

Multipurpose tree species for different zones

Hill zone

Albizia lebbeck, A. procera, Phyllanthus emblica, Eucalyptus camaldulensis, Elaeocarpus robusta, Artocarpus heterophyllus, Acacia auriculiformis and rattans.

Coastal zone

Casuarina equisetifolia, Albizia lebbeck, Acacia procera, S. grandiflora, Cocos nucifera, Phonek sylvestria and *Erythrina indica.*

Mangrove

Heritiera fomes, Avicennia sp., Bruguiera gymnorhiza, Ceriops decandra, Rhizophora mucronata and Sonneratia apetala

Research on FGR

The BFRI conducts research under 12 programme areas in forest management aspects, apart from 6 program areas on utilization of forest resources. Each year the institute undertakes a number of priority research studies following the suggestions of the Bangladesh Forest Department, Bangladesh Forest Industries Development Corporation, Bangladesh Chemical Industries Corporation, Bangladesh TEA Board, Rural Electrification Board, other wood based industries, private owners and non-government organizations. The selected studies are approved by an Advisory Committee.

The BFRI conducts a number of studies on FGR conservation and management under the following programme areas: (i) Biodiversity and its conservation, (ii) Production of quality planting materials, (iii) Plantation techniques and forest management, (iv) Breeding and improvement, (v) Social and non-timber forest products, (vi) Social and farming system research and (vi) Pest and diseases. Seed Orchard Division, Silviculture Research Division, Silviculture Genetics Division, Mangrove Silviculture Division, Plantation Trial Unit Division, Minor Forest Product Division, Soil Science Division, Forest Protection Division and Farming System Research Component are involved in conducting these studies.

A total of 44 technologies have been developed and out of these 28 technologies have been transferred to end users. A total of 16 technologies on conservation and management of FGR have been developed and transferred to different end-users. Training programme based on these new technologies is arranged as and when required.

Other organizations are also involved and have been significantly contributing in the field of FGR conservation and management research. Institute of Forestry and Environmental Sciences of Chittagong University are conducting research on biodiversity conservation and management, clonal propagation of important forest tree species, agro forestry, medicinal plants etc.

Conclusion and Recommendations

The natural forests of Bangladesh have been seriously degraded, resulting in serious genetic erosion of FGR. There is a critical need to develop coordinated efforts to conserve and manage FGR. Effective and hopeful efforts have been undertaken into conservation activities, but national and international financial and technical assistance are needed to bring about success. The following recommendations have been put forward for the conservation and sustainable utilization of FGR in Bangladesh:

- Development of a database on the present status of flora and fauna in different ecosystems of Bangladesh. National Forest and Tree Resources Assessment 2005-2007 was a milestone job, could be successfully conducted and completed with financial and technical assistance of FAO as well as sincere and arduous effort of the Forest Department Officials. In that survey assessment of FGR was not adequately addressed. So, in order to have high quality up to date information on FGR a comprehensive survey is required. Technical and financial assistance from FAO or any other organization is necessary to undertake such survey;

- *In situ* and *ex situ* conservation programme of FGR should be significantly expanded;
- Community based resource conservation needs to be emphasized;
- Improved silvicultural methods should be applied in the management of natural and plantation forest;
- The method of clear-felling followed by burning and plantation establishment must be stopped;
- Silvicultural measures for aided natural regeneration should be followed;
- Enrichment planting should be conducted in low density forest stands with diversified genetic resources collected from natural regeneration in the forest floor;
- Establishment of preservation plots and permanent sample plots in the reserve forest;
- Establishment of gene bank for conservation of FGR;
- Logging in the remaining natural forest must be stopped;
- Creation of diversified job opportunities for hill people through conducive farming system approach which will not be detrimental to FGR conservation;
- Motivation work should be conducted to discourage shifting cultivation as well unscrupulous hill farming;
- Introduction of forest certification system for sustainable forest resource management;
- Education and training to professionals and technicians should be given to equip them with the latest knowledge of forest genetic resource survey, management and conservation;
- Strengthening the international cooperation for FGR conservation;
- Since conservation of FGR is a land based management system, laws regarding transfer and leasing out of forest land should be stringent so that encroachment of forest can be prevented.

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Appendix 1. Value and use of main forest species in Bangladesh

Species name	Value code	Present, future or potential use											
		ti	po	wo	nw	pu	fo	fd	sh	ag	so	am	xx**
1.*Acacia auriculiformis*	1	+		+		+		+	+	+			
2. *A. catechu*	1	+	+	+	+			+					
3. *A. farnesiana*	3			+	+			+					
4. *A. mangium*	1	+		+		+		+		+			pb,v
5. *A. nilotica*	1	+		+	+			+					cw,agi
6.*Acrocarpus fraxinifolius*	3	+											pw
7.*Aegiceras corniculatum*	3			+	+		+						
8. *Albizia chinensis*	1	+				+		+	+				pw
9. *A. lebbeck*	1	+		+			+	+					v
10. *A. lucidor*	3	+		+				+					
11. *A. odoratissima*	2	+		+				+				+	
12. *A. richardiana*	2	+			+		+					+	bb
13. *A. procera*	1	+		+				+					
14. *Alstonia scholaris*	1	+			+	+						+	pc,n
15. *Amoora cucullata*	3		+	+									
16.*Anacardium occidentale*	1	+			+		+						
17.*Anogeissus acuminata*	3	+		+	+							+	agi
18.*Anthocephalus chinensis*	1					+	+					+	
19.*Antidesma ghaesembilla*	3	+					+	+					
20.*Aphanamixis polystachya*	2	+			+								
21. *Aporusa dioica*	3		+		+		+						
22.*Aquilaria agallocha*	2												ab
23. *Artocarpus chama*	1	+				+	+						
24. *A. heterophyllus*	1	+			+		+	+		+		+	
25.*Artocarpus lacucha*	2	+			+		+	+					agi
26. *Avicennia alba*	2			+									pw
27. *Azadirachta indica*	1				+					+		+	
28. *Bambusa sp.*	1			+		+	+	+					pb
29.*Barringtonia acutangula*	2	+		+	+								
30. *Bauhinia purpurea*	3				+		+	+					agi
31. *Bauhinia variegata*	3				+		+	+					
32.*Beilschmiedia pseudomicrocarpa*	3	+											
33. *Berrya cordifolia*	3	+										+	agi,cw
34. *Bischofia javanica*	2	+	+		+			+					agi
35. *Bombax ceiba*	1	+				+	+	+					k
36. *Bridelia retusa*	3		+		+		+	+					

Species name	Value code	Present, future or potential use											
		ti	po	wo	nw	pu	fo	fd	sh	ag	so	am	xx**
37.*Bouea oppositifolia*	3	+					+						agi
38.*Bruguiera gymnorhiza*	2	+	+		+								
39. *B. sexangula*	3	+	+		+								
40. *Buchanania lanzan*	3				+		+						
41. *Butea monosperma*	2	+			+			+					
42.*Callicarpa tomentosa*	3		+	+				+					
43.*Calophyllum inophyllum*	2				+								m,bb, rs
44.*Canarium resiniferum*	3				+								v,pw
45. *Cassia fistula*	2	+			+			+				+	c
46. *C. nodosa*	2	+										+	
47. *C. siamea*	1	+		+				+				+	c
48.*Castanopsis tribuloides*	3	+					+						agi
49.*Casuarina cunninghamiana*	3								+			+	
50. *C. equisetifolia*	1	+		+	+					+		+	bb,m
51. *Ceiba pentandra*	1	+			+			+					k
52. *Ceriops decandra*	3	+	+		+								
53. *Chukrasia velutina*	1	+								+			
54.*Cinnamomum iners*	3												p
55. *Cordia dichotoma*	3	+		+	+		+	+					
56. *Crateva magna*	3	+			+		+						t,n
57.*Croton oblongifolius*	3	+		+	+								
58.*Crypteronia paniculata*	3												cw,c,rs
59. *Dalbergia sissoo*	1	+			+			+					a,v
60. *Delonix regia*	2	+		+					+			+	
61. *Dillenia indica*	3		+	+	+		+						bb
62. *D. scabrella*	3	+					+						
63.*Diospyros montana*	3	+			+								
64. *D. nigricans*	3		+										
65. *D. peregrina*	3	+			+		+						ts
66. *D. toposia*	3	+					+						
67.*Dipterocarpus alatus*	2												bb,rs
68. *D. turbinatus*	1									+			bb,c
69.*Dolichandrone spathacea*	3											+	
70.*Duabanga grandiflora*	3	+				+							pw,d
71.*Dysoxylum binectariferum*	3	+			+								
72. *D. hamiltonii*	3	+			+		+						
73. *Ehretia serrata*	3	+					+	+					agi

Species name	Value code	Present, future or potential use											
		ti	po	wo	nw	pu	fo	fd	sh	ag	so	am	xx**
74.*Elaeocarpus floribundus*	1	+					+						
75. *E. sphaericus*	3											+	
76. *E. varunna*	3									+			tc
77.*Engelhardtia spicata*	3	+			+								
78.*Erioglossum rubiginosum*	3	+					+						c
79. *Erythrina fusca*	3			+				+	+				
80. *E. variegata*	2			+				+	+				d,v,t
81. *E. fusea*	3												
82. *Eucalyptus alba*	3				+							+	
83. *E. camaldulensis*	1			+			+						c,v,rs,pw
84. *E. brassina*	2			+			+						
85. *E. tereticornis*	2			+			+						
86. *E. urophylla*	2			+			+						
87. *E. citriodora*	2	+			+								c, agi
88.*Excoecaria agallocha*	1					+							
89. *Ficus benghalensis*	1	+		+	+			+					
90. *F. hispida*	2			+			+	+					
91. *F. racemosa*	2	+		+	+		+	+					
92. *F. religiosa*	1			+				+				+	pc
93.*Flacourtia jangomas*	3	+			+		+						
94. *Garcinia cowa*	2	+			+		+						va
95. *Garuga pinnata*	2	+			+	+	+	+	+				
96. *Gliricidia sepium*	2			+				+	+				
97. *Gmelina arborea*	1	+			+	+		+		+			
98. *Grevillea robusta*	3	+											v,d
99. *Grewia tiliaefolia*	3						+						agi,m
99. *Heritiera fomes*	1		+										bb,c
100.*Hevea brasiliensis*	1	+				+							v,r
101.*Holarrhena pubescence*	3	+			+								n
102. *Hopea odorata*	1	+	+		+					+			
103.*Hydnocarpus kurzii*	2				+								
104.*Hymenodictyon orixensis*	2	+			+			+					tc,m
105.*Jacaranda mimosifolia*	3				+							+	
107. *Kandelia candel*	3				+								
108.*Lagerstroemia macrocarpa*	2		+										c,bb
109. *L. speciosa*	1	+	+									+	bb,c
110.*Lannea coromandelica*	3	+			+	+		+					
111.*Leucaena leucocephala*	3			+				+		+			

Species name	Value code	Present, future or potential use											
		ti	po	wo	nw	pu	fo	fd	sh	ag	so	am	xx**
112.*Lithocarpus elegans*	2		+	+									
113. *L. pachyphylla*	3			+									c
114. *Litsea glutinosa*	3	+		+	+								
115. *L. monopetala*	3	+			+			+				+	
116. *Madhuca indica*	3	+			+		+						
117.*Mallotus philippensis*	3				+								
118. *Mangifera indica*	1	+			+		+	+		+			
119.*Melaleuca leucadendra*	3		+	+	+	+	+						rs,bb
120.*Michelia champaca*	1	+			+		+			+		+	
121. *Olea dioica*	3			+									
122.*Oroxylum indicum*	3			+	+		+	+					
123.*Paraserianthes falcataria*	2					+							pw,m
124.*Phyllanthus emblica*	1				+		+			+			
125. *Pinus caribaea*	2					+						+	
126.*Pithecellobium dulce*	2	+		+	+		+	+					
127.*Pongamia pinnata*	2				+		+						
128. *Prosopis juliflora*	3	+		+				+					
129. *Protium serratum*	3						+						c,rs
130.*Pterospermum acerifolium*	2	+			+			+				+	agi
131. *Pterygota alata*	2	+				+	+						
132.*Rhizophora mucronata*	1		+	+	+		+						
133. *Samanea saman*	1	+		+				+				+	
134. *Saraca asoca*	2				+							+	
135. *Schima wallichii*	2			+									c
136.*Schleichera oleosa*	2				+		+						
137.*Sesbania grandiflora*	1			+		+	+	+		+			
138.*Semecarpus anacardium*	3				+		+						
139. *Shorea robusta*	1	+			+								c
140.*Sonneratia apetala*	1			+			+	+					
141. *Sterculia villosa*	2	+			+		+						
142.*Stereospermum suaveolens*	3	+		+									
143.*Swietenia mahagoni*	1	+										+	
144. *Syzygium grandis*	2		+							+			
145.*Tamarindus indica*	1	+		+	+		+	+					
146. *Tamarix dioica*	3			+							+		
147. *Tectona grandis*	1	+			+								c,bb
148.*Terminalia bellirica*	1	+			+		+	+					

Species name	Value code	Present, future or potential use											
		ti	po	wo	nw	pu	fo	fd	sh	ag	so	am	xx**
149. *T. catappa*	2				+		+						
150. *T. chebula*	1				+		+						
151. *Toona ciliata*	1	+											bb
152. *Trema orientalis*	3	+		+				+					
153. *Vatica lanceaefolia*	3				+								rs
154. *Xanthophyllum flavescens*	3	+					+						
155. *Xylia kerrii*	2		+										c
156. *Xylocarpus granatum*	2				+								
157. *Zanthoxylum rhetsa*	3	+			+		+					+	
158. *Ziziphus mauritiana*	1	+		+			+	+					agi

VALUE: 1 = Species of current socioeconomic importance; 2= Species with clear potential of future value; 3 = Species of unknown value given present knowledge and technology
UTILIZATION: ti = timber production; po = posts, poles, roundwood; wo = fuelwood, charcoal; nw = non-wood products (gums, resins, oils, tannins, medicines, dyes, etc.); pu = pulp and paper; fo = food; fd = fodder; sh = shade, shelter; ag = agroforestry systems; so = soil and water conservators; am = amenity, antithetic, ethical values; **xx** other:** v = veneer; pw = plywood; cw = cartwheel; pb = particle board; c = construction work; k = Kapok; irs = railway sleepers; mb = mast of boat; p = planking; t = toys; n = novelties; d = decorative; tc = tea chest; va = varnish; agi = agricultural implements; bb = boat building; pc = packing cages; ab = agar batti; m = match splints and boxes; r = rubber

Appendix 2. Conservation and management of important FGR by eco-geographic zone in Bangladesh

Speciesin ecogeographic (or genecological) zones	Nature reserves, protected areas	*Insitu* conservation stands	Managed forests	Unmanaged forests	Plantations	*Exsitu* conservation stands	Villages, fields, homesteads	Experiment, fields, trials
Hill Forest (Chittagong, Chittagong Hill Tracts, Sylhet):								
Artocarpus chaplasha	+	+	+		+			+
Swintonia floribunda	+	+	+					+
Dipterocarpus turbinatus	+	+	+		+			+
D. pilosus	+							
D. costatus	+							
D. gracilis	+							
Mesua ferrea							+	
Hopea odorata	+	+	+		+		+	+
Syzygium spp.		+	+		+			+
Calophyllum spp.	+							
Palaquium spp.	+							
Chukrasia tabularis	+	+	+		+			+
Ficus spp.	+							
Michelia champaca	+	+			+		+	+
Pterygota alata	+							
Lophopetalum fimbriatum	+							
Amoora spp.	+							
Dysoxylum spp.	+							
Albizia procera	+	+			+		+	+
A. lebbeck	+	+			+		+	+
A. chinensis	+	+			+		+	+
Gmelina arborea	+	+			+		+	+
Alstonia scholaris	+	+						
Toona ciliata	+	+					+	+
Quercus semiserrata	+							
Q. gomeziana	+							
Podocarpus neriloforcis	+							

Cassia fistula	+							
Phyllanthus emblica	+						+	+
Tetrameles nudiflora	+							
Bombax insigne	+							
B. ceiba	+						+	
Duabanga grandiflora	+							
Lithocarpus elegans	+							
Castanopsis tribuloides	+							
Calophyllum polyanthum	+							
Macaranga spp.	+							

Species in ecogeographic (or genecological) zones	Nature reserves, protected areas	*In situ* conservation stands	Managed forests	Unmanaged forests	Plantations	*Ex situ* conservation stands	Villages, fields, homesteads	Experiment, fields, trials
Terminalia bellirica	+							
Pterospermum acerifolium	+							
Diospyros embryopteris	+							
Sterculia villosa	+							
Garuga pinnata	+							
Meliosma pinnata	+							
Callicarpa macrophylla	+							
Vitex glabrata	+							
Saraca indica	+							
Elaeocarpus robustus	+							
Lagerstroemia spp.	+				+			+
Mitragyna parvifolia	+							
Calamus guruba	+				+			+
C. viminalis	+				+			+
C. latifolius	+				+			+
Daemonorops jenkinsanus	+				+			+
Melocanna baccifera	+				+			+
Dendrocalamus longispathus	+							+

Species in ecogeographic (or genecological) zones	Nature reserves, protected areas	*In situ* conservation stands	Managed forests	Unmanaged forests	Plantations	*Ex situ* conservation stands	Villages, fields, homesteads	Experiment, fields, trials
D. hamiltonii	+							+
Neohouzeaua dullooa	+							+
Bambusa tulda	+							+
B. polymorpha	+							+
Melocalamus compactiforus	+							+
Oxytenanthera nigrocialata	+							+
B. vulgaris				+			+	+
Plainland Sal Forest (Comilla, Dhaka, Dinajpur):								
Shorea robusta	+							+
Terminalia bellirica	+							
T. chebula	+							
Miliusa velutina	+							
Albizia procera	+				+			+
Dillenia pentagyna	+				+			+
Lagerstroemia spp.	+							
Garuga spp.	+							
Cassia fistula	+							

Species in ecogeographic (or genecological) zones	Nature reserves, protected areas	*In situ* conservation stands	Managed forests	Unmanaged forests	Plantations	*Ex situ* conservation stands	Villages, fields, homesteads	Experiment, fields, trials
Phyllanthus emblica	+				+			+
Adina cordifolia	+							
Butea monosperma	+							
Careya arborea	+							
Schleichera oleosa	+							
Sterculia spp.	+							
Semecarpus anacardium	+							
Litsea polyantha	+							
Aphanamixis polystachya	+							
Microcos paniculata	+							
Littoral and Swamp Forest								
Casuarina equisetifolia					+			+
Calophyllum inophyllum	+							
Terminalia catappa	+						+	
Erythrina variegata	+							
Barringtonia spp.	+							
Hibiscus tiliaceus	+							
Thespesia populnea	+							
Vitex negundo	+							
Trewia nudiflora	+							
Dolichandrone spathacea	+							
Species in ecogeographic (or genecological) zones	Nature reserves, protected areas	*In situ* conservation stands	Managed forests	Unmanaged forests	Plantations	*Ex situ* conservation stands	Villages, fields, homesteads	Experiment, fields, trials
Mangrove Forest (Sundarban and Coastal Forest):								
Heritiera fomes	+				+			+
Excoecaria agallocha	+				+			+
Sonneratia apetala	+				+			+
Avicennia officinalis	+				+			+
Xylocarpus granatum	+				+			+
Nipa fruticans	+				+			+

+ = Available

Appendix 3. Level and nature of threats to the integrity of species/populations of important tree species (Huq and Banik ,1992; Khan, 1991)

Species in ecogeographic (or genecological) zones	Nature reserves, prot. areas	*In situ* conservation stands	Managed forests	Unmanaged forests	Plantations	*Ex situ* conservation stands	Villages, fields, homesteads	Experiment fields, trials	Degree of threat index
1.*Aglaonema clarkei*	+								
2.*Aldrovanda vesiculosa*	+								
3.*Aquilaria agallocha*	+								
4.*Cirrhopetalum roxburghii*	+								
5.*Cymbopogon osmastonil*	+								
6. *Debregeasia dentata*	+								
7. *Elaeocarpus lucidus*	+								
8. *Hippocratea marcantha*	+								
9. *Homalium schlichil*	+								
10.*Justicia orephylla*	+								
11.*Knema benghalensis*	+								
12. *Limnophila cana (endemic)*	+								
13. *Mantisia spathutala (endemic)*	+								
14. *Marsdenia thyrsiflora*	+								

Species in ecogeographic (or genecological) zones	Nature reserves, prot. areas	*In situ* conservation stands	Managed forests	Unmanaged forests	Plantations	*Ex situ* conservation stands	Villages, fields, homesteads	Experiment fields, trials	Degree of threat index
15. Ophiorrhiza villosa	+								
16. Phrynium imbricum	+								
17. Quercus acuminata	+								
18. Rotala simpliciuscula (endemic)	+								
19. Semecarpus sulepanduriformis (endemic)	+								
20. Sonneratia griffithi	+								
21. Spatholobus listeri (endemic)	+								
22. Tournefortia roxburghii	+								
23. Typhonium listeu (endemic)	+								
24. Vatica scaphula (endemic)	+								
25. Vernonia thomsonii	+								
26. Adina cordifolia	+								
27. Aphanamixis polystachya	+								
28. Bassia latifolia	+								
29. Bauhinia malabarica	+								

Species in ecogeographic (or genecological) zones	Nature reserves, prot. areas	*In situ* conservation stands	Managed forests	Unmanaged forests	Plantations	*Ex situ* conservation stands	Villages, fields, homesteads	Experiment fields, trials	Degree of threat index
30. Castanopsis tribuloides	+								
31. Derris	+								

robusta									
32. *Diospyros cordifolia*	+								
33. *Hydnocarpus kurzii*	+								
34. *Lophopetalum fimbriatum*	+								
35. *Mesua ferrea*	+								
36. *Mitragyna parvifolia*	+								
37. *Podocarpus neriifolius*	+								
38. *Pterospermum acerifolium*	+								
39. *Pterygota alata*	+								
40. *Schleichera oleosa*	+								
41. *Sterculia foetida*	+								
42. *Swintonia floribunda*	+								
43. *Tamarindus indica*	+								

+ = Available

Appendix 4. List of priority species for conservation, improvement or seed procurement, their uses and conservation activities needed

Species	End use				Operations / activities needed								Remarks
	W	NW	FW	O	Exploration & collection		Evaluation		Conservation		Germplasm use		
	1	2	3	4	5	6	7	8	9	10	11	12	
1. *Acacia auriculiformis*	+		+					+		+		PVT	Narrow Genetic Base (NGB)
2. *A. catechu*		+		+					+	+			
3. *A. mangium*	+		+					+		+		PVT	NGB
4. *A. nilotica*	+	+	+	+					+	+			
5. *Albizia chinensis*	+		+										

6. *A. lebbeck*	+												
7. *A. procera*	+												
8. *Alstonia scholaris*				+									
9. *Anacardium occidentale*				+									
10. *Anthocephalus chinensis*	+			+									
11. *Artocarpus heterophyllus*	+		+	+					+				MPTS
12. *Azadirachta indica*	+	+	+	+					+				MPTS
13. *Bombax ceiba*				+									

Species	End use				Operations / activities needed								Remarks
	W	NW	FW	O	Exploration & collection		Evaluation		Conservation		Germplasm use		
	1	2	3	4	5	6	7	8	9	10	11	12	
14. *Cassia siamea*			+										
15. *Casuarina equisetifolia*			+										
16. *Ceiba pentandra*				+									
17. *Chukrasia velutina*	+		+										
18. *Dalbergia sissoo*	+		+	+									NGB
19. *Dipterocarpus turbinatus*	+	+											
20. *Elaeocarpus floribundus*				+									
21. *Eucalyptus alba*	+		+										
22. *E. camaldulensis*	+		+										
23. *E. brassina*	+		+									PVT	NGB
24. *E. tereticornis*	+		+									PVT	NGB
25. *E. urophylla*	+		+									PVT	NGB
26. *E. citriodora*	+		+									PVT	NGB
27. *Excoecaria agallocha*	+		+	+									

Species	End use				Operations / activities needed								Remarks
	W	NW	FW	O	Exploration & collection		Evaluation		Conservation		Germplasm use		
	1	2	3	4	5	6	7	8	9	10	11	12	
28.*Ficus benghalensis*			+	+									
29. *F. religiosa*			+	+									
30.*Gliricidia sepium*			+	+									
31.*Gmelina arborea*	+		+	+									
32.*Heritiera fomes*	+		+										
33.*Hevea brasiliensis*	+	+	+										
34.*Hopea odorata*	+		+										
35. *Hydnocarpus kurzii*			+	+									
36.*Lagerstroemia speciosa*	+		+										
37.*Leucaena leucocephala*			+	+									
38.*Madhuca indica*	+	+	+	+									
39.*Mangifera indica*	+		+	+									
40.*Michelia champaca*	+		+										
41.*Paraserianthes falcataria*	+		+										
42.*Phyllanthus emblica*			+	+									
43. *Pinus caribaea*	+	+	+										
44.*Rhizophora mucronata*	+		+										

Species	End use				Operations / activities needed								Remarks
	W	NW	FW	O	Exploration & collection		Evaluation		Conservation		Germplasm use		
	1	2	3	4	5	6	7	8	9	10	11	12	
45.*Samanea saman*	+		+	+									
46.*Saraca asoca*			+	+									

47. *Sesbania grandiflora*			+	+									
48. *Shorea robusta*	+		+										
49. *Sonneratia apetala*	+		+										
50. *Swietenia mahagoni*	+		+										
51. *Syzygium grande*	+		+										
52. *Tamarindus indica*			+	+									
53. *Tectona grandis*	+												
54. *Terminalia bellirica*	+		+	+									
55. *T. chebula*	+		+	+									
56. *Toona ciliata*	+		+										
57. *Xylia kerrii*	+												
58. *Xylocarpus granatum*	+		+										
59. *Ziziphus mauritiana*			+	+									

End uses: 1 = Industrial wood products (logs, sawtimber, construction wood, plywood, chip and particle board, wood pulp etc.); 2 = Industrial non-wood products (gums, resin, oils, tannins); 3 = Fuelwood, posts, poles (firewood, charcoal, roundwood used on-farm, wood for carving); 4 = Other uses, goods and services (food, medicinal use, fodder, land stabilization/amelioration, shade, shelter, environmental values).
Exploration & collection: 5 = Biological information (natural distribution, taxonomy, genecology, phenology etc.); **6** = Collection of germplasm for evaluation
Evaluation: 7 = *In situ* (population studies); 8 = *Ex situ* (provenance and progeny tests)
Conservation: 9 = *In situ*; 10 = *Ex situ*
Reproductive use/germplasm use: 11 = Semi-bulk/bulk seedlots, reproductive materials;
12 = Selection and improvement
Remarks (13): PVT = provenance trials; E = endangered at species or provenance level; PGT = progeny trials; MPTS = multi-purpose tree species; CLT = clonal trials; SO = seed orchard; NGB = narrow genetic base

Forest Cover Degradation at Khadimnagar National Park, Sylhet

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Abstract

Forest cover changes over time. Monitoring cover change is essential to provide forest managers with information they need to assess forest health and productivity, formulate policy decision, and generate management plans. This study maps the forest cover of Khadimnagar National Park (KNP) belonging to Sylhet Forest Division and estimates forest change over a period of 22 years (1988 to 2010) by using Landsat TM imageries and other GIS data. Supervised classification of imageries and Normalized Difference Vegetation Index (NDVI) approaches were applied to classify the imageries to produce three cover classes; namely dense forest, medium dense forest and bare land. The change map was produced by differencing classified imageries of 1988 and 2010 before image and after image respectively in ERDAS IMAGINE. Error matrix and kappa statistics were used to assess the accuracy of the produced maps. Results show that, overall map accuracies resulted from supervised classification of 1988 and 2010 imageries were 84.6% (Kappa 0.75) and 87.5% (Kappa 0.80) respectively. Forest cover statistics resulted from supervised classification shows that dense forest and bare land have decreased from 525.96 ha (66.93%) to 416.52 ha (58.73%) and 104.94 ha (13.35%) to 7.65 ha (0.97%) respectively. Medium dense forest has increased from 154.98 ha (19.72%) to 316.53 ha (40.27%). Forest cover change statistics resulted from NDVI classification shows that dense forest has decreased from 524.88 ha (66.79%) to 420.93 ha (53.57%) while medium dense forest has increased from 252.81 ha (32.17%) to 356.23 ha (45.33%). Amount of bare land remains unchanged. Forest change statistics resulted from both supervised and NDVI classification show similar trend for dense and medium dense forests, i.e., decrease of dense forest and increase of medium dense forest, indicates dense forest has been converted to medium dense forest. Illicit felling, encroachment, settlement close to forest caused the dense forest to decline while short and long rotation plantation raised in different periods caused the medium dense forest to increase. Protective measures should be undertaken to check further degradation of forest at KNP.

Keywords: Forest cover, Landsat TM, supervised classification, NDVI, GIS, change statistics, error matrix

Introduction

Change detection and monitoring of forest cover is essential for forest management (Singh, 1989). Accurate information on forest cover in the form of maps and statistical data is very crucial for spatial planning, management and utilization of forests, investigating forest degradation, growth analysis, forest inventory, preparing management plans, and formulating policy decisions (Karia *et al.*, 2001). Management plan of a forest should be prescribed after evaluating the past and current condition of the area. Forest change detection using satellite imagery is the most powerful monitoring tool for conservation agency, local administration and the non government organizations (Panigrahy, 2010).

Forest cover dynamics are changed by excess human exploitation, mismanagement, illicit felling, social or political force or by natural course (Zhiming et al., 2008). Tropical deforestation contributes approximately to 20% of the world's anthropogenic greenhouse gas emission. Nevertheless, Matthews (2001) reported that the deforestation rate have been increased in tropical Africa, remained constant in Central America and declined slightly in tropical Asia and South America. It is indeed difficult to have trustworthy data on the actual rate of deforestation in tropical forest because of different methods used to estimate the forest resources, deforestation rate and forest cover change.

Conventional ground methods of forest cover monitoring are labor intensive, time consuming, and are done relatively infrequently. Those maps soon become archaic with the passage of time, particularly in a rapid changing environment. More recently, remote sensing data, because of their temporal resolution, synoptic view and digital format, have become the foremost data source for different change detection applications during the last decades. Remote sensing data are widely used in terms of land use and land cover classification. Field base observation for monitoring the forest status is time consuming and critical. However, Satellite data analysis is more sufficient for accurate assessment (Franklin *et al.*, 2000). Digital nature of remote sensing permits for the advanced computer automated analysis, classification and compatibility with geographic information system (Li *et al*, 2007). Due to increasing rate of deforestation, operational forest monitoring systems at the national level are now a feasible goal in most developing countries in the tropics.

In recent year, fine and high resolution imageries (Quick bird, IRS, IKONOS, ALOS, CASI) deliberate an appreciable forest cover change detection and mapping with a considerable accuracy (80-90)%; but these imageries are very costly. A growing number of studies have dealt with monitoring forest change dynamics, land use patterns, landscape ecology using medium and coarse resolution satellite data (Landsat TM, ETM+, SPOT etc) with quite acceptable level of accuracy (Browder *et al.*, 2005; Vina *et al.*, 2004; Roy and Giriraj, 2008). Imageries from these sensors are low cost or free to obtain, therefore providing the ample opportunity for forest managers and scientists of developing countries like Bangladesh to study forest change incurring no cost of RS data acquisition.

Bangladesh is one of the poorest countries with low natural resource pool and a huge population. Country's forests are very important natural resources which are under constant pressure and have already been drastically degraded and fragmented. 11% of the total landmass (or 2.52 million ha) of the country is designated as forest (Mukul *et al.*, 2008) but the actual tree cover is estimated at around 8-9%. The main cause of degradation are encroachment, illegal felling, increased demand of fuel wood, land conversion into settlement, agricultural land, farm land and also for unplanned industrialization(ADB, 2002; Iftekhar *et al.*, 2003). FAO (2001) evaluated the annual rate of negative change of forests by 2000 ha per year or 0.3% in 2000-2005 in Bangladesh at an annual population growth rate of 1.7%. Such deforestation is likely to continue and forests are likely to disappear by next 35–40 years or earlier (Nishorgo, 2008).

Several studies are found in Bangladesh, which analyzed land cover change using satellite imagery in recent decade (Dewan and Yamaguchi, 2008; Uddin and Gurung, 2005). But not many studies except a few updated the forest cover change of various forest sites of Bangladesh (e.g., Halim *et al.*, 2008; USAID, 2006; Islam and Quadir, 1988; Islam *et al.*, 2006; Quadir *et al*, 1998). The management approach throughout sustainable development appears to be theoretical with the absence of no or very few information on forest structure and cover change in our country. Even though most of the developing countries are well equipped and updated with detailed forest cover information, Bangladesh as a developing country, suffers for lack of spatial information of forest resource. Present study is aimed to estimate the extent of forest cover change of Khadimnagar National Park (KNP), located in Sylhet forest division from 1988-2010 using Landsat Thematic Mapper (TM) imagery. No study was conducted at KNP to reveal the actual pictures of forest cover and the pace of forest degradation though the park is an important forest chunk of the region with great ecological value.

Description of the Study Site

Khadimnagar national park (KNP) is located in the Khadimnagar Union of Sylhet sadar Upazila and geographically lies between 24°56'-24°58' N and 91°55'-91°59'E. The park is under the authority of Khadimnagar forest beat of North Sylhet Range-1 under Sylhet forest division (Figure 1). The site is situated approximately 15km northeastern of the center of Sylhet city. The KNP was declared as national park in 2006 under the Wildlife Preservation Amendment Act 1974 with the area of 678.80 ha for the purpose of preservation of remaining natural hill forest in Khadimnagar Reserve Forest. The forest is semi-deciduous tropical forest where the tall trees are deciduous and the understory is evergreen (IPAC 2009). KNP undulates with slopes and hillock, locally named as tilla with a height range of 10-50m. It is is submerged with several watersheds locally named as "chore". Total area is surrounded by eight tea gardens (Anon, 2010). The natural forest was covered with inferior quality natural bamboo and gradually felled and converted by tree plantation during early 1960s for being a tropical forest look (IPAC, 2009). Plantation of Khadimnagar Reserve Forest started from 1951 up to 2004. Initially long rotation species including garjan (*Dipterocarpus turbinatus*), champa (*Michelia champaca*), dhaki jam (*Syzygium grande*), teak (*Tectona grandis*), chapalish (*Artocarpus chaplasha*) were planted .From the early 1990s , the forest was introduced with short rotational monoculture plantation mainly with exotic and rapid growing species such as akashmoni (*Acasia auriculiformis*), chickrashi (*Chickrassia tabularis*), champa (*Michelia champaca*), mangium (*Acacia mangium*) and other short rotation species. Bamboo and cane was also planted by the forest department. Faunal composition of the national park is 20 species of amphibians, 9 species of reptiles, 28 species of birds and 26 species of mammals. Soil ranges from clay loams to pale brown (acidic) clay loams. Climatic condition is warm and humid. The tropical monsoon climate prevails in the area with average maximum temperature of 30.7°C and average minimum temperature of 18.9°C. The average annual rainfall is 3931mm, most of which falls between June-September (BBS, 2005).

Methodology

The overall methodical approach followed in this research has been presented as a schematic diagram in Figure 2.

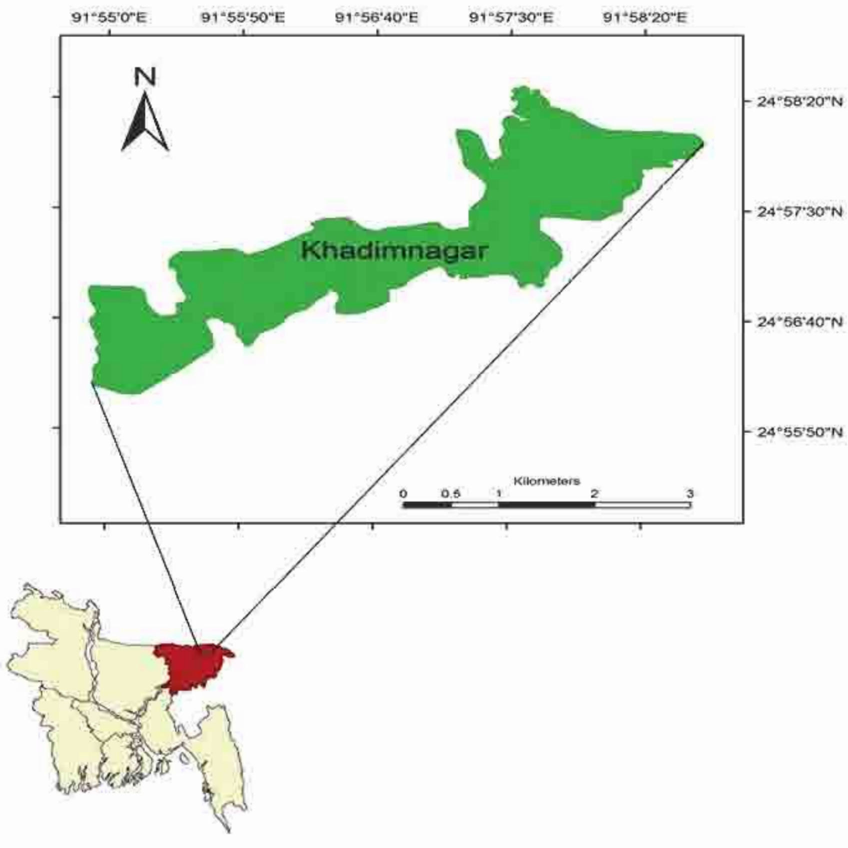

Figure 1. Location of Khadimnagar National Park, Sylhet, Bangladesh

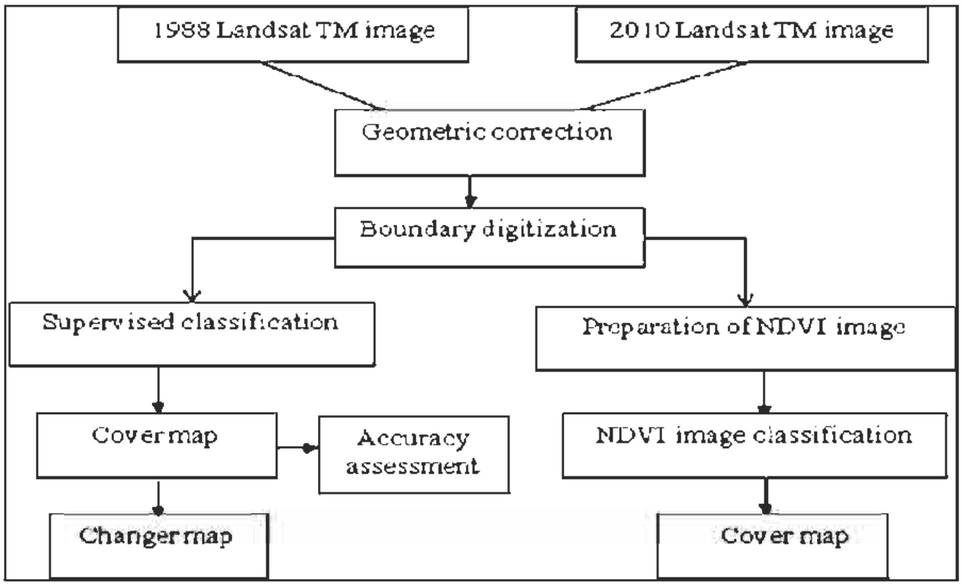

Figure 2. Schematic diagram of the research approach

Acquisition of Satellite Imageries and Preprocessing

Two scenes of Landsat TM sensor of the study site dating 10 November 1988 and 8 February 2010 were acquired. Scenes of KNP were subset from the full scenes (185 km x 185 km) using boundary shape file in ERDAS. Subset images were cloud and defect free. Characteristics of of the imagery used in this study are given in Table 1.

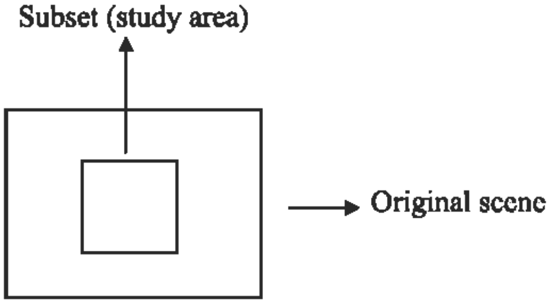

Figure 3. Subsetting process

Table 1. Characteristics of the imagery used in this study

Date	Sensor	Path	Row	Number of bands used	Resolution(m)
10.11.1988	Landsat TM	715	489	6	30 × 30
08.02.2010	Landsat TM	715	489	6	30 × 30

Landsat TM acquires image in seven spectral bands; three in the visible spectrum (band 1, 2 and 3), one in the near infrared (band 4) and two in middle infrared spectrum (band 5 and 7) and one in the thermal infrared (band 6) (Table 2). Bands (1-5) and 7 of have 30mx30m spatial resolution and were used in this analysis. Band no 6 was not used as it thermal band and has coarse spatial resolution of 120mx120m (some similar studies excluded e.g. Fraser *et al*., 2005; Hossain, 2005; Karia *et al*., 2001) as it is thermal waveband and not generally used in vegetation remote sensing.

Table 2. Properties of Landsat TM image

Bands Number	Spectral range (μm)
Bands 1 (Visual blue)	0.45-0.52
Bands 2 (Green)	0.52-0.60
Bands 3 (Red)	0.63-0.69
Bands 4 (near IR)	0.76-0.90
Bands 5 (mid IR)	1.55-1.75
Bands 6 (thermal IR)	10.40-12.5
Bands 7 (mid IR)	2.08-2.35

Pre-processing of satellite image prior to image classification and change detection is an essential task. Remote sensing digital image preprocessing includes atmospheric correction and geometric correction (Singh, 1989). Atmospheric correction was not performed as the imageries were defect and cloud free. Landsat TM image of 2010, which is ready geometrically corrected to the coordinate system to Universal Transverse Mercator (UTM) zone 46N with datum WGS84, was used as a master image for georeferencing and image to image co-registration of 1988 image (Townsend et al., 1992; Lillesand and Kiefer, 2000). 13 Ground Control Points (GCP) taken at crossroads, road carvings, trail crossings, canal bands and crosses were used (RMSE 0.4732). 1st order polynomial equation with maximum likelihood resampling approach was used for image transformation in the geometric correction process. All these operations were performed by using ERDAS IMAGINE 9.2, ENVI 4.3 and Arc GIS 9.3 software.

Field Sampling

Field work was carried out in the month of January 2011 for collecting ground training and validating data and for defining the characteristics of each land cover class. Stratified adaptive sampling with strata based on available forest types (plantation and natural) and cover classes resulted from the supervised classification of 2010 images were applied (Phong, 2004). For classification and validation of 2010 image, total 50 points were sampled. For 1988 image 40 points were sampled taking the help of the existing analog historical forest map of KNP and by visual interpretation of image based on some developed interpretation keys. In the selected field points, the following data was recorded: latitude and longitude, forest cover classes, dominant life form, disturbance factor (clear felling, encroachment, conversion of land use, fire.

Image Classification and Accuracy Assessment

After preprocessing the imageries, supervised classification of both the imageries with maximum likelihood classification algorithm was performed in ERDAS IMAGINE 9.2 using the field data to produce three cover classes namely dense forest, medium dense forest and bare land. Two third of the samples were used for training while one-third of them were used for accuracy assessment. 34 samples were training and 16 samples for accuracy assessment of 2010 image while 27 samples were used for training and 13 samples for accuracy assessment of 1988 image. Training and validation points were separated randomly using Hawth's tool in ArcGIS. After classification in ERDAS, the classified imageries were exported to ArcGIS for map production and generating forest cover statistics (Table 3).
Characteristics of each forest cover classes are presented in the following table.

Table 3. Characteristics of forest cover classes

Cover classes	Dominant species
Dense forest	*Tectona grandis, Dipterocarpus turbinatus* *Michelia champaca, Acacia mangium* *Acasia auricoliformis etc* Tree height: (16-25) m Stem/plot: 45-55
	Tectona grandis, Dipterocarpus turbinatus
Medium dense forest	*Michelia champaca, Acacia mangium* *Acasia auricoliformis, Syzygium grande* *Bambusa tulda, Melocanna beccifera* *Calamus guruba,* Herbs, shurbs Tree height: (5-18) m Maximum stem/plot: 20-30
Bare land	Grass land, Agriculture, fallow land, Cane, herbs

Accuracy assessment is very important for recognizing the classification results. Classified maps are hardly used without assessment of their accuracy as quality of the classified maps depends on their classification accuracy. In this we used error matrix (confusion matrix) and kappa statistics to assess the accuracy of the forest cover maps. In error matrix rows contain the result of the classification and columns contain the reference dataset. Diagonal elements of the matrix represent the accurately classified pixel of each class. And the off diagonal elements represent misclassified pixels or the classification error. Kappa statistics is a measurement of agreement between image data and reference data (Jansen, 1996). Kappa is widely used as an unbiased evaluation of classification accuracy. Kappa coefficient is computed as follows:

$$\hat{k} = \frac{N\sum_{i=1}^{r} X_{ii} - \sum_{i=1}^{r} X_{i+}X_{+i}}{N^2 - \sum_{i=1}^{r} X_{i+}X_{+i}}$$

Where: "r" is the number of rows in the error matrix, x_{ij} is the number of observations in row i and column j, and x_{+i} and x_{i+} are the marginal totals for row i and column i, respectively, and N is the total number of observations.

Preparation of Normalized Difference Vegetation Index (NDVI) Image and Classification

The NDVI is the normalized ratio of reflectance value at red and near infrared part of the electromagnetic spectrum. NDVI is used widely for monitoring vegetation health. A value of NDVI ranges from -1 to +1. Minus (-) value of NDVI corresponds to non-vegetated surfaces like water body, road surface, settlement etc. Zero (0) NDVI values correspond to no vegetation while 1corresponds to lush-green dense vegetation. NDVI is the most widely used of all vegetation indices because it only requires data from the red and near infrared portion of the electromagnetic spectrum and it can be applied to virtually all multispectral data types. For Landsat TM imageries, NDVI is calculated using the following formula:

NDVI = (band 4- band 3)/ (band 4+ band 3)

NDVI for 1988 and 2010 imageries were calculated separately using the above mentioned formula in ENVI 4.3. NDVI images pixels were then classified into 3 cover classes; dense forest, medium dense forest and bare land; with highest NDVI values corresponding to dense forest, mid values corresponding to medium dense forest and lowest values corresponding to bare land.

Forest Change Map

Image differencing is probably the most widely applied change detection algorithm (Singh, 1989) and used in this study. Image differencing involves subtracting one date imagery from a second date one that has been precisely registered to the first. Image differencing appears to perform generally better than other methods of change detection (Fraser *et al*, 2004; Deng *et al*., 2008). The change map was produced by differencing classified imageries of 1988 and 2010 as before image and after image respectively in ERDAS IMAGINE.

Instruments and Accessories

The following instrument and accessories were used:

- Forest cover map: map of KNP (scale 8 inch to 1 mile) was collected from forest Beat office and was used for field navigation and sample plot selection.
- GPS: Megallan GPS used for recording coordinates of field points
- Computer and software: ArcGIS 9.3, ERDAS IMAGINE 9.2, ENVI 4.3, SPSS and MS-Word and MS Excel were used for satellite and field data analysis and report write up.

Results

Forest Cover Maps

Forest cover maps of 1988 and 2010 resulted from supervised classification of Landsat TM imageries of respective years are presented in Figure 4 and those from NDVI image classification are presented in Figure 5. Three forest cover classes include dense forest, medium dense forest and bare land.

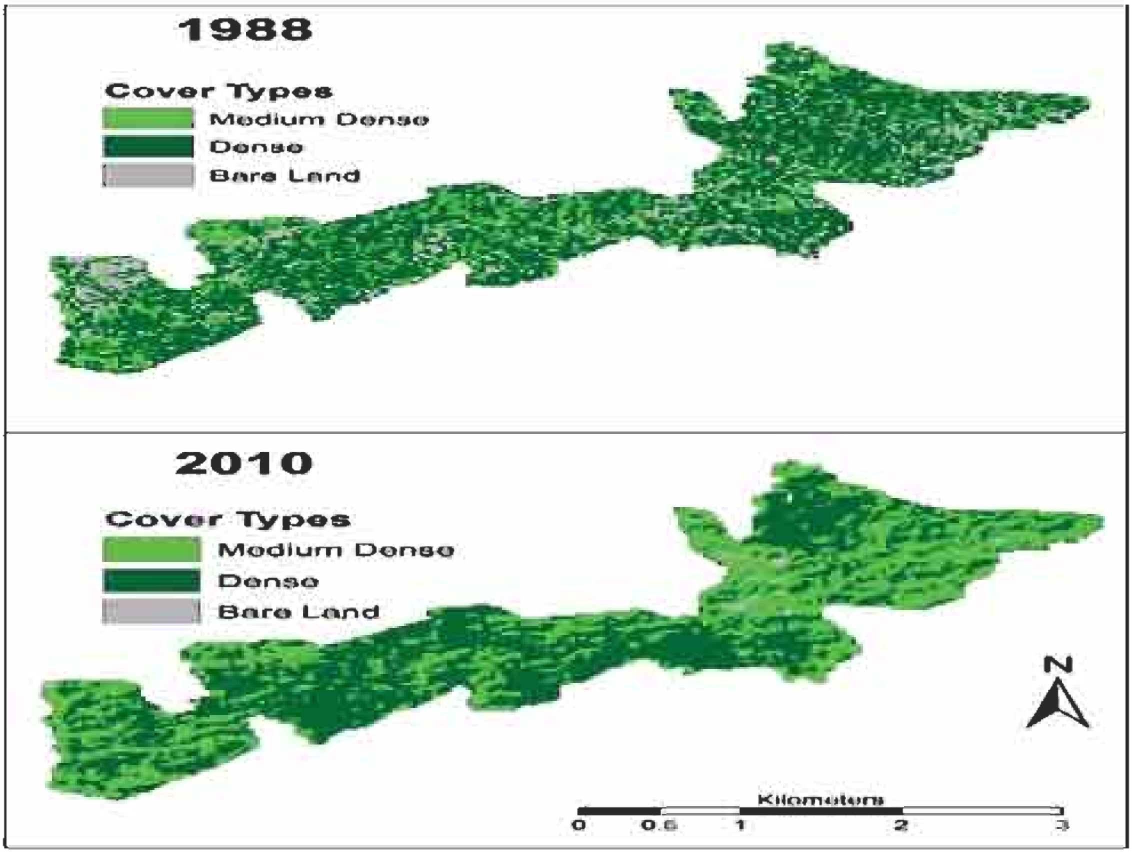

Figure 4. Forest cover maps of 1988 and 2010 resulted from supervised classification

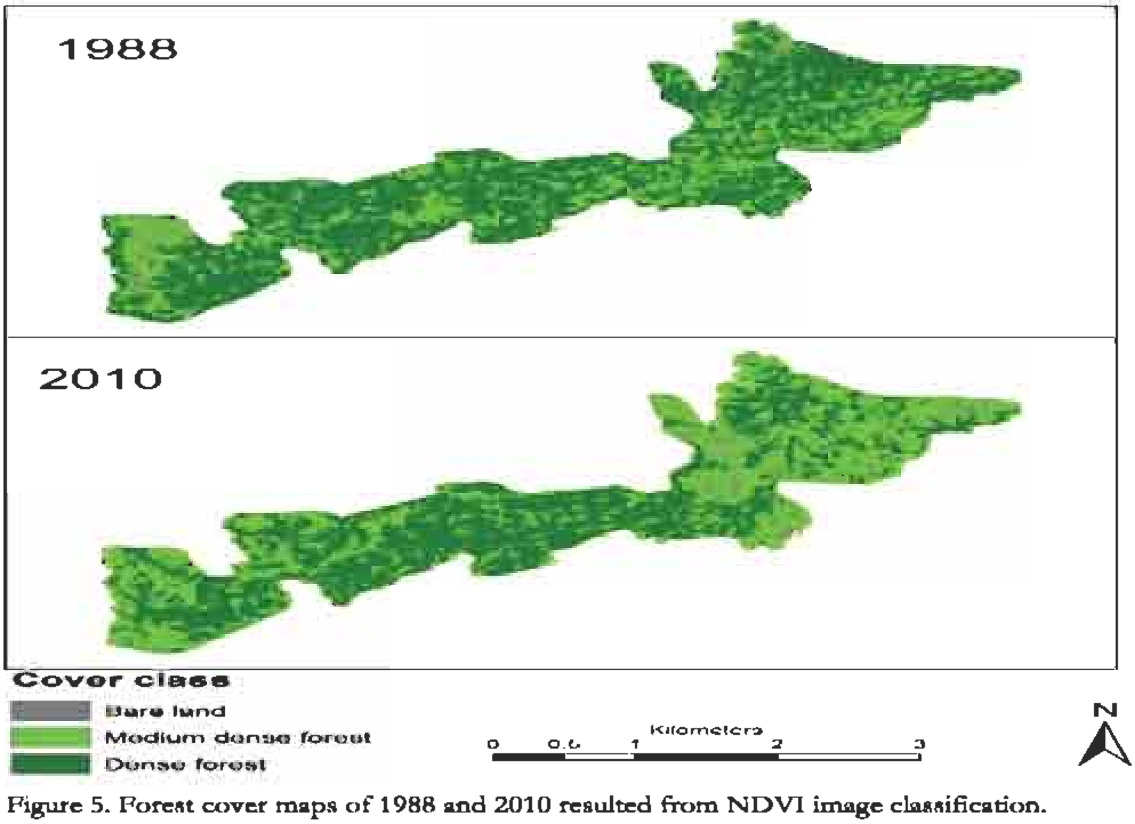

Figure 5. Forest cover maps of 1988 and 2010 resulted from NDVI image classification.

Forest Change Statistics

Summary statistics of forest cover classes of KNP obtained from the supervised classification has been presented in Table 4 (and a diagrammatic representation of the same has been presented in Figure 6). Dense forest has decreased from 525.96 ha (66.93%) to 416.52 ha (58.73%) in 1988 to 2010 respectively whereas medium dense forest increased from 154.98 ha (19.72%) to 316.53 ha (40.27%). Bare land has significantly decrease from 104 ha (13.35%) to 7.65 ha (0.97%).

Table 4. Area (in hectare) of forest cover classes resulted from supervised classification

Year	Dense	Medium dense	Bare land	Total area
1988	525.96 (66.93%)	154.98 (19.72%)	104.94 (13.35%)	785.88
2010	461.52(58.73%)	316.53(40.27%)	7.65(0.97%)	785.70
Change	8.2% (-)	20.55% (+)	12.38% (-)	

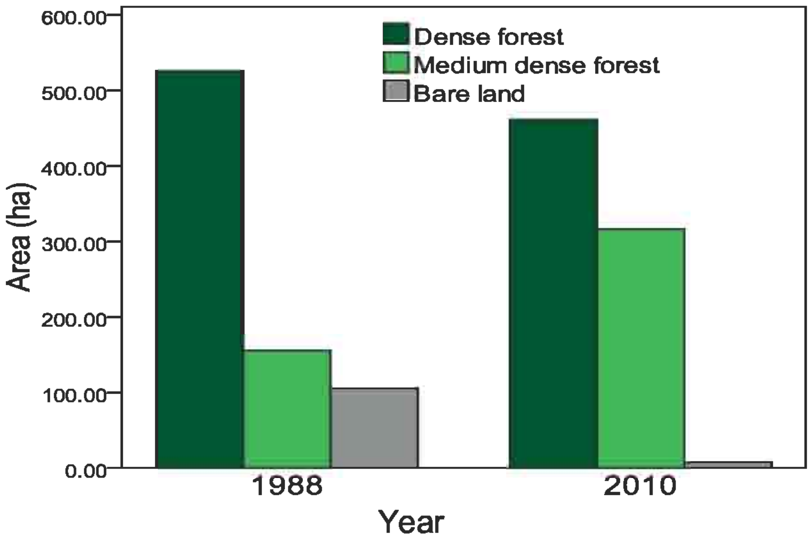

Figure 6. Bar chart of forest cover classes obtained from supervised classification

Forest cover areas resulted from the NDVI classification has been presented in Table 5 (and a diagrammatic representation of the same has been presented in figure 7). In this classification, from 1988 to 2010, dense forest has decreased from 524.88 ha (66.79%) to 420.93 ha (53.57%) whereas medium dense forest has increased from 252.81 ha (32.17) to 356.23 ha (45.33%). Bare land has remained unchanged.

Table 5. Area (in hectare) of forest cover classes resulted from NDVI classification

Year	Dense	Medium dense	Bare land	Total area
1988	524.88(66.79%)	252.81(32.17%)	8.19(1.04%)	785.88
2010	420.93(53.57%)	356.23(45.33%)	8.54(1.08%)	785.70
Change	13.22% (-)	13.16% (+)	0.04% (+)	

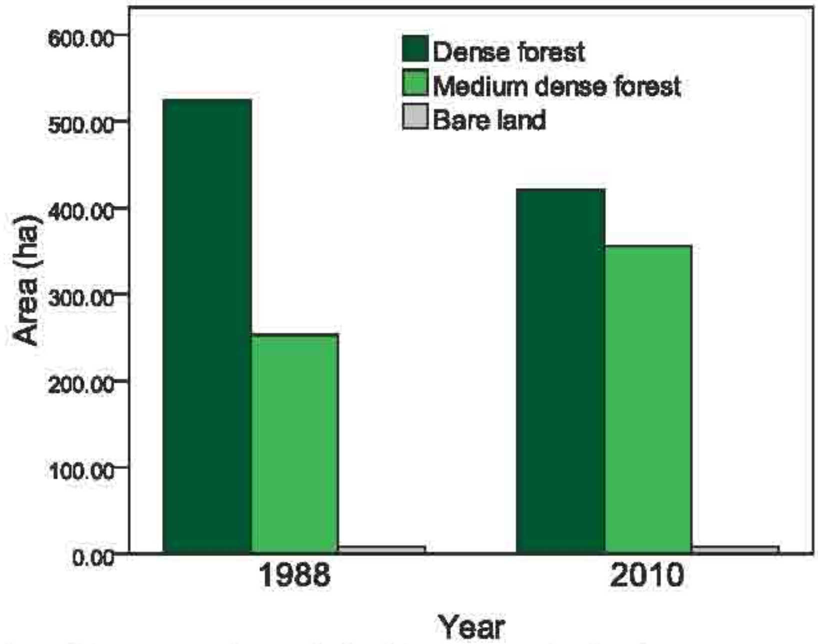

Figure 7. Bar chart of forest cover classes obtained from NDVI classification

Cover class statistics obtained from both supervised and NDVI image classification show similar trend of forest change i.e. decrease of dense forest and increase of medium dense forest. In supervised classification, dense forest decreased by 8.2%, where in NDVI classification, dense forest decreased by 13.22%. Medium dense forest has increased by 20.55% in supervised classification (Table 4) and 13.16% in NDVI classification (Table 5).

Forest change map (Figure 8) was prepared by differencing supervised classification maps of 1988 and 2010 images as before image and after image. Areas with 25% change have been marked as increase or decrease. Red areas correspond to decrease whereas green areas correspond to increase of forest cover. Areas marked white indicate no change.

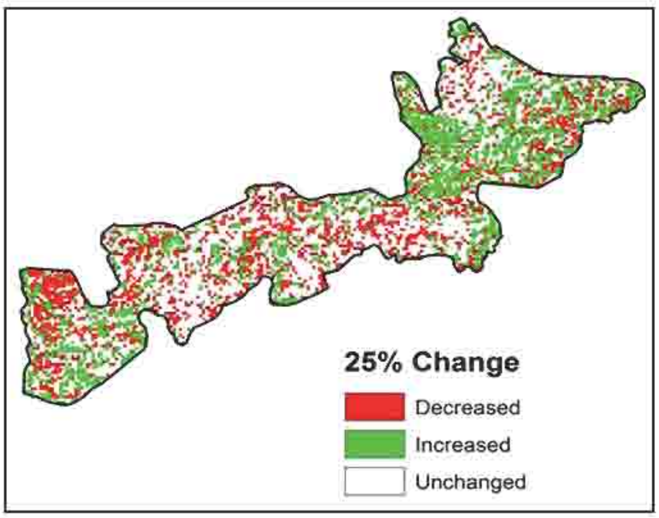

Figure 8. Forest cover change map obtained by differencing supervised classified 1988 image as before image and 2010 image as after image in ERDAS

Accuracy Assessment for Forest Covers Class

For assessing the accuracy of the forest cover maps, error matrices (confusion matrices) were generated. Error matrices of 1988 and 2010 maps have been presented in Table 6 and 7 respectively. Overall accuracy, user accuracy, producer accuracy and kappa statistic (or kappa coefficient) were calculated. The overall accuracy of 1988 map is 84.6% (with associated kappa value 0.75) and of 2010 map is 87.5% (with associated kappa value 0.80). Kappa is intended to give the reader a quantitative measure of the magnitude of agreement between observers. Kappa value 0.75, for example, indicates that produced map is 75% better than that would have been made by chance.

Table 6. Error matrix of forest cover map produced by supervised classification of 1988 image, with Overall Accuracy, Producer Accuracy and User Accuracy and Kappa statistic

Classified data	Reference data				
	Bare	Medium dense	Dense	Row total	User accuracy (%)
Bare	2	0	0	2	100
Medium Dense	0	4	1	5	80
Dense	1	0	5	6	83
Column total	3	4	6	13	
Producer accuracy (%)	67	100	83		

Overall accuracy: 84.6, Kappa statistic 0.75

Table 7. Error matrix of forest cover map produced by supervised classification of 2010 image, with Overall Accuracy, Producer Accuracy and User Accuracy and Kappa statistic

Classified data	Reference data				
	Bare	Medium dense	Dense	Row total	User accuracy (%)
Bare	3	0	0	3	100
Medium Dense	0	5	1	6	83
Dense	0	1	6	7	86
Column total	3	6	7	16	
Producer accuracy (%)	100	83	86		

Overall accuracy: 87.5, Kappa statistic 0.80

For 1988 map, 9 validation field samples out of 13 were correctly classified. 1 validation point belonging to bare land fall under dense forest class while 1 dense forest point fall under medium dense forest class (Table 6).

For 2010 map, 13 validation samples out of 16 were correctly classified. The main classification confusions were between dense forest and medium dense forest classes with 1 validation point of dense forest classified as medium dense forest while 1 point of medium dense forest classified as dense forest (Table 7).

Discussion

Distribution and Rate of Forest Cover Change at KNP

Both supervised and NDVI classification show similar trend of forest change over 22 years, i.e., relative decrease of dense forest and increase of medium dense forest classes. As the study area is constant both for 1988 and 2010, it can be said that dense forest has been converted to medium dense forest. Dense forest, as categorized in this study, include various important tree species with height range of 45-55 metre with 50-60 stem per 30m square plot along with undergrowths. Medium dense forest category has growing stock of 20-30 stems per plot with 5-18 metre height. The phenomenon of forest changes from dense to medium dense in majority areas of the park, what we say 'degradation' of growing stock can be attributed to several factors acting locally like close distance to settlements, absence of zoning, felling history, plantation rotation, illicit felling and also the management effort of the park.

Five tea estates are located adjacent to the national park in the range of 1-3 km and the rest are located outside the park in the range of 1-5 km. People of twenty two villages were identified having wide range of dependency on forest products for their daily need and alternate income generation (IPAC, 2009). The closer the settlements to the forest, the more are the disturbances. Unlike some other hill forests of Chittagong hill tracts and Cox's Bazar of Bangladesh with higher altitude and steeper terrain, KNP engulfs plain lands and undulated lower altitude hillocks (10-50 m) also known as 'tilas' where accessibility is much easier. Many researchers reported that the accessibility is an important factor determining forest degradation (Karia *et al.,* 2001; Bentum, 2009; Fraser, 2005). Since KNP is surrounded by tea estate, roads and transport systems are well developed by private and public entrepreneurship. Therefore, human interference is the vital issue of deforestation at KNP. Vina *et al.,* (2004) reported that 30% deforestation of Colombia occurred surrounding 5 km area of a road. Pong (2004) studying forest cover change at Bach Ma National Park in Thailand found distance of forest from village and population density negatively related to deforestation. Rahman (2000) denoted that the main causes of deforestation in Chittagong forest division, Bangladesh were settlement of rural people in and around the forest, logging practice and excess interference in the forest floor.

Initiation of co-management system has proven helpful in conserving forest. Some other studies in Bangladesh (Halim *et al.,* 2008; Quadir *et al.*, 1998) found forest cover was drastically reduced from the year 1988 to 1996, and gradually increased from 1996 after involvement of forest co management approach involving local people. Co-management approach initiated an alternative livelihood mechanism to motivate the people from encroachment, illicit felling and other misuse of forest product. One alternative forest management at KNP can be the introduction of co-management.

Zoning of protected area is one of the popular management strategies for sustainable forest management (Islam *et al.,* 2006). Buffer zone extensively manages to protect the ecosystem, forest stock, biodiversity as well as floral and faunal composition of the core zone. In KNP, no sound buffer zoning is established for which disturbances to mainstream forest resources are immense (Anon, 2010).

One of the reasons of increasing medium dense forest and decreasing bare land in KNP is the plantation activity undertaken by park authority. Plantation activities in KNP started from 1960s. According to PRA report of IPAC (2009), about 2090.50 acres areas have been planted by long rotation (LR) species from 1951 to 2004. Furthermore, 200 acres short rotation (SR) species have been planted from 1987 to 1989. From 1981 to 2004, different types of bamboo and cane plantation were established in 618 and 563.15 acres respectively. An extensive plantation including SR species (*Acacia auriculiformis, A. mengium, Eucalyptus camaldulensis, Pinus spp, Albizia chinensis*) and bamboo and cane species were established in a considerable area from 1980-1995. The LR plantations were felled periodically after maturity. In the meantime, several SR plantations (1991, 1992, 1993, 1994, 1987, and 1989) have grown up and identified as medium dense forest in the classified image of 2010. In the Northeast corner of the 1988 map (Figures 4 and 5) dense forest cover is noticeable but in 2010 map, the areas have been converted into medium dense forest. This area was planted with long rotation plantation in early 1960s and had matured enough in 1988 (Anon., 2010), as indicated dense forest cover in that year. On the other hand, after 1980 this area was gradually harvested and replanted with short rotation plantation of dhaki jam, chapalish, acasmoni, chompa, meheguni in 1991, 1992, 1993, 1994 plantation year (Anon, 2010). By 2010, the plantations were grownup and seemed as medium dense forest in 2010 map.

Similarly, decreasing bare land (indicated in supervised classification) can be attributed to the increased afforestation efforts by forest department with short rotation plantations. In 1988 map, much area in the North West part of the study area indicated as bare land. In that period, SR plantation of 1988, 1985 were established and LR of 1963, 1964 were harvested (Anon., 2010). But in 2010 image, those areas were indicated as medium dense, as the SR plantations got maturity. Again, bamboo plantation area seemed to be bare in 1988 image may be detected medium dense in 2010 image because of their natural regeneration.

Remote Sensing and GIS implications

To minimize error in estimating amount of change, satellite imageries used should be of same date of the year. Difference in irradiance recorded by the sensor at top of the atmosphere may vary due to change in land cover and other ancillary factors such as atmospheric condition, sun angle, soil moisture etc. However, it is difficult to obtain matching-date imageries, especially free of cost. Acquisition dates of the Landsat TM imageries used in this study are 10th November 1988 and 8th February 2010. Differential date imageries might have some implications in the accuracy of the forest cover maps. However, dry winter season prevails in the image acquisition months (November-February) in Bangladesh while no sharp change in the vegetation phenology is observed in the tropical monsoon forest of KNP. Therefore, error in image classification is expected to be minimal.

Supervised classification and NDVI methods were used for image classification. Both the methods are quit straightforward techniques and easy to use. We did not perform the accuracy assessment of cover maps produced by NDVI method, rather this approach was used as crosscheck to the statistics obtained by supervised classification. Both classification approaches produced similar statistics of forest change and therefore the statistics is confirmed. However, amount of bare land (104.94 ha) as indicated in 1988 map by supervised classification was many times higher than that resulted from NDVI classification (8.19 ha) of the same year. This might be the result of classification confusion between medium dense forest and bare land. In that case, NDVI classification is likely to be most trustworthy than supervised classification as NDVI is based on the spectral characteristics of vegetation and unbiased record of vegetation health.

Several areas belonging to dense and medium dense forest classes were mixed up in pixel level classification. This possibly happened for spectral overlapping resulted from the discontinuity of the forest cover classes. Also it was complicated to distinguish dense class from medium dense, probably due to reflectance of tall trees in the dense class sometimes more or less same in case of thick herbs and shrub of medium dense classes.

Map accuracies obtained by both the classification approaches were high. Accuracy of the change map depends on the accuracy of the independent maps from which it is calculated. Therefore, accuracy of the change map is also high too. Hence, use of medium resolution imageries like Landsat TM proves useful in estimating forest cover change in tropical monsoon forest like KNP. Numerous efforts have been recently undertaken in an attempt to document forest cover change detection using medium and coarse resolution imageries.

Error might propagate in image classification due to 'selective availability' (SA) error of GPS in field training and validation data collection. SA error for Magellan GPS as used in this study is 10 meter. Therefore, real position of field points might shift 10 meter away in any directions from the observed positions. To minimize this error to propagate in the image classification, stratified adaptive sampling strategy was applied and samples were taken such that there is continuation of similar cover class even 20-30 meter away in any direction from the observed points. A number of studies suggested similar sampling technique with increasing number of sample unit that providing more robust and precise change estimation (Achard et al., 2002; Eva et al., 2009). Use of differential GPS (DGPS) however reduces this SA error to centimeter level but present study could not avail DGPS due to unavailability of the machine and high cost involving its purchase.

Conclusion

Forest cover was mapped and the change estimated over 22 years from 1988 to 2010 of Khadimnagar National Park, Sylhet, using Landsat TM imageries and other ancillary GIS data with supervised and NDVI image classification approaches. Accuracy of the forest change map depends on the accuracy of the individual forest cover maps. Forest cover maps of 1988 and 2010 obtained by supervised classification possess high level of accuracy (overall accuracy 84.6% and 87.5% respectively). Accuracy of NDVI approach were not assessed, rather it was used as crosscheck to confirm the forest cover statistics obtained by supervised classification. Statistics of both supervised and NDVI approaches show similar trend of forest change i.e. decrease of dense forest and increase of medium dense forest. Bare land showed decrease in supervised classification but no change in NDVI classification, which might be caused by SA error of GPS field data in training imageries for supervised classification. Afforestation effort of the forest department in different years has contributed in the increase of medium dense forest while human interference and illicit felling are the principal causes of decrease of dense forest cover. Forest department should undertake appropriate measures to scientifically manage and conserve the existing forest stock at KNP.

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Community-led Monitoring Can Supplement Scientific Rigors

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Abstract

Enhancement of biodiversity conservation and local livelihoods entails active involvement of local communities in management as well as monitoring of the natural resources. Monitoring of ecosystem health typically envisages an expert-driven, highly technical and expensive endeavor Few such attempts of monitoring forest resources in Bangladesh are Permanent Sample Plots (PSPs) for plantations in hill forest divisions and the Sundarbans, nation-wide National Forest Assessment sample plots (FAO, 2007), etc.A consistent, regular and sustainable monitoring protocol is still a concern. Conversely, to supplement these, many recent experiences and development discourses reveal that community-led monitoring protocols can also be worthwhile and cost-effective to monitor natural resources which can reasonably be useful in participatory management of natural resources. To be more precise, a blend of community based monitoring protocol coupled with traditional methods, can ensure a sustainable monitoring process in collaboratively managed natural tracts. Nishorgo Network- a platform for collaborative management of natural resources in Bangladesh, has been promoting this venture with empirical evidences in the frame of community score-card, participatory bird monitoring, illegal felling monitoring and monitoring of regenerations in protected landscapes of Bangladesh. The study reveals that given adequate recognitions from public institutions and experts through adoption and promotion, community-led frameworks which are often easy and cost-effective, ensure sustainable natural resources monitoring process.

Key words: Collaborative management, Monitoring, Participatory monitoring, Protected area

Background

Bangladesh forestry sector appreciated people-oriented forestry and adopted 'social forestry in the forest reserves'. More recent initiative (since 2004) for 'collaborative management of protected landscapes' adds to the list of successful initiatives. The collaborative management exhibits a progressive pace in adaptive management of the orest resources of the country. Both the initiatives portray a preview of paradigm shift in forest management from traditional 'command and control' approach. Hence, it is evident that the Government, with the assistance from developing partners, came forward to mediate the interaction between the natural resources and neighboring communities. Due appreciation is echoed to the involvement of local communities in management and conservation of forest resources.

Alike, in many other developing countries, community based forest management has been a proven approach for biodiversity conservation and livelihoods improvement. Community forestry program in Nepal, since 1980s, brought significant improvement in social capital-through developing local institutions (forest user groups) as well as in natural capital-through improved forest health. Joint forest management (JFM) in India also contemporarily evolved through decentralization and devolution of forest management and policy supports from the Government. Few other examples of community-led natural resources regimes are community based forest management (CBFM) in the Philippines and Hutan Kemasyarakatan (social forestry) in Indonesia. These initiatives apply participatory learning in the context of social and biophysical challenges in resource management and local livelihood. While traditional forest monitoring approach is based on periodical data collection and analysis to facilitate a resources management plan, community based participatory learning is a continuous process and gives more focus on diagnosing prevailing threats, challenges and practical ways to resolute those challenges.

Community-led monitoring involves local active stakeholders who has been performing social roles and interests, bears site-specific knowledge, skills, and might not have sound scientific specialization in professional fields of interests. This process might enrich and empower the resource users in systematically record information about their forest patches and subsequently encourages them in reflecting information through management responses. Guit (2007) identifies that participatory monitoring shifts the emphasis away from externally defined and driven programs and stresses the importance of a locally relevant process for gathering, analyzing, and using the information.

Rationale of the study

Forestry sector in Bangladesh has gone through a number of site specific forest inventories namely Forestall Forestry inventory (GOB, 1960) in the Sundarbans Reserved Forests in 1960, inventory of Sitapahar, Kassalong and Rainkheong forest reserves in 1961-62 (GOB 1963), village forest inventory of Bangladesh (Hammermaster, 1981), 120 Permanent Sample Slots (established during 1984/45) ,inventory in the Sundarbans (ADB, 2008), forest inventory of the natural forests and plantations in the Sundarbans, Cox's Bazar, Chittagong and Sylhet Forest Divisions (Revilla, 1998), PSPs in the plantations under Cox's Bazar, Chittagong and Sylhet Forest Divisions, Forest Inventory of the Sal Forests of Bangladesh (Sylvender, 2000), National Forest and Tree Resources Assessment 2005-2007 (FAO, 2007), Bangladesh, Forest Carbon inventory in the Sundarbans 2009-2010 and five other protected areas, etc. These inventories paved a strong basis for developing forest management plans in the concerned forest reserves. However, varied methodologies are adopted during these monitoring. Almost all these approaches applied the traditional methods, and none of these is truly participatory. Consequently, forest dependent communities always remained aside from forest management. The major issue about these inventories is that no particular method can sustain for long-term monitoring of respective forest sites. All these inventories are project driven initiatives devoid of linking the previous inventories. However, it should be noted that since per hectare based results are drawn in almost all the cases, it was useful for later inventories.

Recent studies reveal that monitoring of forest ecosystems is of utmost importance and consequently, the paradigm shift in monitoring further reveals that it is not an exclusive arena for forest managers/ scientists rather local stakeholders are also an integral part of it. A blend of scientists' guidance and community led monitoring empowers the CMO actors to play vital management role in improving ecosystem health and their wellbeing based on forests. Through this, the stakeholders feel ownership to review the change in the ecosystem and respond adequately. Thus, community-led monitoring can be a process to foster adaptive learning and improvement (Evans, 2008) towards sustainable management of forest resources.

This study explores the events of community-led forest ecosystem health monitoring, recently applied in few protected areas whereby collaborative management is introduced. These initiatives are participatory bird survey, illegal felling monitoring in FD field management units, regeneration studies and participatory (CMOs) scorecard.

Methods

The study mostly bases on empirical evidence of community-driven initiatives of forest monitoring in Bangladesh during Nishorgo Support Project (2004-2008) and Integrated Protected Area Co-management (IPAC) Project (2008-2013), in particular and other developing country experiences, in general. Hence literature review, opinions from the active CMO members, GOB officials, practitioners and focus group discussions are accounted during the study.

Results and Discussion

CIFOR (2007) recognizes monitoring as a systematic gathering and analysis of information in order to gauge whether changes occurs and this is workable than a one-off assessment. It should be done at regular time interval and the information is analyzed, evaluated and be used for decision-making. Such monitoring assists resources users and managers to portray the concerns relevant to biodiversity conservation, community wellbeing, institutional processes and overall ecosystem health (Cunha dos Santos, 2002) It acts as a catalyst for adaptive learning in the process of collaborative management and as a cycle that generates systematic progress and adaptation to change (Colfer, 2005, Guijt 2007). It helps to further monitoring that can be a crucial mechanism for enforcing compliance with important forest management rules, such as resource access, use, conservation and benefit distribution (Evans, 2008).

Collaborative initiatives for resource monitoring, with scientific knowledge and local experience can bring a dynamic and adaptive management whereby local people are encouraged to ask how their ecosystem changed over time and what are the issues to be addressed. While a participatory monitoring mechanism is adequately onboard, it can bring some distinct outcomes like stakeholder empowerment, strengthening CMOs in decision-making, building social capital, reducing costs from highly paid consultants-which is often project-based. Above all, it can integrate indigenous knowledge into monitoring. However, Evans, (2008) considers planning and implementing participatory monitoring largely depends on issues like: (i) who participates and how? (ii) what will be monitored and how? (iii) how can a participatory monitoring program be developed and scaled up? and (iv) What are the pitfalls, and how can they possibly be avoided when implementing future programs? In the collaborative management regime of protected areas in Bangladesh, a wide segment of stakeholders are onboard in management and conservation of PA resources, including forest department as a legal custodian of forest reserves. Lessons learned, in this context, from the literature and experiences from the Nishorgo Support Project and consequent Integrated Protected Area Co-management (IPAC) project, are given below:

- In many cases of traditional scientists-led monitoring has been almost unsustainable and sometimes ethically problematic (Danielson *et al*,. 2005; Ghate and Nagendra, 2005; Garcia and Lescuyer, 2008), where the role of local people are kept limited to data acquisition merely. Contrarily, community-led monitoring ensures access of local people to resources and brings their time-efforts and knowledge.

  Co-management organizations (CMOs) showed their utmost enthusiasm in assisting site level personnel from forest department in all sorts of activities including monitoring ranging from information gathering to data analysis, interpretation in local context and learning to feed decision-making process.

- Through the Dry Zone Asia Process in 1999 (FAO, 2003) set criteria and indicators (C&I) for sustainable forest management in this region; C&I framework for participatory monitoring is yet to be well-shaped. Consequently Colfer *et al.* (2005) remarked that C&Is of sustainable forest management are complex and difficult to implement participatory monitoring with forest dependent communities, hard to measure and require too much professional expertise.

  Birds are one of the best indicators of the ecological changes (Johnston, 1956, Morrison, 1986, Welsh, 1987, Temple and Wiens, 1989, Canterbury *et al.,* 2000, Browder, 2002). Different species of birds occur in different strata of an area and are adapted to varied types of plant and animal food. Therefore, the avian population density and species diversity reflect the temporal changes of their habitat conditions. In other words, birds indicate the health of different strata of the forest. Determination of the extent to which ecological systems are experiencing changes is critical for long-term conservation of biotic diversity in the face of changing landscapes and land use (Canterbury *et al.* 2000).

  At this context, NSP and IPAC introduced participatory indicator bird monitoring at 10 forest PAs of the country which proved to be an easy tool to monitored ecosystem health by local people, particularly by the eco-tour guides and community patrol groups. With the guidance from bird monitoring specialist, CMOs are progressing with this approach in Bangladesh since 2004.

- A participatory monitoring program needs to be simple to measure, locally adaptable and relevant to particular site. Stuart-Hill *et al.* 2005 noted that information are needed to be returned back to the community so that they can be on the same page in terms of (program) relevance and can use in their decision-making process. However, adequate emphasis needs to be given for institutional development and capacity building of the CMOs.

Though volunteering by the CMO members for monitoring often brings challenges, CMOs' scorecards to review their institutional capacity has been well-adopted both in forest PAs and wetland RMOs in Bangladesh. This portrays their progress in terms of organizational, leadership, capital, skills, self-reliance, gender dimension, participatory planning and conflict resolution issues. Eventually, such scorecard enables the CMCs in strengthening particular aspects of their institutions. Similarly, another scorecard assessment protocols, for wetland RMOs, has been maintaining to evaluate their capacity for resource management, pro-poor stands to ensure equity, involvement of women, institutional perspectives, good governance, financial management and networking efficiency over time.

- Alike all other monitoring protocols, the biggest challenge for community-led monitoring is also long-term sustainability. The key concern is the method needs to be simple, locally appropriate and linkinged with their livelihood. Topp-Jorgensen *et al.* (2005) described a Tanzanian successful forest-monitoring program, where local communities were managing forests through joint initiatives, which tracked resource extraction and disturbance. This case study describes in details how and when the community monitored its management practices, with particular emphasis on transparency, social control and the monitoring system's economic sustainability.

  Danielsen *et al.* (2005) identified six principles that contribute to the sustainability of a locally-based monitoring program without external support. These are:

- Locally-based monitoring has to identify and respond to the benefits that the community derives from the habitat or population being monitored;
- The benefits to local people participating in monitoring should exceed the costs;
- Monitoring schemes must ensure that conflicts and politics between government managers and communities do not constrain the involvement of local stakeholders in the monitoring process;
- Monitoring should build on existing traditional institutions and other management structures as much as possible;
- It is crucial to institutionalize the work at multiple levels, from countrywide policies down to the job descriptions of local government officer;
- Data should be stored and analyzed locally, even if this means some loss of quality. It should also remain accessible to local people.

In the verge of above discussion, experiences from protected area co-management initiatives in Bangladesh, with their relevance to promote community-led monitoring are highlighted below.

Community scorecard- a conceptual framework for capacity and performance assessment of the CMOs developed (Khan, 2008) under the purview of Nishrogo Support Project, has been using to assess the capacity and performance of the CMOs in Bangladesh. This framework envisages that a number of complex issues and dynamics, at both ecology and entity level, regulates/affects the capacity and performance of the local institutions. These are (i) at the broader environmental level-'the Ecology' –as mentioned by Fred Riggs (Riggs, 1961; also Arora, 1990; Khan, 1998); (ii) at the more immediate level of the organization – 'the Entity' (particular CMC) and associated community- as referred by UNDP (UNDP, 1997; 1998).

This simple matrix for assessment is participatory, whereby representatives of the CMCs opined on a set of indicators (related mainly to soundness of the concerned CMC and its governance, quality of services/activities, and the impact) and assigned value to each indicator based on his/her own judgment. Average of the scores shows the status of the institution. The indicators set (10 points of measure each with maximum score 10) are as below:

- Extent of organizational development (within the CMCs);
- Leadership development;
- Formation and nurturing of (human, financial and social) capitals; capital formation;
- Development of self-reliance;
- Skills and awareness enhancement;
- Soundness in the conduct of routine tasks and operations; (Development Projects/Works);
- Status of poorest households in the community
- Women and gender development;
- Participatory planning and networking and relations with relevant agencies/organizations and
- Conflict resolution and benefit sharing

The score assigned by individual/sampled CMC members against each indicator gives a broad (indicative) impression of status of the concerned CMC.

Participatory bird monitoring- a tool to assess the impacts of collaborative management of selected protected areas in Bangladesh, in the frame of biophysical improvement of ecosystem health since 2004. As a tool for community-led monitoring of ecosystem health, birds are more visible, relatively fast-breeder, and more responsive to any change and community are well aware of the resident birds in their forests. Johnston (1956), Morrison (1986), Welsh (1987), Temple and Wiens (1989), Canterbury *et al.* (2000), Browder (2002) also identified birds to be one of the best indicators of the ecological change. Khan, (2008) reports that different species of birds occur in different strata of an area and are adapted to varied types of plant and animal food. Therefore, the avian population density and species diversity reflect the temporal changes of their habitat conditions. In other words, birds indicate the health of different strata of the forest. Determination of the extent to which ecological systems are experiencing changes is critical for long-term conservation of biotic diversity in the face of changing landscapes and land use (Canterbury *et al.,* 2000).

During 2005-2008, in five protected areas, namely Lawachara national park, Satchari national park, Rema-kalenga wildlife sanctuary, Chunati wildlife sanctuary and Teknaf wildlife sanctuary in Bangladesh, this tool has been applied. Since 2009 five more protected areas viz. Khadimnagar national park, Kaptai national park, Modhupur national park, Fasiakhali wildlife sanctuary and Medhakachapia national park have been brought under participatory bird monitoring approach. The local communities of concerned PA sites and members of Bangladesh Bird Club (BBC) actively participated in the surveys. About 40 transacts are identified for the survey during breeding season whereby population densities (number of individuals/km^2) of birds are recorded and compared over the year. Through continued on-site orientations, it is anticipated that over the years, community will lead this assessment and make this tool sustainable.

Monitoring of regenerations - Mark and McGean (1996), in the Village Voices, Forest Choices remarked, in the context of Joint Forest Management in India, that either all parties lose when the forest is destroyed or all benefit through its regeneration and sustainable management. In this latter win-win scenario, the empowerment of community management groups to take the lead reaffirms the forest department's role as state 'custodian,' overseeing and endorsing the work of local forest-user communities. Further, Ghate and Nagendra (2005) found that local enforcement has been most effective in the case where forest management was initiated by the community, with better regeneration, and negligible evidence of grazing and fire. Nishorgo Network- a platform for collaborative management of natural resources in Bangladesh, has been promoting sample plot based natural regeneration counts in selected PA sites involving communities to assess growth, abundance and diameter distribution of natural regenerations. This is a simple species-abundance count based enumeration whereby local community identifies abundance of seedlings by local name of the species and gets an impression of reduced disturbances in the PAs concerned.

Illegal Felling Monitoring- Since inception of forest regulation through declaration of forest reserves and protected areas, illegal poaching of forest produce have been a major challenges in forestry sector. In recent days, though there are forest management plans developed for major forest division, merely protection came in the forefront as a major activity in forests. And filing forest cases, in the frame of POR, UDOR found to be a significant time-burden to forestry personnel at field level. Nishorgo network, thus identified offence registrar monitoring as a tool for gauging effective collaborative management in some protected areas. Studies (site appraisal reports by Mollah *et al.,* 2004) found the illegal felling as a main threat to our Protected Areas.

Thus illegal felling was selected as indicator of increased levels of protection resulting in part in improved capacity of FD and community groups actively participating in the protection of the PAs. The data have been collectied from Forest Department's Offence Register on a monthly basis since 2004. Community patrolling groups (CPGs) including few women CPGs are participating in joint patrolling with forest guards in selected forest protected areas. This illegal felling monitoring has been applied as a tool to assess effectiveness of community patrolling groups and FD's enforcement in forest protection and overall impact of the co-management regime in Bangladesh.

Integration of scientific research into community-led monitoring- This is obvious that the choices and scale of stakes varies among the stakeholders participating in the co-management process and hence mere community driven monitoring program might not generate robust data to be useful for scientific research. There may be problems of conception, precision and might lack scientific rigors. Danielsen *et al.* (2005) confirms that there is a major gap in understanding the comparability of data between scientifically and locally-collected data. Based on the few comparisons of scientific and local monitoring that have been conducted, fewer amount of data are to be collected by local monitoring programs to generate the same results as with the traditional scientific methods. The authors observed that local monitoring on its own has the ability to detect qualitative changes in forest cover, abundance of wildlife, threats to forest conservation and wildlife habitats, and patterns of resource use adequate accuracy to serve for scientific decision-making.

Hence a blend of scientifically valid protocol, obviously easy to be used by the community, with adequate orientations and supports, can generate a cost-effective and sustainable framework whereby community-led monitoring can be useful to their management planning and would be invaluable information base for scientific communities.

Conclusion

Monitoring framework with active involvement of local communities, which is grounded on scientifically-designed and empirically proven, has manifold advantages, viz., cost effective, information with indigenous knowledge, encourages the local stakeholders in participating management planning, capturing historical perspectives and above all sustainability. In this context, the monitoring tools need to be locally developed; not too technical; should be simple to conduct, less expensive and locally relevant; benefits of monitoring be clear to the CMOs and linked to their livelihood. To ensure this, adequate nurture of the CMOs developed under Nishorgo Network in Bangladesh should be extended with strong commitment from GOB, researchers, NGOs, development partners.

"*By generating data, people become conscious of underlying problems, for example perceived or actual over-hunting of a certain species...Reflection processes can lead to preliminary management action that can be consolidated in an adaptive management process...Communal decision-making is the key, participatory methods provide the inputs and framework for discussion, and detailed scientific information with sophisticated analyses may not be essential, as long as we utilize information with which resource managers and assistants are familiar and confident.*" - from Noss *et al.* (2005)

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Sundarbans Mangrove Forest Carbon Inventory: An initiative towards REDD+

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Abstract

The Sundarbans, world's largest contiguous natural mangrove forest has drawn global attention in recent years. Unique natural beauty of Sundarbans represents Bangladesh to the globe. Out of nearly 10,000 square kilometers, Bangladesh encompasses 6,017 square kilometers. This reserve forest represents more than 40% of Bangladesh forests, and likely represents a key terrestrial carbon stock or sink/source for the country.

Three complete forest inventories were done for Sundarbans in 1959, 1983 and 1997. Reasons for these three inventories were similar in nature and that was: assessment of resources for felling prescriptions. Reasons for Sundarbans carbon inventory were different than those of previous three. It was done mainly to get a baseline carbon stock and make opportunity to sale Sundarbans carbon to international market.

A total of 155 sample plots were selected for the carbon inventory. These plots have been systemically extracted from 1,200 sample plots of 1997 inventory. Each plot was divided into 5 sub plots. Measurements were taken in these plots as per protocol.

For the SRF carbon assessment, in consultation with FD and USFS personnel it was agreed to measure trees, non-tree vegetation, dead wood and soil. Two inventory teams collected data during December 2009 to April 2010.

Mean total carbon (C) density (including soil) is 255.20 Mg/ha (95%CI: ±17 Mg/ha). Total SRF C was found 105.06 Mega ton. Mean C density without soil is 136 Mg/ha and mean soil C density is 119.2 Mg/ha. Total C density of non-soil pools ranged from a low of 20 Mg/ha in one gewa- dominated stand to a high of 446 Mg/ha in one Sundri-dominated stand. Trees constituted the bulk of the C density across the forest reserve, with a mean of 82 Mg/ha above ground and 36 Mg/ha below ground, which combines to account for 47% of total mean C. Result for C density without soil was compared with 1997 inventory and it is found that change in C density is 40.5 Mg/ha.

Change analysis was done and it is found that C density has increased by nearly 54% in 2010 than that of 1997.

Keywords: Carbon, Inventory, Sundarbans, C density, REDD+

Introduction

This document presents field-based carbon (C) stock estimates for the Sundarbans Reserve Forest of Bangladesh. First, it presents an estimate of current C stocks, obtained from the 2009-2010 field-based forest inventory. Second, it contains an estimate of change in C stocks since the previous inventory, which was conducted in 1996-1997. This latter analysis provides an estimate of certain "emission factors" over the recent past, which, when combined with remote sensing and other data on land-cover change ("activity data"), can be used to establish a baseline C trend against which future changes in C stocks can be evaluated.

This write up provides some of the quantitative information necessary for carbon market/monitoring projects (e.g., REDD+ proposals)—specifically current C stocks, their distribution among above ground and below ground pools, and recent trends in C stocks (relevant to baseline). Findings of this C inventory will enable FD to prepare a collaborative REDD+Integrated Forest Management Sundarbans Project.

Background Information

The current forest inventory began with an extensive training program led by the U.S. Forest Service (USFS) and USAID in November 2009, followed by a 5-month field campaign led by the Bangladesh Forest Department (FD) and the Integrated Protected Area Co-Management (IPAC) project, from December 2009 through April 2010. For this carbon inventory, a tier 3 approach (per IPCC sourcebooks) was considered most appropriate for the Sundarbans Reserve Forest. The reserve represents approximately half of all Bangladesh forests, and likely represents a key terrestrial carbon stock or sink/source for the country. In addition, the existing need for forest inventory data in support of an updated forest management plan already justified an intensive field campaign. The measurements required for a typical forest resource inventory and a tier 3 carbon inventory are generally quite similar. Finally, an existing forest inventory plot grid in Sundarbans provided an opportunity to leverage past data to compare historic and future carbon stocks and emissions.

Objectives

A specific objective is to establish a plan for a combined carbon and resource inventory of the SRF to support: a) entry into global carbon markets, and b) an updated forest management plan. Although there are a number of suitable methods for measuring forest carbon stocks, the focus here is to adapt international standards per guidelines of the Intergovernmental Panel on Climate Change (IPCC) and relevant sourcebooks. The aim is to provide instruction on field measurements and computations that will support entry into regulatory or voluntary carbon markets at a high tier. However, it should be noted that the technical aspect of quantifying forest carbon is one of several elements of carbon accounting schemes. These other important elements include social, political, and economic factors—for example, addressing permanence, leakage, governance, etc., are not covered here. Definitions and information on those topics can be found in the IPCC guidelines and associated sourcebooks.

Inventory of Current C Stocks

Project Area Boundary

The inventory area is defined as the Sundarbans Reserve Forest (SRF), the boundaries of which are well defined by relevant legislation and are well mapped. The aquatic portions of SRF, the rivers and sea channels are not considered with respect to carbon storage under current regulations or markets. Carbon accounting and markets are currently focused on terrestrial carbon stores only, particularly forests. This means that, although the total area within SRF is ~600,000 hectares, only the ~412,000 hectares of actual land area are currently eligible for carbon accounting and carbon markets. This means that total carbon stocks in SRF were computed over the 412,000 hectares of land, not by the 600,000 hectares of total area.

Stratification of the Project Area

For Sundarbans, it was recommended not to priori stratify the project area. This recommendation was for several reasons. First, an existing systematic sampling grid is already in place, with historic data available from those ground points. This will allow past, current, and future data to be evaluated in a consistent manner. Second, as long as a systematic sampling grid was started from a random point (which the SRF inventory grid was), that sample layout is considered the most rigorous and intuitive. Third, Sundarbans is a dynamic region, with short- and long-term changes in forest cover and biomass occurring due to changes in hydrology, sedimentation, disease, and human factors. Thus, a stratification employed today may not make sense in the future as vegetation communities and lands shift spatially. For information purposes, in addition to presenting reserve-wide estimates (non-stratified), we also present summaries by vegetation type and management unit.

Carbon Pool Measured

Most international standards divide forests into roughly five carbon pools: i) above ground and below ground biomass of live trees, ii) non-tree vegetation, iii) dead wood, iv) forest floor (litter), and v) soil. Not all pools are required to be measured in every project; decisions can be made at the project level to streamline the effort involved in carbon assessment. A pool should be measured if it is large, if it is likely to be affected by land use, or if the land-use effects or size of the pool are uncertain. Small pools or those unlikely to be affected by land use may be excluded. For the SRF carbon assessment, FD suggested a recommendation to measure trees, non-tree vegetation, dead wood, and soil. Trees are the most susceptible to land use activities, and soil may be the largest and most uncertain carbon pool in mangroves. Dead wood and non-tree vegetation may be a significant biomass component in SRF and may change significantly with logging activities. Forest floor is usually a minor or even negligible biomass component in Asian-Pacific mangroves; as SRF is similar, this pool was excluded.

Methods for measuring trees, non-tree vegetation, and dead wood were adapted from relevant IPCC-associated sourcebooks. In brief, trees were quantified by stem surveys for large and small trees, non-tree vegetation was quantified by counts combined with allometric destructive harvests, and dead wood was quantified by line-intercept transects. Because mangrove soils are often C-rich and vulnerable to land-use change to deeper layers, soils were measured to 1-meter depth rather than only 30 cm as commonly recommended. To reduce the amount of material to be processed, sub-sampling was employed, taking advantage of the fact that mangrove soils are typically non-differentiated over the top meter of soil. Thus, rather than taking a core of the entire top metre, manageable sub-samples of 5 cm were taken representing 0-30 cm depth and 30-100 cm depth, respectively.

Type, Number and Location of Measurement Plots

Plot Shape and Clustering

The shape and size of sample plots is a trade-off between accuracy, precision, time, and cost for measurement. Plots can either be one fixed size or 'nested,' meaning that they contain smaller sub-units for various C pools. Nested plots are generally more practical and efficient in forests with a range of stem diameters and densities, and were used in this inventory. Clustered plot designs (using multiple 'subplots') tend to capture more micro site variation in vegetation, soils, etc., thereby reducing among-plot variation (increasing overall precision). For the SRF carbon assessment, a clustered plot composed of five circular subplots was employed, thus taking advantage of the increased precision of clustered sampling, and the fact that this plot design was employed during the previous forest inventory for SRF.

Number and Location of Plots

The last SRF inventory conducted in 1997, sampled approximately 1,200 plots situated on a systematic grid at 1-minute intervals of latitude/longitude. Based on logistical constraints communicated by the Forest Department, approximately 150-300 plots were the maximum number that could be sampled in a given census effort (300 in two field seasons). Although 300 were the desired and recommended number, 150 were adequate to achieve reasonable precision. The lower number is still likely adequate for the C assessment given local circumstances, and is similar to plot densities in difficult-access, hard to reach areas that has been used by the United States' Forest Inventory and Analysis program. To facilitate these options, the original plot grid was sub-sampled by selecting every second plot in both the x and y directions. This yielded 295 plots (the full option). To attain a lower plot density, every second row of this new grid was sampled; this yielded 155 plots. Carbon inventory sample plots in the Sundarbans is shown in Figure 1.

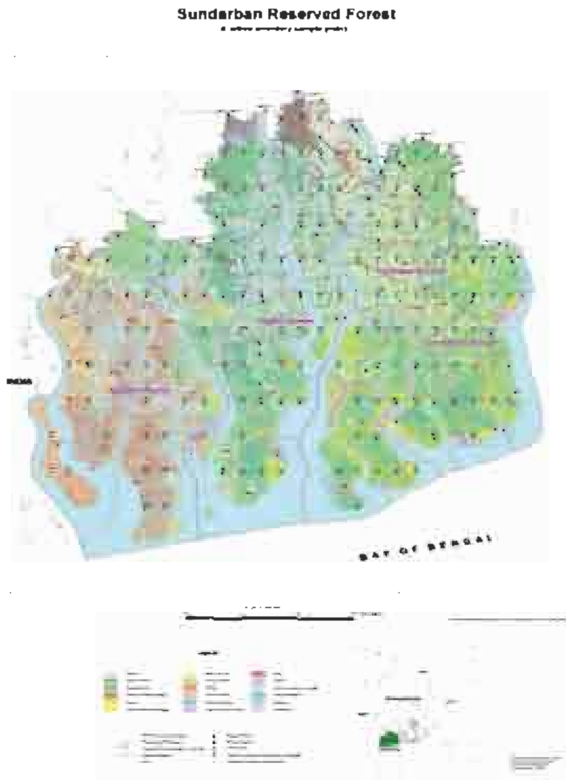

Figure 1. Carbon inventory sample plots in the Sundarbans.

Field Inventory

The field inventory started with four days of in-situ field training, during which the first plots were surveyed. Officials from the USFS, Bangladesh Forest Department, and IPAC accompanied the participants. Participants learned the field protocols, practiced the use of instruments, and discussed probable questions regarding the inventory process. The actual inventory started in December, 2009, led by two Assistant Conservator of Forests (ACFs).

Of the 155 inventory plots (originally established in 1996-97) targeted for re-sampling, 5 were now under water due to erosion, subsidence, or canal migration (and possibly sea-level rise). At least two of these five losses were apparently due to recent cyclone damage. Thus, a total of 150 plots were sampled in the 2009-10 inventory. Plots which were partially under large canals were recorded as such, with an estimate of the percent of the plot area under water and measurements taken as normal in above-water portions.

Quality Assurance / Quality Control (QA/QC)

- Quality assurance / quality control activities were emphasized from the outset of the 2009-10 inventory. Field procedures were subject to strict oversight and review by the project leaders. QA/QC had been maintained by following ways:The crew carried the protocol at all times in the field, and any confusion could be solved by referring to the protocols as well as the local knowledge of team members.
- Before starting the journey, the plot location and access route were thoroughly studied using GPS units and detailed maps.
- Re-arrangement of team composition was done weekly. In this way, any gaps or methodological differences were minimized

- Each completed data sheet was reviewed in the field. The bottom of every data sheet provides room to document quality control activities. At the end of every field outing, all data sheets were reviewed by a crew member for completeness, legibility and accuracy.
- At the end of the inventory, completed data sheets were photo-copied and stored in two physically separate secure locations (Forest Department and IPAC offices).
- Field data collection procedures were also observed and checked by higher officials of the Forest Department and IPAC. The officials accompanied the inventory team to a subset of plots to observe the data collection procedure.

The data entry process was conducted very carefully, with close supervision by the team leaders. Entered data were also checked and reviewed. After completion of data entry, a randomly selected 10% of plots were cross-checked for data entry errors, plus spot-checking of others. The observed error rate was less than 1%, which was deemed acceptable and unlikely to affect overall estimates significantly. The database was also checked for extreme outlier values (e.g., trees larger than 200 cm) to eliminate potentially influential errors. The final electronic data files, including one version with only field-collected numbers and one version with C computations, are stored with FD personnel, IPAC offices, and USFS personnel.

Data and Sample Management

Field data were entered into computerized spreadsheets periodically and backed up electronically in multiple physical locations. Completed data forms were checked and reviewed in the field and data entry was also reviewed. At the end of the inventory, completed data forms were photo-copied and stored in two physically separate secure locations (Forest Department and IPAC offices). The final electronic data files, including one version with only field-collected numbers and one version with C computations, are stored with FD personnel, IPAC offices, and USFS personnel. Soil samples were air-dried in the field, oven-dried to constant mass at 60°C at the Khulna IPAC cluster office, then sent to Chittagong. Soil carbon analyses were conducted in the laboratory of the soil science in Bangladesh Forest Research Institute (BFRI).

Data Analysis and Results

Above ground and root C pools were computed using both locally derived allometries (via destructive harvests of various shrub species outside the plots) and international standard common mangrove tree allometries, combined with local tables of wood density by tree species. Soil C storage was calculated as the product of soil C concentration (% of dry mass determined by wet oxidation techniques by BFRI), soil bulk density, and soil depth range. All plot-level computations were corrected for the portion of the plot falling on a canal >30 m width, so as not to bias the land-based C density estimates with areas that are officially considered water. The bulk density was estimated (by dividing the mass of the oven-dry soil sample by the volume of the sample) at the office whereas %OC carbon was estimated by the BFRI based on wet oxidation method. The following formula was employed for calculating soil carbon per ha :

Soil C (Mg/ha) = bulk density (g/m3) x soil depth interval (m) x %OC x 0.01

Carbon Density

Mean C density (including soil) was found as 255.20 Mg/ha (95%CI: ±17 Mg/ha). Total SRF C was 105.06 mega ton. Estimated current carbon pools are shown in Table 1. Mean total C density (excluding soil) was 136 Mg/ha (95%CI: ±16 Mg/ha), or moderate to high compared to other mangroves around the world. C density of non-soil pools ranged from a low of 20 Mg/ha in one gewa- dominated stand to a high of 446 Mg/ha in one sundri-dominated stand. Trees constituted the bulk of the C density across the forest reserve, with a mean of 82 Mg/ha above ground and 36 Mg/ha below ground, which combines to account for 87% of all non-soil C. Soil C density ranged from a low of 53 Mg/ha to a high of 438

Mg/ha. Both of them belong to Sundri-dominated stands. Soil C contributes 47% and the rest 53% coming from non soil pools of Sundarbans.

Table 1. Mean carbon pools in the Sundarbans Reserve Forest, 2009-10 inventory

Carbon pool	Carbon Density Mega gram/ hectare	Percentage
Trees aboveground (stems + foliage)	82.4	32.29
Trees belowground (roots)	35.9	14.07
Saplings + seedlings aboveground	1.4	0.55
Saplings + seedlings belowground	1.0	0.39
Non tree vegetationj	2.8	1.10
Goran	7.9	3.10
Down wood	4.3	1.68
Soil 0-100 cm	119.5	46.83
Total	**255.2**	**100.00**

Uncertainty estimates (95% confidence intervals, or 95% CIs) were computed using standard techniques outlined in the protocol. The 95% CI for the total C density was derived through basic error propagation (square root of the summed squares of component pools), as outlined in the protocol. Because some pools were highly correlated, those pools were aggregated in an ecologically sensible way for error propagation (e.g., tree above ground and below ground pools were obviously correlated and were combined into a single 'tree' pool for the uncertainty propagation step).
Although the plot sampling was not strictly stratified a priori, the grid-based sample covered all major land types and allowed post hoc analysis of different strata (e.g., vegetation types, management units). With respect to vegetation type, plots classified as sundri-dominated forest contained by far the highest C density at 169 Mg/ha, followed by gewa-dominated classifications at 102 Mg/ha . Low-stature goran-dominated vegetation contained the lowest C density at 64 Mg/ha.

Carbon stock of SRF

Total C stock and CO_2 equivalents across the Sundarbans Reserve Forest is given in Table 2.

Table 2. Carbon stock and CO_2 equivalents of SRF

Mean Total C Density (Mega gram/ha)	SRF land area (ha)	Total SRF C stock (Mega ton)	CO2 Equivalents (Mega ton)	95% Cl of Total C stock (Mega ton)	95% Cl for CO2 Equivalents (Mega ton)
255.20 (± 17)	411693	105.06	385.6	98-112	360-411

Notes: - 1 Mega tone = 10^6 Mg.
- Land area is from RIMS, FD GIS data.
- 95% confidence limits for total C stock and CO_2 equivalents are simple propagation of lower and upper confidence limits of C density multiplied by the land area. No uncertainty estimate was available for land area, precluding full error propagation incorporating uncertainties in both parameters

Assessing C Stock Change during 1997-2010

The current inventory re-sampled a subset of a previous field inventory, which was conducted in 1996-97. This allows a direct comparison between C stocks at the different time points, and an assessment of associated C emissions or uptake during the interim.

All efforts were made to conduct the change assessment using consistent methodologies. Computations of C density and C stocks in the 1996-97 inventory followed the exact same procedures as that for the 2009-10 inventory. For consistency, only the 155 plots in common between both the surveys were included in the change assessment (rather than using all 1,200 from the 1996-97 inventory). It should be noted that the re-sampled plots were in the same locations in both inventories, but some spatial errors likely existed.

Certain differences existed in the 1997 dataset, requiring some adjustment of method and limiting what could actually be compared between time points. Mainly, the 1997 inventory was largely a timber resource inventory rather than a carbon inventory, so effectively only trees were measured. Non-tree pools were largely ignored in the previous survey. Golpata *(Nypa Fruticans)* was measured in some plots in 1996-97, but the sample size was insufficient to include in the change assessment. Therefore, only tree pools (above ground and below ground) could be tracked over time. Trees are the most ready indicators of forest change and degradation, so this change assessment should still yield quite valuable insight.
For the five inventory plots, that were surveyed in 1996-97 but were under water in 2009-10 due to land subsidence, erosion, channel migration, or cyclone damage, were included these in the change assessment. The loss of standing C stock in these sites (reduction to zero tree biomass) was factored into the estimate of change. Because of the inclusion of these five plots, there was the need to use an adjusted estimate of mean C density for the 2009-10 dataset compared to the estimate presented above, which excluded areas now under large canals. This difference was relatively minor. Table 3 gives a comparison of mean C pools in SRF between the 1996-97 and 2009-10 inventories.

Table 3. Comparison of mean C pools in SRF between the 1996-97 and 2009-10 inventories

C Pool	1997 inventory		2010 inventory		Change(2010 minus 1997)	
	Cdensity (Mega gram/ha)	95% CI	Cdensity (Mega gram/ha)	95% CI	Cdensity (Mega gram/ha)	95% CI
Trees Above ground (Stem+ foliage)	46	± 4.3	80	±11	+34	±12
Trees below ground (Roots)	27.4	±2.3	35	±4.2	+7.6	± 4.6
Sapling+ Seedling (Above ground)	1.6	± 0.2	1.3	± 0.1	- 0.3	± 0.2
Sapling + Seedling (Below ground)	1.0	±0.1	1.0	± 0.1	0	± 0.1
Total (Trees, Sap-Seedling Only)	76	± 6.6	117	± 15	+ 41	± 17

Note: Only tree and sapling/seedling pools could be compared because these were the only pools measured in the 1996-97 inventory.
(+) and (-) in change column indicate increases or decreases, respectively, during the 1997 to 2010 time period. Estimates for 2010 pools are slightly adjusted from previous section because this analysis included plots that were land in 1997 but now submerged in 2010 (land subsidence, etc.). These were excluded from the land-based C density estimate for the current C stock analysis, but were included as negatively changing plots in the change assessment. The difference is minor.

It is clear from Table 3 that in 2010 C density has increased nearly 54% than that of 1997.

The change quantified (Figure 2) was strongly positive, with confidence intervals significantly different from zero. A significant portion of this difference could be an artifact of sampling error. Some of the changes in C density within particular plots were extremely high (e.g., >200 Mg/ha change in 13 years) and likely unrealistic in biological terms. Errors in re-locating exact plot locations could also play a role. In addition, metadata and protocol locating exact plot locations could also play a role. In addition, metadata and protocol descriptions for the 1996-97 inventory were lacking, meaning that the data had to be interpreted through the inventory report results only. , dead trees were not measured in that survey and adding those would have

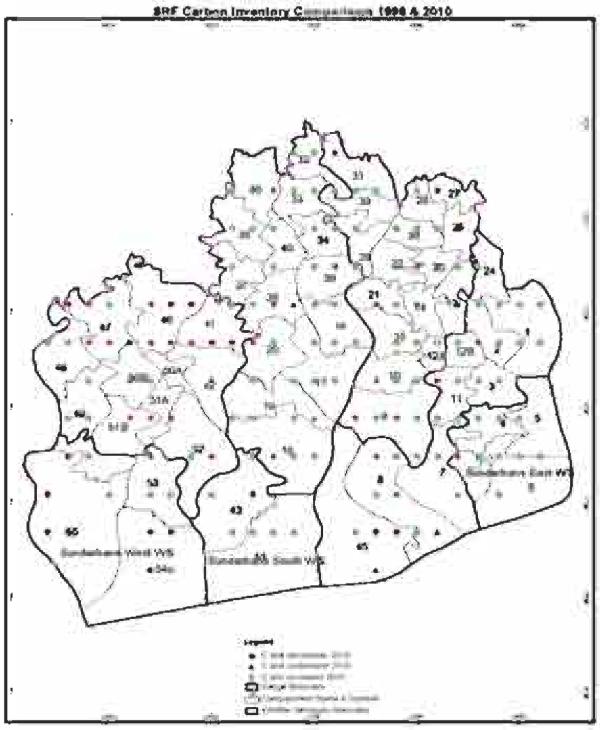

Figure 2. 2010 C inventory plots increased or decreased compared to 1997.

increased the 1997 C stocks and reduced the amount of positive change between surveys. The quality of the 2010 field data collection and data management was documented for the current inventory, but documentation of QA/QC for the 1996-97 inventory was not available. The degree to which any or all of these errors may have affected the change estimate is almost impossible to know with certainty.

The general pattern of observed change is ecologically sensible. In the absence of commercial harvesting, a typical stand development pattern is that tree densities thin out over time (through competitive exclusion and other mortality), with the remaining trees increasing in size. Indeed, compared to the 1997 data, the 2010 inventory showed lower stem densities, especially of small trees, but larger mean stem size and total basal area (Figure 7.2). The magnitude of this difference was large for a 13-year period, but the general pattern is fairly reasonable. Whether due to actual succession dynamics, sampling error, or some combination of the two, this difference is largely what explains the higher C stocks in 2010.

Estimation of Annual Growth

The Annual Allowable Cuts (AAC) have been prescribed in the IFMP based on the 1996-97 inventory. Based on 2009-10 inventory the AAC for different species in the Sundarbans Reserved Forest was estimated using the following formulae:

AAC = (Present standing mature volume+ ½ growth during the period) / Period of cutting cycle.

As per the Austrian formula:

$AAC = I + (Ga – Gr)/A$

where, I = annual increment,

Ga = present Growing stock,

Gr = desired growing stock (indicated by yield table or some other empirical standards)

A = an arbitrary adjust period, which may be a full rotation or any selected period

Here, if we consider Ga = Gr, then AAC approximates to the annual increment.

Table 4 . Annual growth statistics of different species in the SRF

Species	Growing Stock (V10/ha)	Increment (V10/ha)	AAC (V10/ha/year)	DBH limit (cm)	Total area (ha)	Estimated AAC (V10/ha/year)	Working Plan Suggested AAC (cum)	Removal of increment (cum)
1	2	3	4	5	6	7	8	9
Sundri	8.815	7.165	0.620	30	231159	143285	54000	82808
Gewa	0.462	0.410	0.033	15	296698	9887	53000	6081
Keora	0.945	-1.335	0.014	25	31920	4424	29852	-21308
Baen	4.601	2.914	0.303			0		0
Others	2.313	1.092	0.143	25	231159	33041	23000	12626
Goran (Volume)	1.357	0.346	0.077	2.5				0
Goran (kg)	1458	402	82.96					0

Estimates for Additionality for REDD+

The total annual increment (Table 4) for sundri, gewa, keora and other species (except goran) stand at 53,739 tons (=0.67x80,207 cu.m), whereas the annual harvests for goran averaged as 62,400 metric tons. This means that the annual biomass increment is approximately 116,139 metric tons or 58,068.5 metric tons of C. If multiplied by the molecular conversion factor of 44/12, the total annual CO_2e equivalent (CO_2e) is 213,115 metric tons. Thus for 30 years project the CO_2e will be 6,393,452 metric tons.

The above-derived estimates of the additionality do not include soil carbon additions; although it is found that 49 mega ton (47% of 105) of soil C is stored in this forest, which may be substantially reduced in case mangroves are degraded. Additionality of soil C needs to be considered and calculated on consideration of some references to achieve full advantages of REDD+.

Collaborative REDD+IFM Sundarbans Project, CRISP (Proposed)

The Collaborative REDD+IFM Sundarbans Project, CRISP (\proposed) is a project currently being designed to meet the requirements of an Agriculture, Forestry and Other Land Use (AFOLU) project. Specifically, CRISP is hoped to qualify for consideration under the REDD category of eligible activities aimed at avoiding unplanned frontier deforestation and degradation, and IFM category. In this case activities are aimed at conversion of logged forests to protected forests including protecting currently logged or degraded forests from further logging as defined in the Voluntary Carbon Standards (VCS) 2007.1 and VCS Tool for AFOLU Methodological Issues (published on 18 November 2008). The project document has been developed by largely following the approved VCS methodology : VCS Methodology VM0006 – Methodology for Carbon Accounting in Project Activities that Reduce Emissions from Mosaic Deforestation and Degradation. The CRISP is not being designed as a Grouped Project as defined in the VCS 2007.1.

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Application of Dendrochronological Techniques in Bangladesh Forests

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Abstract

Long-term tree growth data both in instrumental as well as proxy climate are scant in Bangladesh. This paper describes convenient strategies for application of dendrochronological techniques in Bangladesh forests. Preliminary step of applying this method is to asses the nature and periodicity of tree rings in the expected tree species growing here. Different strategies for the identification of tree ring boundary in different specie were discussed. Effective strategies include sampling useful tropical or subtropical species that extend naturally or planted into the country; sampling species of same genus that have already provided examples useful for dendrochronology; targeting deciduous species in seasonally dry forests. Next step is to proof the annual periodicity of the identified tree rings. A simple method for determining the periodicity of tree rings is counting rings in trees and to validate with plantation age, if reliable plantation history is known. Dendrochronology can also be used to test the annual nature of growth banding in tropical species. The cross-dating of long tree ring series between individual trees and between multiple sites in a region is strong evidence that the growth rings are indeed synchronized with the annual calendar. This can be confirmed by statistical test using GLK% and TBVP values. Another option is to check whether the ring-width data are correlated with long annual records of climate variability, for instance precipitation. Blind cross-dating to test the harvesting dates of known-age trees can provide another rigorous proof of annual growth rings in a particular species.

Keywords: Tropical dendrochronology, Tree ring, Periodicity

Introduction

Tropical forests are facing challenges due to overwhelming population pressure and rapid degradation of forest resources. Establishment of new management plan is essential to conserve rich biodiversity, and to ensure sustainable forest management. However, there is paucity of age, growth rate, age related yield data which are necessary basic information for sustainable silvicultural practice. Dendrochronology (tree-ring studies) is a powerful tool for developing high-resolution proxies for long-term growth dynamics and climate reconstruction in temperate and boreal forests (Schweingruber, 1988; Briffa, 2000). In the tropics, this method is not widely applied due to complex ring anatomy and in most of the species tree-rings are not distinct (Worbes, 1990; Sass *et al.*, 1995; Schmitz *et al.*, 2007). While rings are reasonably evident in some species, their periodicity is not tested to develop long chronologies because there is an assumption that tropical trees do not form annual growth rings (Whitmore, 1998). Moreover, the problem is aggravated by suppressed or senescent growth, particularly when attended by false rings, discontinuous rings, and other anatomical complications (Priya and Bhat, 1999; Détienne, 1989). Nevertheless, there is a growing interest in tropical dendrochronology globally, because of its potential benefits to climatology, forest ecology, and silviculture.

Development of tropical tree-ring chronologies of teak from India and Thailand was the land mark for stimulating dendrochronology in the tropics (Pumijumnong and Park, 1999; Shah *et al.*, 2007). Due to lack of seasonality, clear dormancy in cambial activity is absent and many tropical species fail to produce clear growth ring (Détienne 1989, Sass *et al.* 1995), which restrains dendrochronologists from using classical denrochronological method, for instance, tree-ring analysis (Worbes, 1990). Despite of these difficulties, distinct annual rings have been identified in a large number of tropical trees over past two decades (Brienen and Zuidema, 2005; Roig *et al.*, 2005; Verheyden *et al.*, 2005; Schöngart *et al.*, 2006), and their formation has been linked to local climatic factors, i.e., rainfall and temperature (Worbes, 1995), hydrological factors, i.e. flood (Worbes, 1989) or phenology of trees (Jacoby, 1989; Borchert, 1999).

Even though Bangladesh forest has been managed under scientific forest management plan from colonial period, the stock of timber has drastically declined. Due to the inverse trend of population growth, the country is facing to the challenge of a large gap between the supply of and demand for wood materials which is expected to be more acute in the near future (Chowdhury *et al.*, 2005). Previous management plans prescribed on the basis of volume estimation of the trees ignoring long-term intra-annual growth data (Pant, 1990). Dependable intra-annual growth data are also lacking for most of the species. Short-term growth data are available for few species (Siddiqi, 2001). But those were from few locations and collected by traditional dbh measurement where a considerable error may exist on those estimations. Without long-term intra-annual growth data, it is difficult to determine allowable annual cut, and thus management plans fail to ensure sustainable forest management. Proxy data is also scarce in the country which is an important requisite for past climate data reconstruction.

This paper attempts to summarize some of the useful strategies that have already been suggested, and explains how dendrochronology can also be used to provide rigorous testing for reliable annual ring formation in the tree species growing in Bangladesh. In addition, few applications of tree ring series have been discussed.

Strategies for Searching Potential Tree Species with Distinct Growth Rings

Primary step of applying dendrchronological techniques is to identify the distinct growth ring. However, tree ring characteristics in most of species growing in Bangladesh are so far unexplored. Therefore, some efficient strategies have been described here to identify growth rings.

One highly effective strategy is to simply identify those tropical or subtropical species of known dendrochronological value which have a distribution into Bangladesh. For example, *Tectona grandis* is distributed in Bangladesh and its potentiality and long-term chronologies have been developed in India and Thailand (Pumijumnong and Park, 1999; Shah *et al.*, 2007). Therefore, this species can be used for dendrochrnogical studies in Bangladesh. While there is no guarantee that the tropical members of a particular species will indeed be useful for this. For example, *Acacia auriculiformis* growing in India does not produce clearly distinct growth ring (Rao *et al.*, 2007), while samples of same species growing in Bangladesh show distinct growth ring (Chowdhury *et al.*, 2009a; Figure 1B).

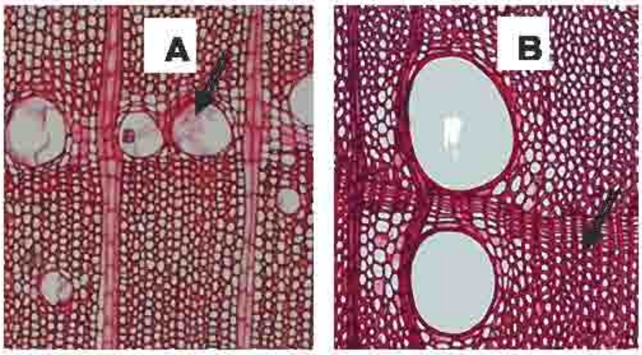

Figure 1. Microtome images showing wood anatomical nature of the distinct growth rings (arrow indicated). –A: *Tectona grandis* –B: *Acacia auriculiformis*; Scale bars = 200 μm.

Another strategy would be to build upon previous success in a particular genus. A few species of some genera have been shown to produce growth rings with specific boundary marker. And progress can be made searching species of same genus growing in Bangladesh. For example, *Sonnertia alba* is an important species of *Sonneratia* genus and growth rings can be delineated by flattened fibers (Rao *et al.*, 1987).

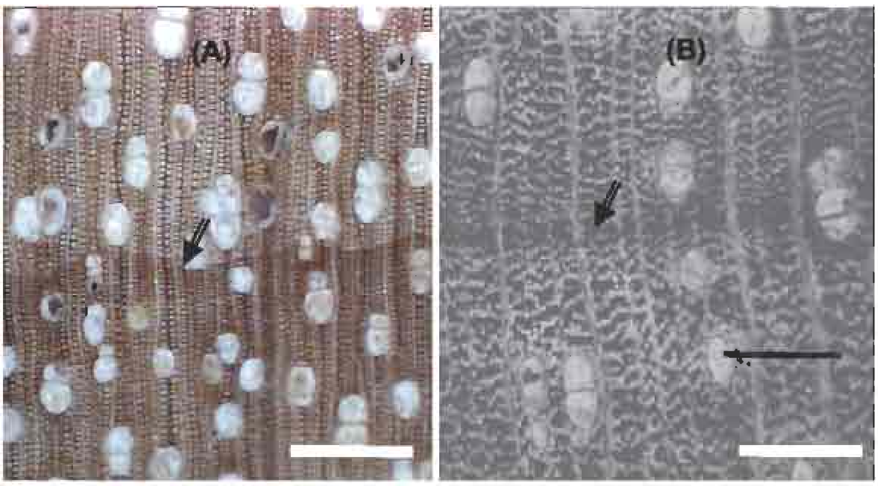

Figure 2. Detail of sanded stem discs showing wood anatomical nature of the distinct growth rings (arrow indicated). (A): *Sonneratia apetala.* (B): *Heritiera fomes*; Scale bars = 500 μm.

Another species of same genus, for instance, *S. apetala* growing in Bangladesh mangroves also shows distinct growth rings which also can be identified with same anatomical features (Chowdhury *et al.*, 2008; Figure 2A). This phenomenon is not common always. For example, the growth rings in *Heritiera littoralis* from the Philippines were reported to be delineated by an initial band of a high frequency of vessels (Panshin, 1932). On the other hand, distinct growth rings delimited, by a decreased frequency of parenchyma bands towards the latewood in *H. fomes* growing in mangroves of Bangladesh (Chowdhury *et al.*, 2008; Figure 1B). The difference in the anatomy of the ring border might be an inter-specific variation.

Another effective strategy would be to target the seasonally deciduous species in the effort to identify useful for dendrochronological study (Jacoby, 1989; Worbes, 1995), particularly those forests which experience a single prolonged dry season and wet season. Bangladesh climate is characterized by monsoon with one dry and a wet season (Figure 3). Therefore, this can be assumed that deciduous trees should show cambial dormancy in the dry season. Because those trees shed their leaves at the end of wet season and leaves flush at the beginning of wet season as an indicator of cambial reactivation. Borchert (1999) has also discussed the important aspect of phenology, and by inference moisture relations, of species in moist evergreen and dry deciduous forests in the tropics. In deciduous species, a clear seasonal segregation of leaf flush and leaf fall appears to be an important factor in the formation of distinct growth bands (Stahle *et al.*, 1997, 1999a). This trait is evident in the phenology of several broadleaf species growing in Bangladesh, and known to be useful for dendrochronology, for example *Tectona grandis.*

According to Troup (1921) the leafless period of this species is from November to March (Figure 3). Growth reactivates in this species might be started with onset of the rain and flushing new leaves. In this stage, earlywood (ring porous vessels) used to form in *T. grandis* and the growth ring boundary can be delineated easily with this anatomical feature (Figure 1A).

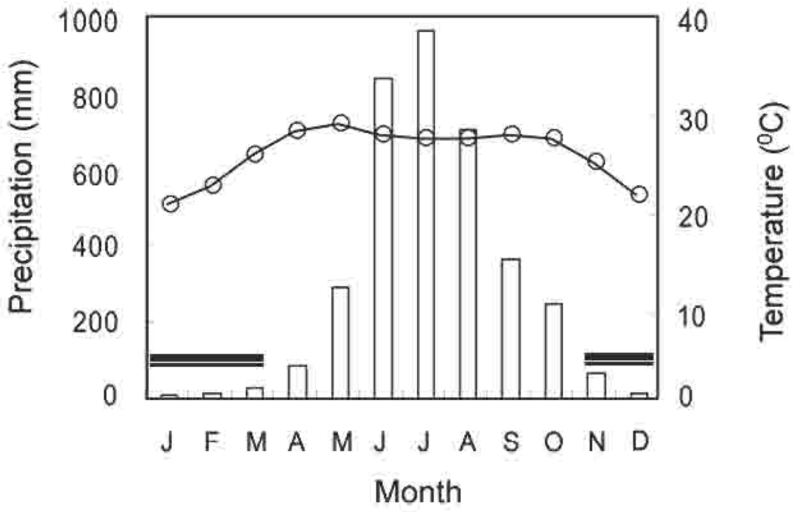

Figure 3. Climate diagram of Bangladesh. Open square, average monthly precipitation; open circle, average monthly temperature. Dash lines indicate the leafless period of *T. grandis*.

Other species which has not any existent clue about growth ring, ring formation can be checked through detailed anatomical studies. This could be a troublesome strategy and success may not be always achieved because indistinct tree ring boundary is also common in Bangladesh, for instance *Casuarina equsetifolia* (Chowdhury *et al.*, 2009b).

Strategies for Searching Periodicity of Growth Rings

Once distinctive growth ring banding has been identified in the minute cellular anatomy of a particular species, whether based on ring porosity, semi-ring porosity, marginal parenchyma, flattened fibers or other structures, it can be very difficult to prove that these growth bands are indeed reliable annual tree rings.

A simple method for determining the periodicity of tree rings is counting rings in trees of known age (Stahle *et al.*, 1999b). However, this method has limited scope and can be applied where exact plantation date is known, such as in trees from plantations and botanical gardens. In a recent study, (Chowdhury *et al.*, 2008) describes that the number of growth rings in plantation-grown *S. apetala* (sample location, Kumira, Chittagong, Bangladesh) corresponding with the plantation age. In this study, out of three sample trees of the 22-year-old plantation, one tree (Tw57952) only showed 21 tree rings. Vacancy filling used to be done after one year of plantation establishment can explain this time lag, although the possibility of a missing ring can not be excluded.

Dendrochronology can also provide a robust test of the annual nature of growth banding over the entire life span of tropical species. If the patterns of wide and narrow growth bands identified in a particular tropical species actually cross-date among all trees in a stand, and among trees of the same species at different locations in a given climate province, then there is little doubt that the growth rings are indeed annual and are not simply structural features of the xylem that fail to synchronize with the annual cycle. In a preliminary study (Chowdhury *et al.*, 2008) showed the annual periodicity of *S. apetala* and *H. fomes* on the basis of visual synchronization among the trees with the climate data. In this paper, we have assessed tree ring series using dendrochronological statistics, i.e., GLK% and TVBP values (Table 1). The ring chronologies of the three plantation-grown trees are very similar (Fig. 4a) and cross-dated very well (Table 1) indicating that the trees showed a common growth response towards external factors.

Table 1. GLK and TVBP values of crossdating

Species	Location	Samples	GLK%	TVBP
S. apetala	Plantation	Tw57952 & Tw57953	79	3.9
		Tw57952 & Tw57954	84	2.7
		Tw57953 & Tw57954	80	8.2
	Natural	Tw57955 & Tw57956	82	3.3
		Tw57955 & Tw57957	76	2.4
		Tw57956 & Tw57957	79	4.5
H. fomes	Natural	Tw58370 & Tw58602	76	4.9
		Tw58602 & Tw58601	73	3.1
		Tw58370 & Tw58601	70	4.1

Cross-dating exists because the growth of trees is periodical, tied to the annual calendar by the seasonality of climate, and synchronized among the trees. When considering *H. fomes*, visual synchronization (Fig. 4c) and statistical values (Table 1) show that all three trees have a similar ring width pattern indicating that the growth rings of this species are likely to be annual too. The lower synchronization and GLK% were found in *H. fomes*.

If the growth banding cannot be strictly linked to the annual cycle, then the width variations will not readily synchronize among trees and the ring sequences will not cross-date. Many tropical hardwoods are obviously quite old and have distinctive growth boundary (Goldsmith and Carter, 1981), but this boundary is usually sub-annual and the time series patterns created by these bands cannot be cross synchronized among opposite radii of the same tree, much less between different trees.

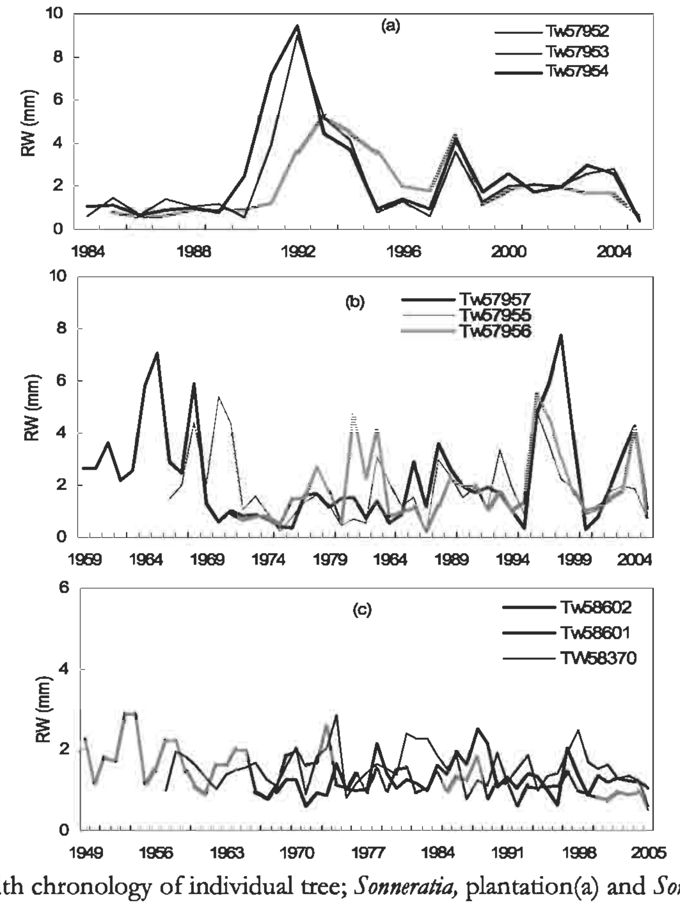

Figure 4. Ring width chronology of individual tree; *Sonneratia,* plantation(a) and *Sonneraita,* natural (b); *Heritiera* (c) (Adapted from Chowdhury *et al.*, 2008).

Examples of Application of Tree Ring Series

Even though previous examples (tree ring series of two major mangrove species) were based on limited number of samples, we tried to show some potential applications of those tree ring series as examples.

Correlation with Precipitation

The correlation of the average ring width with the annual precipitation is ($r = 0.43, p < 0.05, n = 22$) for *S. apetala* in the plantation, ($r = 0.29, p < 0.05, n = 45$) in the natural forests and ($r = 0.35, p < 0.05, n = 52$) for *H. fomes*. Lower correlation values indicate that the formation of the growth rings is not primarily determined by the precipitation. This finding is in agreement with the ring formation in the mangrove *R. mucronata*. Here, it is the soil water salinity, and not the precipitation per site, that influences ring formation (Verheyden *et al.*, 2004a, 2005). Also rivers (channels inside the forests) water salinity in the Sundarbans is higher in the dry season compared to the wet season (Siddiqi, 2001) and can therefore trigger ring formation at the beginning of the wet season. The changes in salinity are due to a decreased water flow in the main river channel of the Sundarbans in the dry season (November to June) compared to the wet season (July to October) (Mirza, 1998).

Developing Growth and Age Curves

Growth and age curves were constructed from both mangrove species (Figure 5). The growth rate of the plantation-grown *S. apetala* was higher than that of the trees in the natural forest (Figure 5a). The growth rate of *S. apetala* (0.23 cm/year and 0.20 cm/year for plantation and natural forest respectively) was higher than that of *H. fomes* (0.14 cm/ year).

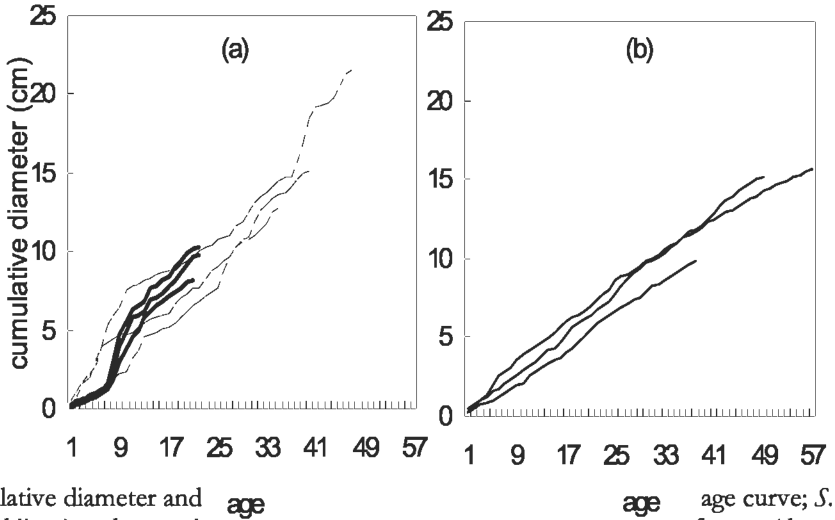

Figure 5. Cumulative diameter and age curve; *S. apetala* (a), plantation (bold lines) and natural forests (doted lines); *H. fomes* from the natural forests (b)

However, higher growth rate in the plantation trees might be due to the more favorable light conditions in the regular spaced plantation. *S. apetala* from the plantation grew much slower in the initial, i.e., juvenile phase as compared to *S. apetala* from the natural forest. After the initial phase of low growth, the plantation trees show a higher growth level than the naturally-grown trees. This can be explained by the fact that the 1-year-old seedlings after transplanting into the plantation need some time to adjust to the site conditions. However, in comparison between two species *S. apetala* has a higher growth rate due to its pioneer tree characters whereas *H. fomes* is a slow growing and shade tolerant species (Siddiqi, 2001).

Strategies for Searching Other Distinct Variables

When annual growth rings are identified, ring width series do not always cross-correlate (i.e. the ring width series of different trees show different patterns) or do not show a clear relationship with environmental variables (February and Stock, 1998). In this case, it is important to check for other proxy variable/s because environmental information can also be archived in the wood in a variety of other ways, such as in the stable carbon and oxygen isotope ratio composition (e.g. Farquhar *et al.*, 1982, Verheyden *et al.*, 2004), in the wood density (Schweingruber *et al.*, 1991) or in the wood anatomy (Baas and Carlquist, 1985; Baas, 1987). Only a limited number of studies have used wood anatomical features in tree rings in the context of a dendrochronological investigation. However, these studies have confirmed the great potential of time series of wood anatomical features, in particular vessel density and diameter, as a proxy for environmental conditions (Sass and Eckstein, 1995; Gillespie *et al.*, 1998; Pumijumnong and Park, 1999; García-Gonzales and Eckstein, 2003; Verheyden *et al.*, 2005; Eckstein, 2004; Schmitz *et al.*, 2006). In contrast to the expectations, all analysed vessel features, i.e. density, tangential diameter, radial diameter and percentage solitary vessels did not show a clear annual periodicity in species, *S. apetala* and *H. fomes* (Figure 6). In a previous study (Chowdhury *et al.*, 2008) noted similar opinion for another anatomical variable, i.e., vessel area.

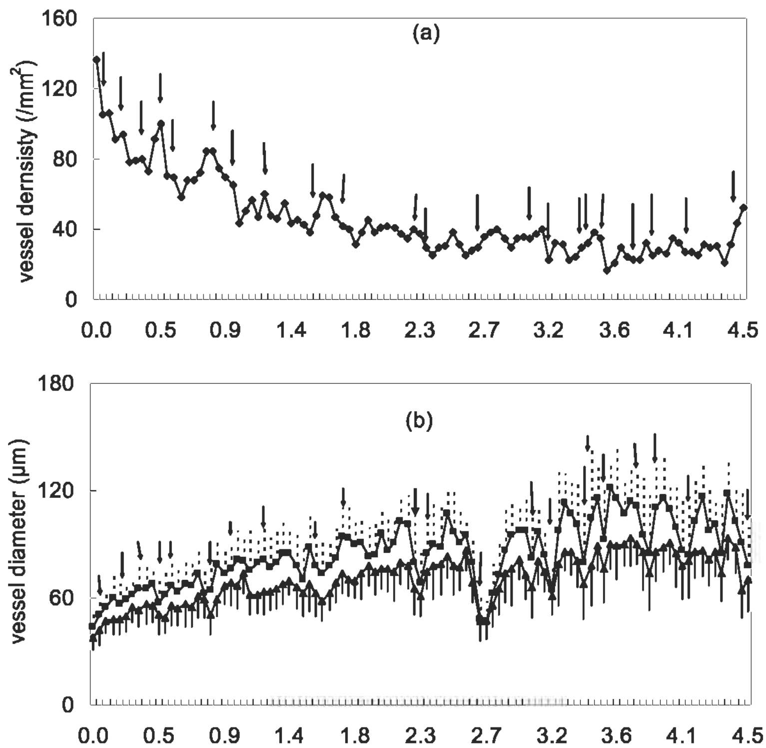

Figure 6. Vessel density (a) and diameter (b) curve of *S. apetala* from plantation sample; arrow indicates the ring border

There is a slight tendency in both species that abrupt changes in both vessel density and vessel size coincide with tree-ring boundaries, i.e., the location of the band of flattened fibres in *Sonneratia* or decreased frequency of parenchyma bands in *H. fomes*. This might be due to the climatic patterns. Arnold and Mauseth (1999) reported that plants can respond to changes in water availability by either changing the vessel diameter or vessel density strongly or by both weakly. The difference in mean diameters was therefore as a result of a higher percentage of small vessels produced during the dry season (Verheyden *et al.*, 2005). In our case ring boundary sometimes corresponded with higher number of vessel density and higher vessel diameter but not always. *S. apetala* and *H. fomes* samples from the natural forests also showed similar trend (data not shown). This might be due to shifting growing season in accordance with early and/or late precipitation.

However, vessel characters (vessel density and diameter) indicated an age trend (Figure 6). Meaning that for comparative anatomical study sampling should be done from similar age group. Vessel diameters also showed fluctuations in the life time of the trees. The larger diameter vessel might produce in the favorable season (especially in starting period of the growth) to meet the increasing demand of the water conduction of the developing crown (Verheyden *et al.*, 2005).

Conclusion and Perspectives

It is observed from the findings that the tree ring characteristics in many species growing in Bangladesh are so far unexplored from dendrochronological point of view. However, the data presented in this paper showed potentiality for future dendrochronological studies. Specially, both (*S. apetala* and *H. fomes*) could provide data on tree ages and forest productivity of stands with additional possibilities for reconstructing climate records. For this purpose, it is unquestionable that further dendrochronological studies are needed in order to explore in detail into the nature of the ring formation. The annuity of the growth rings is the necessary prerequisite for the success of the cross-dating approach and the development of climate reconstructions. As useful as these dendrochronological tests can be, it will be preferable to include as many independent lines of evidence as possible, including phenological studies and cambial activity analysis. The presented are data based on high resolution microscopic system, and it is a laborious to archive the dendrochronological data with bigger number of samples and with bigger size discs. In that sense dendrochronological potentiality assessment with radio-isotope studies and/or X-ray densiometric analysis might reveal another alternative solution.

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A Model House - Made of Cement Bonded Particle Board (CBPB), an Environmental Friendly Housing Material

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Abstract

Cement bonded particle board (CBPB) is an eco-friendly housing material. The main raw materials of cement bonded particleboards (CBPB) are wood chips and Portland cement, an inorganic binder. It is virtually incombustible and can be readily machined with normal tools. It also offers properties of excellent sound absorption, thermal insulation and structural performance. Wastage of wood based industries can be used for manufacturing cement bonded particleboard (CBPB) which ensures better utilization of forest produce. In the present study cement bonded particle board (CBPB) were made using wastage of rubber wood *(Hevea brasiliensis)* and veneer. To increase the bending strength, a frame made of bamboo strips was used in the middle portion of the board. Bending strength, internal bond strength, thickness swelling and water absorption of the board were determined. The values of bending strength and internal bond strength meet the British standards specification for cement bonded particle board (BS 3669). The laboratory tests show that the strength properties and dimensional stability of CBPB meet the standard of outdoor housing materials. Beside this, compressive strength, flexural strength, porosity and water absorption of the board were investigated in Housing and Building Research Institute and compared with the other building materials (mortar and concrete). It was found that values of compressive strength and flexural strength of CBPB were better in comparison with other building materials. The higher porosity and water absorption were slightly hogher in the board materials. To investigate the durability of the board as housing materials, a demonstration house was built using CBPB at Bangladesh Forest Research Institute (BFRI) campus in 2009.

Key words: Cement bonded particle board (CBPB), Static bending strength, Internal bond strength, Thickness swelling, Water absorption, Durability, Construction material.

Introduction

Bangladesh is an over-populated country. For the construction of houses, bamboo and other vegetable fibers are used extensively in rural area of Bangladesh. These materials are very susceptible to degradation by biological agents and damaged within 4-5 years. Besides these, in rural area peoples also live in mud houses. Bangladesh has a long rainy season with humid weather and encounters disaster like flood. In some low land area, corrugated iron sheets are used for the construction of houses which are very uncomfortable in summer season and also undergo damages due to rusting. In such circumstances cement bonded particleboard (CBP) is an alternative product, which is eco-friendly, waterproof and long lasting.

Cement bonded particleboard (CBPB) is a composite made of cement, waste wood and small amounts of additives. The manufacture and utilization of the cement bonded particle board as housing component is in practice around the world. Wood cement composites materials are gaining acceptance as construction housing material because this combines advantages of constituents, cement and wood. There are over 38 CBPB plants in operations throughout the world(Moslemi,1989). The first CBPB plant was built in Switzerland under supervision of the Durison engineer Hans's Knopfel who therefore can be considered as the pioneer of CBPB. People of Soviet Union, Japan, Germany, Italy, Malaysia, Philippines, France and Thailand prefer CBPB as low cost housing component. The low income house in Manila, is made of Elton board. It withstood the force of a 250 km/hr hurricane. Not only the walls but also the floors, doors, certain furniture and shingles on the roof are made of Elton board (Engand Elten, 1996).

CBPB is used in building construction because it offers properties of excellent sound absorption, fire resistance, thermal insulation, dimensional stability, and structural performance. Wang and Takashi (1997) showed that cement-bended particleboard had high biological resistance compared to other common wood-based composite materials. Some tests done in UK suggest that conventionally made CBPB is very resistant to attack by white and brown rot fungi as well as termites (Dinwoodie and Paxton, 1991). Stillinger and Wentworth (1977) pointed out that, in tropical and subtropical countries, the problem of building low cost houses can be solved by using high density wood-cement board at extreme climatic conditions.

Proper utilization of forests and forest produce are directly related to the economy of a country especially where such resources are limited. The inefficient use of these resources has adverse impact on the forest stock. To improve this situation, effective and economic utilization of forest produces is important. Wastage of wood based industries can be used for manufacturing cement bonded particleboard (CBPB), which ensures maximum utilization of wood forest produces.

The purpose of the present study is to fabricate big size (2 feet x 4 feet) cement bonded particle board using frame of bamboo strips inside the board and to determine the strength properties and dimensional stability of CBPB. To determine the durability (fungus and termite resistance, weather resistance), a model house was constructed at Bangladesh Forest Research Institute (BFRI) campus, Chittagong, using cement bonded particle board (Figure 1).

Materials and Methods

Raw Materials

The raw materials for making cement bonded particleboard are mainly wood chips, Portland cement, calcium chloride ($CaCl_2$) and water.

Figure 1. Model house-made of Cement bonded Particle Board

Preparation and Treatment of chips

Waste wood and veneer of rubber wood *(Hevea brasiliensis)* were converted to chips in a hammer mill machine. The chips were sieved through 20 meshes screen to remove dust and fines. The wood chips were submerged under water for 48 hours to remove water soluble extractives, which inhibit the setting of cement. The chips were then air dried to 12-15 % moisture content. Frame was made using bamboo strips and soaked under water for 24 hours to leach water soluble particles.

Amount of Raw Materials

Cement bonded particle boards were produced at normal board density of 1,100 kg/m^3. The cement particle ratio was 70:30. The dimensions of the board were 4ft X 2ft X 12 mm. Ordinary Portland cement was used as binder. Calcium chloride (2% by weight of cement) was added into the mixture of cement and chips as an accelerator to improve cement hydration. The quantity of water used for mixing cement and wood chips was calculated using the formula developed by Simatupang (1979).

Preparation of Board

The quantity of cement and wood chips required to make boards was weighed out and stored in polythene bag to control moisture content changes. The required quantity of calcium chloride was dissolved in the part of the measured quantity of water and then added to the wood chips and mixed thoroughly with hand. The mixture was allowed to keep for 2 minutes for the penetration of calcium chloride to the wood chips. After that, the required amount of cement was mixed with the chips gradually until all the chips were thoroughly covered with cement. The mixing time was 2-3 minutes. The mixture was spread into a mould to form a mat. Bamboo frame was kept
inside the mat, so that it was placed in the middle position of the materials. The boards were pressed under hydraulic cold press (140 psi pressure) for 24 hours. Thereafter, the board were removed from mould (cauls) and covered with a wet cloth wetting for 3-4 weeks. The boards were then subsequently trimmed and cut sample of different size according to standard BS 5669: part1: 1989.

Testing of Board

Samples were prepared from five replicate boards for determining static bending strength, nternal bond strength, water absorption and thickness swelling. These tests were performed according to British Standard 5669 part 1:1989.Thickness swelling and water absorption of CBPB were investigated after soaking under water for 1hour, 2 hours, 24 hours, 3days, 6 days, 9 days and 30 days.

Results and Discussion

Cement bonded Particle boards (CBPB) were made with rubber wood *(Hevea brasiliensis)* chips after 24 hours soaking to leach out the water soluble extractives which interfere the cement bonding. Researchers noted that setting of cement can be improved by reducing the extraneous matter with cold/hot water treatment (Zenglian and Moslemi, 1986). A cold water solubility test performed on the chips showed that they contained 2.97% soluable ingredients that could have inhibited the curing of cement (Akther, 1995). Browning (1967) observed that these water soluble extractives include sugars, gum, organic salts, tannins, cyclitons, galactons and pectin. Cold water treatment and the addition of calcium chloride generally reduced the retarding effect of extractive components (Moslemi *et al.* 1985)

Mechanical properties

The results of strength properties of five CBPB were determined and compared with the British standard (BS: 5669) are shown in Table 1.

Static Bending Strength

The bending strength (Modulus of rupture, MOR) of five CBPB, made of cold water treated rubber wood chips was investigated. Two categories of CBPB –using bamboo frame inside the board and without bamboo frame were made and investigated. The maximum average bending strength values was observed 51 kg/cm^2 for the board prepared without bamboo strips frame whereas the minimum values was found 45 kg/cm.^{2} The maximum average bending strength values was observed 62 kg/cm^2 for the board prepared with bamboo strips frame whereas the minimum values was found 51 kg/cm^2. The values are illustrated in Table 1. It was found that static bending strength (MOR) improved by using bamboo splits frame inside the board. But the bending strength of the two types of boards were lower than the acceptable limits of BS standard (Table 1).

Tensile Strength

It was found that the values of tensile strength (internal bond strength) were found 5.50 to 7.01 kg/cm^2 for the board without bamboo strips frame. The values of tensile strength (internal bond strength) were found 5.50 to 6.95 kg/cm^2 when the board was prepared using bamboo strips frame (Table 1). These values fulfilled the specification mentioned in the British Standard both for the two grades of board, namely T1 (low to moderate rate of performance in the presence of moisture) and T2 (high level to performance in the presence of moisture).

Bison-Werke and Greten (1977) noted that the cement/wood ratio of commercially produced CBPB ranged from 2.75:1.25 to 3:1 on weight basis. Oyagade (1990) reported that density of commercially produced CBPB ranged from 1100 to 1,300 kg/m^3. Therefore decreasing the cement in cement/wood ratio and density of the CBPB can reduce the problem of high weight.

In the present study, the board density was 950-990 kg/m^3. The boards were used in the wall and for making door and windows, not for use as roof. High weight of CBPB tests the problem in handling and application in situation such as ceiling construction.

Water Absorption and Thickness Swelling

Dimensional stability of the five boards is shown in Table 2. The average values of water absorption and thickness swelling after prolonged soaking in water for 30 days ranged for 15.66 to 34.73 and 1.57 to 3.47 respectively (Table 2). Thickness swelling increased initially with soaking time. Maximum increase in thickness swelling took place initially. With the increase of soaking period (after 3 days), there was slow increase of thickness swelling.

Fabiyi (2002) reported that an increase in board density resulted in a corresponding increase in MOR and IB but a decrease in WA and TS. The effect of density on MOR, WA and TS was in agreement with the findings of Fuwape and Oyadade (1993) on CBCP made from tropical hard wood species. Researcher explained (Huang and Cooper, 2000) that boards with high density were subjected to greater compression during production. Such high density boards may likely experience more spring back disrupting bonds between particle and cement and may result in higher WA and TS, compared with low density levels. The board density of CBPB made from rubber wood chips was 950 kg/m^3 and chips and veneer mixture 990 kg/m^3 which were lower than the board made of *Albizia falcataria* chips (Biswas *et al.,* 1997).

Report of Housing and Building Research Institute

The strength properties of CBPB were investigated at Housing and Building Research Institute (HBRI), Dhaka .It was reported that compressive strength and flexural strength of the CBPB were 3,057 psi, and 1,575 psi respectively, which are in acceptable range of building materials. The porosity and water absorptions of CBPB were investigated after 1 hour and 6 hour interval. It was found that porosity and water absorptions of CBPB are slightly higher comparative to other building materials (mortar and concreteIt was reported that the compressive strength and flexural strength showed inspiring result of the CBPB to use as a building material. It was noted that slightly higher porosity and water absorption could lead to physical deterioration after long time exposure in water or humid condition. So this material can be recommended for indoor using (ceiling material, partition board etc) as building material (HBRI Report, 2011).

In the present study, water absorption test was carried out for 30 days (Table 2) and found that initially the percentage of water absorption was remarkably high, but after 9 days, the water absorption increased slowly. It is recommended that the CBPB can be used as out door housing materials.

For durability test, a model house was constructed at BFRI campus using CBPB and service test data were collected periodically after three months.

Table 1.Strength properties of cement bonded particle board

Properties	Mean	Max.	Min.	SD	Standard requirement (BS 5669) T1	T2
Density((kg/m³)	965	990	950	19.49	--	--
Thickness(cm)	1.45	1.40	1.38	0.028	0.6- 40	0.6- 40
Static bending strength (kg/cm²) (with bamboo strips)	55	60	50	4.57	100	100
Static bending strength (kg/cm²) (without bamboo strips)	46	50	38	4.75	100	100
Tensile strength(kg/cm²) (with bamboo strips)	6.11	6.95	5.50	0.833		4.5
Tensile strength(kg/cm²) (without bamboo strips	6.12	7.01	5.50	0.834	5	4.5

T1=CBP that has only low to moderate levels of performance in the presence of moisture.
T2=CBP that has very high levels of performance in the presence of moisture.

Table 2. Dimensional stability of cement bonded particle board after prolonged soaking in water

Water Soaking time	Water Absorption (%)				Thickness Swelling (%)				Standard requirement for TS(BS 5669)	
	M	Max	Min	SD	Mean	Max	Min	SD	T1	T2
1 hour	15.66	16.50	14.96	0.61	1.57	1.94	1.24	0.29	3	1.5
2hour	16.84	17.61	16.30	0.55	1.98	2.30	1.60	0.30	-	-
24hour	23.43	14.31	22.44	0.80	2.20	2.50	1.78	0.32	12	1.8
3 days	27.80	29.00	26.31	1.06	2.46	2.70	2.13	0.35		
6 days	31.27	33.89	29.50	1.85	2.53	2.78	2.37	0.38		
9 days	32.00	34.00	30.30	1.24	2.96	3.20	2.59	0.40		
30 days	34.73	36.03	33.50	1.07	3.47	3.70	3.20	0.42		

Conclusion

As Bangladesh is a low lying country, cement bonded particleboard (CBPB) will be useful in construction of houses, especially in rural area where most of the houses are made of bamboo, mud and corrugated iron sheet. It is virtually incombustible and can be readily machined with normal tools and suitable for exterior applications. It also offers properties of excellent sound absorption, thermal insulation and structural performance. The combination of wood chips and Portland cement produces a board, which is environmentally friendly. The production of CBPB using rubber wood *(Hevea brasiliensis)* chips is technically feasible. CBPB made from rubber wood chips can be used as housing materials. Large size board (4 feet X 2 feet) were made using bamboo strips frame inside the board which increased the bending strength and will decrease the risk during use as housing materials. The boards are water resistant and dimensionally stable and can be used in low lying flood affected area.

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Improvement of Traditional Extraction Technique of Agar Oil from Agar Wood (*Aquilaria malaccensis* Lam.)

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Abstract

Artificially and naturally infected agar chips were collected from Barolekha upazila of Moulavibazar district. Agar oil was extracted from agar chips using prototype distillation and Clevenger apparatus. Yield of oil varied from 0.001 to 0.09% when using prototype distillation apparatus. Extraction with Clevenger apparatus yielded 0.89% oil. The distillation technique was compared to the traditional extraction technique used by the agar traders. It was found that traditional extraction technique needs improvement to get better yield and quality of oil. Condensation, separation and purification techniques of traditional method were improved. One hundred and twenty numbers of agar traders of Barolekha upazila were trained on improved extraction technique. Extracted agar oil was analyzed through GC-MS chromatograph at BCSIR, Chittagong and major chemical constituents were identified.

Key words : Agar oil, Agar wood, Extraction, Perfume

Introduction

Agar oil and agaru or agarwood is one of the most valuable perfumery raw materials obtained from the infected wood of trees of the genus *Aquilaria*, a member of the Thymelaeceae family. *Aquilaria malaccensis* is one of 15 tree species of genus *Aquilaria.* According to Oldfield *et al.* (1998), *A. malaccensis* is found in 10 countries: Bangladesh, Bhutan, India, Indonesia, Iran, Malaysia, Myanmar, Philippines, Singapore and Thailand. *A. malaccensis* and other species in the genus *Aquilaria* sometimes produce resin-impregnated heartwood that is sweet-scented and highly valuable. This wood is in high demand for medicine, incense and perfume across Asia and the Middle East.

Several methods are used to extract agar oil from agar wood chips. The most common method is water or steam distillation method. Water distillation is the oldest method to produce essential oil from plants and herbs. This method produces the highest quality essential oil because it does not extract harmful components. Other methods of extracting essential oils are solvent extraction and supercritical fluid extraction. However, in pilot scale extraction, the later two methods are not found feasible. In Bangladesh, the major agarwood-based industries are located in the Barolekha upazila of Moulavibazar district. Most of the industries are following traditional method for agar oil production. Several visits were made to identify the limitations of the present extraction technique. A prototype extraction unit was designed and fabricated at Bangladesh Forest Research Institute by observing the limitations of traditional agar oil extraction units. Agar oil was extracted using the prototype extraction unit and improvement of the extraction technique was made. Training programme was arranged to train the agar traders on the improved method.

Previously it was believed that cause of agar formation was due to fungal attack. Gibson (1977) suggested that agar formation was not related to fungal activity. Rahman and Basak (1980) and Rahman and Khisa (1984) studied the relationship between fungal activities and agar formation. But they did not find any relationship between fungal activity and agar formation. However, Oldfield *et al.* (1998) states that resin production is responsible to fungal infection. Ng *et al.* (1997) stated three hypotheses regarding agarwood formation, that it is the result of pathological, wounding/pathological and/or nonpathological processes. Heuveling van Beek (2000) states that it is due to wounding. However, it is now believed that the production of the fragrant resin is associated with wounding and fungal invasion, possibly assisted by insects. As a response to the infection, the tree produces a resin high in volatile organic compounds that aids in suppressing or retarding the growth of the fungus or insects. Various fungi are associated with agarwood formation although it is still not completely clear which ones make the plant generate the resin (Gratzfeld and Tan, 2008).

The major constituents of agarwood oil are sesquiterpenes, the chemical structure of which makes them very difficult, hence extremely expensive, to synthesize. Although synthetic agar wood compounds are used to produce poor-quality fragrances and incense sticks, there are currently no synthetic substitutes for high-grade incense or oil.

Agarwood Trade

The international trade in agarwood involves wood, wood chips, powder and oil. Agarwood is currently traded in large quantities. Over 700 t of agarwood from *Aquilaria malaccensis* were reported in international trade in 1997. Twenty countries are reported to export/re-export, of which Indonesia and Malaysia are taking the lead. Agarwood chips of high quality is very expensive. It is reported that the price of per kilogramme of agar may sell for several hundred to several thousand US dollars. The price of oil distilled from agarwood is generally between five and ten thousand US dollars per kilogramme, (Barden, *et.al.*, 2000). Another report shows that one litre of agarwood oil can be sold for around $US10,000 - 14,000 (Vietnam Chemical Technology Institute, 2007). The main consumer of the agarwood in international trade is the Far and Middle East, including Saudi Arabia, the United Arab Emirates, Hong Kong and Taiwan.

Once Bangladesh was one of the important traders in the international markets, but the country is now facing serious shortage of raw materials, But no export data of the species is recorded from Bangladesh. The country appears as an importer of *A. malaccensis*. From CITES data, it is shown that the country imported a total of 10 112 kg of agar wood from Singapore between 1995 and 2001 (Anwar Faruque, 2003).

The agar industries of Bangladesh are exporting agar oil to the Middle East countries through their own initiatives and therefore no export records are available. However, Bangladesh Government has now taken initiative for agar plantation in large scale and it is expected that in future the industries will overcome the problem of shortage of raw materials. Therefore it is important to improve the present traditional method of oil extraction for optimum yield.

Materials and Method

Distillation of Agar Oil

A proto-type agar oil distillation plant has been designed, constructed and installed in the laboratory of Chemistry Division of Bangladesh Forest research Institute (BFRI). The plant was equipped with long condenser for complete condensation. In this type of distillation plant, both water and steam distillation processes can be performed well. At the end of the condenser, a separatory funnel was set. Water circulation system was designed for auto pouring of water in to the plant.

Agar chips were collected from Barolekha upazila of Moulavibzar districts. Two types of chips were collected- one was from artificially infected trees and another types from naturally infected agar trees. Chips were cut into smaller pieces and soaked in tap water at room temperature for 1 month. At the end of the soaking periods chips were subjected to steam distillation

Baseline Survey

Survey was made in Sylhet and Moulavibazar for collecting information on the present status of agar trade and applied techniques of agar distillation. Two well-known agar industries in Sylhet city, one in

Khadimnagar, and 10 of Dhakhinbhag, Barolekha and Kulaura areas were visited. Observations were made on types of distillation unit, condensation process, oil recover process etc. Some other relevant data were also recorded.

Training Programme for Agar Entrepreneurs

Training programmes on agar production, extraction and utilization were conducted for agar traders at Barolekha, Moulovi Bazar.

Results and Discussion

Extraction of Essential Oil by Prototype Distillation Plant

One prototype distillation apparatus was fabricated and oil was extracted in water distillation method. Yield of oil varied from 0.001 to 0.09% from artificial and natural grades of agar wood. Extraction with Clevenger apparatus yielded 0.89% oil from artificial grade of agar wood. Improvement was made on separation and purification technique of the oil.

During our field visit it was found that most of the plants are situated in Barolekha upzila of Moulavibazar district and are owned by private owners. At present 118 numbers of agar oil industries were recorded (Baksha *et. Al,* 2009). The trade associated with agar oil is inherited from their ancestors. But recently some of the new individual traders are also being involved in the business. The plants owners set up their factories adjacent to their house. The traders are associated in groups locally known as *Samity*. Three main individual Samity namely Barolekha Upazila Agar Attar Business Co operative Society Ltd., Patharia Agar Attar Manufacturers Co operative Society Ltd. and Jalalabad Agar Attar Co operative Society are actively working and negotiate to the appropriate authority to meet their demand.

Raw Material Collection and Traditional Extraction Method

The Plants owners plant agar trees in their homesteads and artificially inoculated these trees with nailing. Nailing starts at an age of 6-10 years of age of tree. After nailing treatment, trees are kept for 2-4 years. The trees are then felled for collection of raw material. Sometimes they purchase raw materials locally or import from Singapore.

From the collected agar wood, black portion of wood is separated and cut into smaller chips. The chips are then soaked in water for 15-30 days or more. At the end of soaking periods, chips is subjected to steam distillation in a big metallic retort locally known as *deg*. The capacity of deg vary from 40-60 litre. The chips and water are poured into the deg for water distillation. Distillation process is continued for 7-16 days without any break. The *deg* is equipped with a metallic condenser which passes through a tank of water. The end of the condenser is connected to a reservoir containing water. The distilled oil is set down above the water layer which is collected manually and stored.

Following observations were made

- In traditional process, fuel wood is used for heating purpose. Thus uniform distillation temperature cannot be maintained. This may cause incomplete condensation. It is recommended to use gas for continuous and uniform heating.
- Long condenser pipe is recommended instead of short condenser.

- Manual collection of oil results incomplete separation of oil from water. It is recommended to use separatory funnel for complete separation.
- During extraction process, it is necessary to add water into the *deg* to maintain water level. This is done by manually through funnel. The process needs extra labour.
- Collected oil is stored in bottle and remaining water is eliminated by sun drying. This may cause degradation of oil components. Use of anhydrous sodium sulphate is recommended for drying purpose.

Training Programme for Agar Entrepreneurs

Based on the field observations, the traditional oil extraction method was improved and disseminated to the agar traders through training programme. So far 3 training programme were arranged and 120 agar traders were trained on improve extraction technique. Recent field visit shows that some of the distillation plants are already using the improved method.

Conclusions

Trade of agar oil in international market is highly competitive. The quality of oil must be ensured while marketing of agar products. Therefore, during processing and distillation process it is essential to follow the standard and improved extraction method.

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