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ANALYSIS OF REGENERATION AND SPECIES DIVERSITY ALONG HUMAN INDUCED DISTURBANCES IN THE KASSALONG RESERVE FOREST AT CHITTAGONG HILL TRACTS, BANGLADESH

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Abstract

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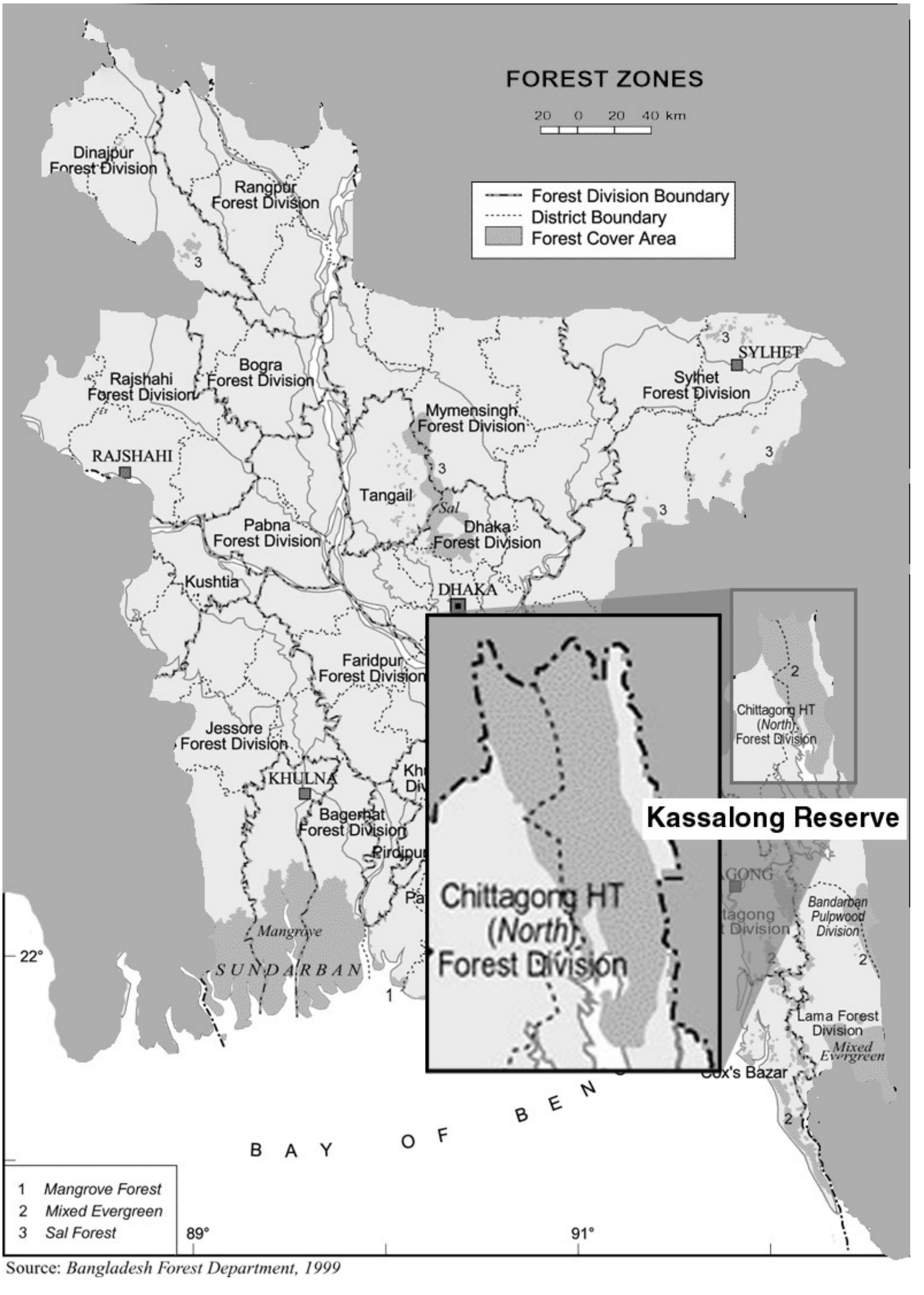
The forests of the Kassalong Reserve are some of the large important and productive government managed reserve forests located in the north forest division of the Chittagong Hill Tracts of Bangladesh. Legal or illegal logging, shifting cultivation with short rotation periods and fires used as a preparatory measure for shifting cultivation are important causes for a decreasing forest cover in the area. Based on different categories of disturbances (near to natural forest type-NNF, moderately disturbed forest type-MDF and highly disturbed forest type-HDF) 45 circular sampling plots with 9.77 m radius were chosen randomly for data investigation. The chemical status (pH, OM, N, K, P, S, B, and Zn) of the topsoil was investigated with 5 replications for each category. The natural regeneration was studied in accordance with three different height classes (< 30 cm, 31–150 cm and >150 cm). In total 91 tree species (dbh of > 5 cm) were observed on the sample plots in the forest. The species richness declined with increasing disturbances. Introduction of species showed an adverse effect on forest diversity even though stand density increased. The regeneration in HDF had more or less the same density as in NNF but the species richness was the lowest. The species richness in MDF declined with increasing height classes as result of human interventions. The important value index of dominant tree species in the three different forest types varied. A discussion of the major findings of this study with comparable research studies allowed drawing conclusions on further research activities and conservation management activities in the Kassalong Reserve Forest.

Key words: natural regeneration, species richness, diversity, disturbances, soil analysis

Introduction

Habitat loss is the major factor causing the current decline in the world's biodiversity (Anon, 1992). The Chittagong region (Chittagong and Chittagong Hill Tracts) is one of seven trans-boundary landscapes in Hindu Kush-Himalayas proposed for biodiversity conservation and management (Messerli, 2009). From a recent study it was observed that green biomass and net primary productivity decreased by an average annual rate of almost 0.2% on about 62% of the land area of Chittagong Hill Tracts (CHT) over the period of 1981–2003 (Bai, 2006). There are different factors responsible for the hill forest reduction and loss of species in the Kassalong Reserve (Salam et al., 1999). Permanent land-use change for agriculture or plantation often results in degraded grasslands or degraded fallows (Tinker et al., 1996; Gafur et al., 2003; Milde et al., 1985). However, indigenous people were using the forests in a sustainable way as in previous times the population pressure was less and the cultivation cycles were long enough. The resources were not degraded until external interventions had taken place (Rasul, 2007). The history of external interventions in the forests of the CHT is more than two centuries old. Since 1871 the hill forests are managed under clear felling followed by an artificial regeneration system ('taungya') with valuable timber species like *Tectona grandis* (Anon, 1970). It was observed that the natural forest, replaced by plantations, resulted in a low nutrient content of the soil, dramatic changes to the landscape and loss of species (Amponsah, Meyer, 2000; Alam, 2005; Shankar, 2001; Shankar et al., 1998). After construction of the Kaptai dam in 1962, new settlements were established periodically in and nearby the Kassalong Reserve Forest (Internal displacement monitoring centre, 2006). The newly settled population was directly or indirectly responsible for the deforestation and degradation of the land in carrying out their livelihood. The timber industry can be identified as another factor in putting pressure on the natural resources by legal and illegal logging. In this context, the Government (Forest Department) is not able or willing to implement a sustainable management policy.

During an inventory in the Kassalong Reserve in 1961, there were more than 100 tree species reported (Milde et al., 1985). Twenty years later, the timber volume was estimated as 136.6 m^3/ha in 1983 and it was found to be reduced to 100 m^3 /ha in the last decade (FAO, 2000). Even though the Kassalong Reserve Forest is facing degradation for more than centuries, the forests are still some of the large productive government forests of the country. The diversity of the plant community and natural regeneration were drastically hampered in the past and no studies are at present available in order to assess the actual condition of forest diversity. There were some studies carried out in other reserves of the country (Nath et al., 1997, 1998, 1999; Hossain, 2007; Hossain et al., 1995, 1997) which can serve as reference for species richness. Considering the present situation of the forests of the Kassalong Reserve a study was carried out to identify the human impacts on species richness, diversity and structure of the forests and to observe the regeneration status. This contribution will present the results of the study as means for biodiversity conservation management of the reserve and further research activities.



Source: *Bangladesh Forest Department, 1999*

Fig. 1. Location of the study area at Chittagong Hill Tracts (Rangamati district) in Bangladesh.

Material and methods

Study site

The forests of the Kassalong Reserve are situated in the Chittagong Hill Tracts in the Hindu Kush-Himalaya region bordered with Myanmer to the south and east, with Assam and Tripura in India to the east and north and to the west by the Chittagong District (Fig. 1). The reserved forests cover approximately 1,645 km^2 (Milde et al., 1985). The present study was conducted in three compartments (62, 66 and 68) of the Massalong block in the north forest division as different intensities of human influences were to be expected there. The latitude of the forests is between 22°57´ N and 23°45´ N and the longitude is between 91°55´ E and 92°21´ E. The hills are generally not very high but very uneven and facing steep slopes. The valley bottom ranges from 30 to 90 m whereas the maximum elevation within the reserves is just over 900 m. Soils are acidic and clay to clayey loams in the valleys and sandy to sandy loams in the hillsides. The accumulation of the humus layer varies according to the topographic condition. Annual temperatures vary according to altitude from 10 °C to 35 °C and mean annual rainfall is between 2450–3810 mm (Bai, 2006). The vegetation of the forests comprises a mixture of tropical evergreen and deciduous trees, occurring in association with bamboo jungle as well. The height of the trees varies between 30–60 m. In addition, plantations of Teak along with other timber species have been raised by the 'taungya' system after clear felling.

Sampling design and data collection

In total 45 circular sampling plots with 9.77 m radius were chosen randomly for the data investigation in order to sample a total of 300 m² per plot. Within each plot diameter at, breast height, all individuals having a diameter of 5 cm and above were recorded. Twigs along with available flowers and fruits were collected from unidentified tree species for herbarium preparation, to identify species with the help of experts. Each sampling plot was divided into two subplots for data investigation of the natural regeneration. The natural regeneration along with number of individuals and identification of species was sampled according to three different height classes (< 30 cm, 31– 50 cm and > 150 cm but < 5 cm dbh), by means of three additional respective square plots (1x1 m, 2x2 m, 4x4 m). Different human disturbances like logging, making fires, shifting cultivation (traditional agriculture), girdling, bamboo cutting and plantations were assessed in the field, and the level of disturbance was recorded for each sampling plot. Topsoil from 15 sampling plots was collected according to the field manual of Soil Research Development Institute (SRDI) to investigate the chemical status (pH, OM, N, K, P, S, B, and Zn) of the topsoil.

Classification of sampling plots

A disturbance index of the average value of disturbances was calculated after the modified disturbance index by Rahman et al. (2009). The index is based on a qualitative assessment of the intensity of human activities like logging, cutting of regeneration, cutting of non-wood products, bark peeling, shifting cultivation, introduction of fire and girdling (Fig. 1). The weighted average sum of all kinds of disturbances for each plot was used to categorize each plot (Fig. 2).

Based on the disturbance index values, 16 sample plots were classified as near to natural forest type (NNF), 15 plots as moderately disturbed forest type (MDF) and 14 plots as highly disturbed forest type (HDF).

$$\text{Disturbance Index (DI)} = \frac{1}{n} \cdot \sum_{i=1}^{n} \left(w_i \cdot d_i \right)$$

where n is the number of disturbances, w_i is the weight of the ith (i = 1, 2, 3,…n) element and d_i a qualitative score [1–5] of intensity for each element.

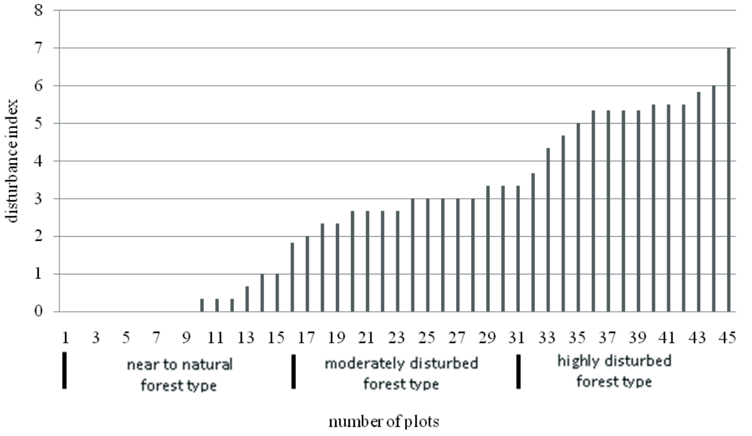


Fig. 2. Classification of sample plots regarding the three classes of disturbances.

Analysis

Stand structure and diversity was investigated according to the following measures: basal area and forest density, frequency and abundance of the species, important value index, Shannon-Wiener diversity index (H) (2), Evenness index (E) (3) and Simpson's dominance index (D) (4) following the formula of Mueller-Dombois, Ellenberg (1974) and Magurran (1988). Kruskall-Wallis non-parametric tests (SPSS, 2008) were carried out to find out significant differences among the three different forest types.

$$H = -\sum_{i=1}^{S} pi \ \mathrm{In}\, pi \quad (2)$$

where ρ_i is the proportion of the *i*th species and the number of all individuals of all species (n/N).

$$E = \frac{H}{logS} \quad (3)$$

where H is the Shannon-Wiener diversity index and S is the number of species.

$$\mathrm{D} = \sum_{i=1}^{S} pi^2 \quad (4)$$

where ρ_i is the proportion of the *i* th species.

Results

The history of external interventions in the forests of the Kassalong Reserve is more than two centuries old. Since 1871, the hill forests are managed under clear felling followed by an artificial regeneration system with valuable timber species like *Tectona grandis* (Anon, 1970). The application of the 'taungya' system allowed leaving a strip of natural regeneration in between the plantations. However, people cleared even those natural forest strips for shifting cultivation in the past. As a complete exclusion of local people from the reserve forest area still has not been possible, those living within and nearby the forest area are engaged in shifting cultivation, initiating fires as a preparatory tool for shifting cultivation and collecting non-timber forest products. These activities have direct and indirect influences on stand structure, species diversity, as well as on natural regeneration of the forest.

Stand structure and diversity

Species richness, density and basal area

The median value of stems/ha were 399, 233 and 533 in near to natural forest type (NNF), moderately disturbed forest type (MDF) and highly disturbed forest type (HDF) respectively (Table 1). Even though the median basal area of the three different forest types was more or less same, HDF had the lowest basal area of 33.9 m^2/ha. The MDF had the highest basal area (37.2 m^2/ha) followed by NNF (35.5 m^2/ha). There were significant differences found

Table 1. Total number of tree species, median value of stems/ha and basal area/ha according to the forest types.

	NNF	MDF	HDF	Kruskal-Wallis test	
				Q2	ρ
Density (N/ha)	399	233	533	16.634	0.000
Basal Area(m^2 /ha)	35.5	37.2	33.9	0.294	0.864
Species present (No.)	63	54	14	-	-

in stem numbers/ha among the three forest types but no significant difference in basal area (Table 1).

On the sample plots 91 tree species having dbh of > 5 cm were observed in total, including introduced species. Among them only important species, according to three forest types, along with their important value index are shown in the Table 2. The highest number of

Table 2. Important Value Index (IVI) of important tree species with local name according to forest types (NNF, MDF and HDF).

Local name	Botanical name	Family	IVI		
			NNF	MDF	HDF
Kala koroi	*Albizia lebeck*	Leguminoceae	-	-	4.9
Sada Koroi	*Albizia procera*	Leguminoceae	-	-	37.71
Tulon pagor	*Anisoptera scaphula*	Dipterocarpaceae	4.32	-	-

T a b l e 2. (Continued)

Local name	Botanical name	Family	IVI		
			NNF	MDF	HDF
Shiuri	*Anogeissus acuminata*	Combretaceae	1.46	4.46	4.94
Kadam	*Anthocephalus chinensis*	Rubiaceae	-	2.32	-
Soley	*Aphania danura*	Anacardiaceae	1.56	-	-
Chapalish	*Artocarpus chaplasha*	Moraceae	12.74	9.14	-
Lotkon	*Baccaurea ramiflora*	Euphorbiaceae	2.32	1.97	-
Gutguti	*Bursera serrata*	Burseraceae	2.78	17.3	-
Dhup	*Canarium resiniferum*	Burseraceae	2.05	-	-
Toon	*Cedrela toona*	Meliaceae	-	3.21	3.38
Chickrashi	*Chickrasia tabularis*	Meliaceae	4.2	5.17	-
Bongal	*Cordia dichotoma*	Boraginaceae	-	-	3.95
Modon mosta	*Dechasia kurzii*	Lauraceae	1.16	-	-
Jumur	*Derris robusta*	Fabaceae	1.11	5.59	3.45
Dhali garjan	*Dipterocarpus gracilis*	Dipterocarpaceae	3.01	7.97	-
Rangi Garjan	*Dipterocarpus* sp.	Dipterocarpaceae	8.34	2.46	-
Kali garjan	*Dipterocarpus turbinatus*	Dipterocarpaceae	17.69	9.99	-
Bandorhola	*Duabanga sonneratioides*	Lythraceae	5.95	9.43	7.28
Pitraj	*Dysoxylum* sp.	Meliaceae	17.79	15.69	-
Dumur	*Ficus hispida*	Moraceae	-	1.93	-
Joggo dumur	*Ficus* sp.	Moraceae	-	1.94	-
Kao	*Garcinia cowa*	Guttiferae	3.66	1.96	-
Gamar	*Gmelina arboria*	Verbenaceae	-	9.07	44.19
Borpada	*Haplophragma adenophyllum*	Bignoniaceae	-	2.3	-
Rosbharala	*Holigarna* sp.	Anacardiaceae	5.41	-	-
Telsur	*Hopea odorata*	Dipterocarpaceae	1.86	-	-
Chalmogra	*Hydnocarpus kurzii*	Flacourtiacea	8.24	3.97	-
Jarul	*Lagerstroemia speciosa*	Lythraceae	2.15	9.51	-
Uriam	*Mengifera sylvatica*	Anacardiaceae	2.49	4.07	-
Nageswar	*Mesua ferrea*	Clusiaceae	9.01	-	-
Hona	*Oroxylum lucidum*	Bignoniaceae	-	1.94	-
Mon hona	*Oroxylum* sp.	Bignoniaceae	5.22	1.95	-

Table 2. (Continued)

Local name	Botanical name	Family	IVI		
			NNF	MDF	HDF
Tali	*Palaquium polyanthum*	Sapotaceae	1.25	1.99	-
Narikeli	*Pterygota alata*	Sterculiaceae	1.64	-	-
Batna	*Quercus* sp.	Fagaceae	1.62	3.31	-
Moma	*Saraca* sp.	Caesalpiniaceae	4.72	2.1	-
Dharmara	*Steriospermum personatum*	Bignoniaceae	1.56	23.8	-
Civit	*Swintonia floribanda*	Anacardiaceae	1.86	-	-
Dhakijam	*Syzygium grande*	Myrtaceae	12.16	-	-
Putijam	*Syzygium* sp.	Myrtaceae	3.99	-	-
Teak	*Tectona grandis*	Verbenaceae	-	-	167.9
Bahera	*Terminalia bellirica*	Combretaceae	3.03	3.97	-
Horitaki	*Terminalia chebula*	Combretaceae	1.57	9.91	-
Sundul	*Tetrameles nudiflora*	Datiscaceae	30.85	2.52	6.93

species (63) was found in the NNF followed by the MDF (54), and only 14 species (including 3 introduced species namely *Tectona grandis, Gmelina arborea, Albizia* sp.) were found on the plots of the HDF (Table 1).

Species diversity

The Shannon index value was found high and almost the same species diversity for NNF (4.08) and MDF (3.93), as by contrast HDF (2.18) had a lower species diversity (Table 3).

Table 3. Indices according to forest types of mature trees.

Indices	NNF	MDF	HDF
Shannon index	4.08	3.93	2.18
Simpson index	0.02	0.02	0.16
Evenness index	0.98	0.98	0.83
Disturbance index	0.34	2.82	5.31

Notes: NNF – near to natural forest type; MDF – moderately disturbed forest type; HDF – highly disturbed forest type.

The same trend was observed for the Simpson index, too. The Evenness index indicated that the species in all three forest types were almost evenly distributed. The Disturbance index showed a continuous increasing trend from NNF to MDF and HDF.

Important value index

It was observed that the important value index (IVI) varies substantially for the same species with different forest types (Table 2). The highest IVI (30.85) was found in NNF for *Tetrameles nudiflora*, followed by *Dysoxylum* sp. (17.79) and *Dipterocarpus turbinatus* (17.69). Around 14 species have an IVI within the range of 5–10 and the rest of 44 species have the value of IVI lower than 5. Among 54 species the highest IVI (23.80) in MDF was found for *Steriospermum personatum*, followed by *Bursera serrata* (17.30) and *Dysoxylum* sp. (15.69). In the MDF for 18 species the IVI were observed within the range of 5–10. The rest of the 33 species were found to have an IVI below 5. Among 14 species in the HDF, the introduced species (*Tectona grandis*, *Gmelina arboria* and *Albizia procera*) had higher IVI: 167.90, 44.19, and 37.71 respectively. Only two species (*Duabanga sonneratioides* and *Tetrameles nudiflora*) were found having the IVI between the range of 5–10, and the rest of the 9 species have an IVI below 5.

Diameter class distribution

In all three forest types, the number of individuals declined with increasing diameter classes (Fig. 3.). But the HDF had a very low range (< 10 cm to 60–70 cm) of diameter class distribution. The highest number of individuals (42%) for the HDF was found in the 20–30 cm dbh

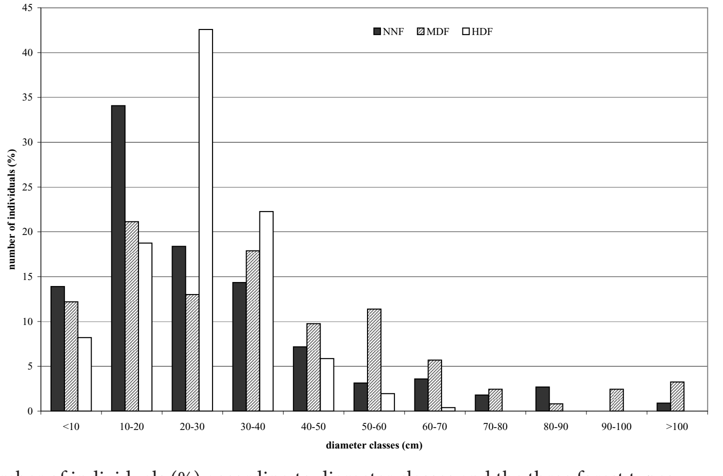


Fig. 3. Number of individuals (%) according to diameter classes and the three forest types.
Notes: NNF – near to natural forest type; MDF – moderately disturbed forest type; HDF – highl disturbed forest type.

class. In the NNF there was observed a continuous decline of individuals from the 10–20 cm diameter class with the increasing diameter class. There were no individuals found under the dbh class of 90–100 cm. In the MDF almost all diameter classes had some representative individuals, but there was no continuous declining trend of individuals (%) observed.

Rarity

Mature trees were categorized as very rare (individual = 1 among the sample plots), rare (individuals = 2 to 9), frequent (individuals = 10 to 20) and very frequent (individuals > 20) (Table 4). In NNF, among 63 species, 59 species were found as rare and very rare, which collectively comprising around 80% of the total individuals. Only four species were found frequently (23% of total individuals), whereas only one species (8%) was found frequent in MDF. Most of the species found under the category of rare and very rare species comprised a total share of more than 90%. Except for the introduced species in HDF, there were 6 and 5 species found to be very rare and rare respectively.

Table 4. Number of species (%) according to rarity and different forest types.

Species category	NNF	MDF	HDF*
Very rare	22(10%)	23 (19%)	6 (38%)
Rare	37(67%)	30 (73%)	5 (62%)
Frequent	4(23%)	1 (8%)	-
Very frequent	-	-	-
Total	63 (100%)	54 (100%)	11(100%)

Notes: very rare = 1 individual, rare = 2–9 individuals, frequent = 10–20 individuals, very frequent – > 20 individuals; * introduced species are excluded.

Table 5. Correlation of species richness, stems/ha and basal area with disturbance index.

	Correlation coefficient
Species number	
Disturbance Index	-0.776**
Stems/ha	
Disturbance Index	0.167
Basal area	
Disturbance Index	-0.094
Shannon Index	
Disturbance Index	-0.763**

Note: ** correlation is significant at the 0.01 level (2-tailed).

Correlation

There were negative correlations found between the species number and the disturbance index, and also between the Shannon index and the Disturbance index using the Spearman correlation index (SPSS, 2008) (Table 5). There was no correlation found between stems/ha and the Disturbance index and also between the basal area and disturbance index.

Chemical status of top soil

The chemical status (pH, OM, N, K, P, S, B and Zn) of the topsoil was examined and it was observed that the average pH value and organic matter (%) is little bit higher in NNF than

T a b l e 6. Chemical status (pH, OM, N, K, P, S, B, and Zn) of the top soil according to forest types.

Forest types	pH	OM (%)	N (%)	K (meq/100g)	P (μg/g)	S (μg/g)	B (μg/g)	Zn (μg/g)
NNF	5.42	2.756	0.16	0.328	1.2	7.6	0.326	0.604
MDF	5.32	2.626	0.152	0.59	4.4	5	0.268	0.706
HDF	5.32	2.498	0.142	0.432	1.6	6	0.254	0.71

Notes: NNF – near to natural forest type; MDF – moderately disturbed forest type; HDF – highly disturbed forest type.

MDF and HDF (Table 6). Percentages for N were highest in NNF, whereas K and P content were found highest in MDF, followed by HDF, while the lowest average values were found in NNF. S and B were higher in NNF compared to other forest types. But Zn was the highest in HDF, followed by MDF and NNF.

Natural regeneration

Density and species recruitment

The number of individuals (N/ha) in natural regeneration according to different height classes and for the three forest types are given in Fig. 4. With increasing height classes the number of individuals declined in all forest types. The highest number of individuals (66666) was found regenerating at < 30 cm height class in MDF, followed by NNF (49375), and was lowest in HDF (26785). Even though the highest number of regeneration was

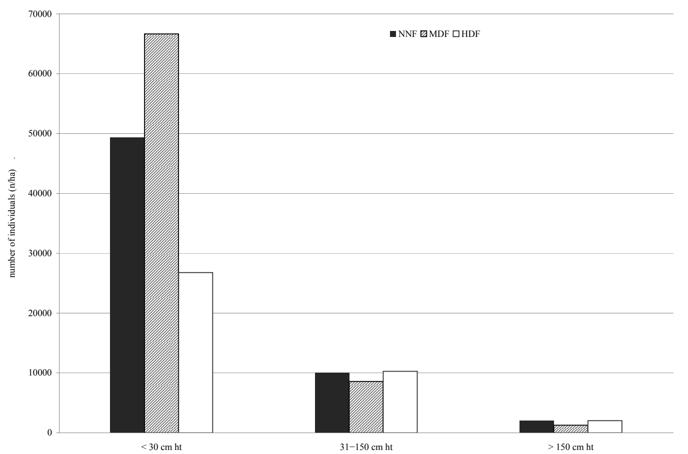


Fig. 4. Number of individuals (N/ha) in the natural regeneration according to height classes and forest types.

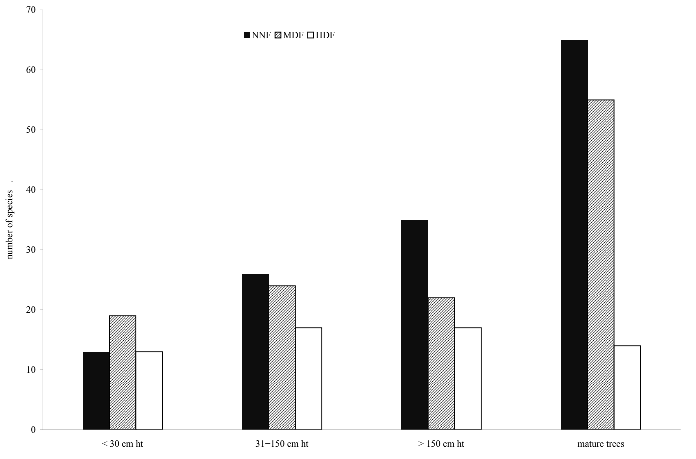


Fig. 5. Number of species in the natural regeneration and mature stand according to forest types.

found in MDF at < 30 cm height class, regeneration was lowest in the other two height classes (31–150 cm ht and > 150 cm ht). In the height class of 31–150 cm and > 150 cm, the number of individuals in the regeneration were found almost similarly, between NNF and HDF. The number of species regenerating in the three forest types at different height classes is presented in Fig. 5. The number of species increases with increasing height classes. At the height class of < 30 cm, MDF had the highest number of species (19), and among them *Garuga pinnata*, *Bursera serrata* and *Derris robusta* were most frequent. By contrast, NNF and HDF have similar number of species (13) where *Garuga pinnata*, *Artocarpus chaplasha*, *Syzygium* sp. and *Dipterocarpus* sp. in NNF and *Derris robusta* and

Table 7. Shannon index, Simpson index and Evenness index according to height classes and forest types.

Indices	Seedlings	NNF	MDF	HDF
Shannon index	< 30cm ht	1.89	2.00	2.40
	31–150cm ht	3.14	3.05	2.69
	> 150 cm ht	3.50	2.76	2.70
Simpson index	< 30cm ht	0.26	0.23	0.10
	31–150cm ht	0.05	0.05	0.08
	> 150 cm ht	0.03	0.10	0.08
Evenness index	< 30cm ht	0.74	0.68	0.94
	31–150cm ht	0.96	0.96	0.95
	> 150 cm ht	0.99	0.89	0.95

Notes: NNF – near to natural forest type; MDF – moderately disturbed forest type; HDF – highly disturbed forest type.

Sterculia villosa in HDF were the most frequent species. But in the NNF, the number of species at height class of 31–150 cm and > 150 cm were found higher compared to the other two forest types. *Mengifera sylvatica*, *Syzygium* sp. at 31–150 cm ht class and *Artocarpus chaplasha*, *Dysoxylum* sp., *Mesua ferrea*, *Dipterocarpus* sp. at > 150 cm ht class were the most frequent saplings. The same view of a higher number of species in NNF was also observed in mature stand. On the other hand, HDF had a low number of species throughout all height classes.

Table 8. Number of species (%) according to rarity, different forest types and height classes in regeneration.

	< 30 cm ht class			31–150 cm ht class			< 150 cm		
	NNF	MDF	HDF	NNF	MDF	HDF	NNF	MDF	HDF
Very rare	-	6 (3%)	2 (3%)	6(5%)	5 (5%)	4 (3%)	18 (17%)	12 (20%)	6 (6%)
Rare	10 (19%)	9 (19%)	9(53%)	16 (53%)	15 (49%)	10 (35%)	15 (59%)	8 (44%)	10 (42%)
Frequent	2 (14%)	1(9%)	2 (44%)	4 (42%)	4 (47%)	1 (13%)	2 (24%)	2 (36%)	-
Very frequent	1 (67%)	3(69%)	-	-	-	2 (49%)	-	-	1 (52%)
Total	13(100%)	19(100%)	13 (100%)	26 (100%)	24 (100%)	17 (100%)	35 (100%)	22 (100%)	17 (100%)

Notes: very rare – 1 individual, rare – 2–9 individuals, frequent – 10–20 individuals, very frequent – > 20 individuals; * introduced species are excluded.

Species diversity

The NNF had less species diversity in < 30 cm height class of regeneration compared to the other two forest types (Table 7). The highest index value (2.40) was found in HDF, followed by the MDF (2.00). However, in the other two height classes (31–150 cm ht and >150 cm ht), the highest index value (3.14 and 3.50 respectively) was found in the NNF, which represent high species diversity in this type of forest. The HDF had less diversity compared to the other two types. More or less the same trend was observed for the Simpson index among the three different forest types at three different height classes of regeneration (Table 7). The individuals among the three forest types were distributed evenly at the height class of 31–150 cm (Table 7). But in the NNF and the MDF at the height class of < 30 cm, the individuals were not distributed evenly. In the > 150 cm height class, the evenness index value for the NNF and the HDF were found near to 1, which indicates an even distribution of individuals.

Rarity

Rare species based on occurrence along with their composition are given in Table 8, according to the forest types and the three height classes of regeneration. There were 10 species (19%) found rare and only one species found as very frequent among 13 species in NNF at < 30 cm ht class. Only one species (67%) was found very frequent in NNF, and 3 species

(69%) in MDF. In total 26 species (78%) were found rare and very rare in MDF and HDF. Collectively 22 species (58%) were found as rare and very rare in NNF, 20 species (54%) for MDF and 14 species (38%) for HDF at 31–150 cm ht class. Only 2 species (49%) were found to be very frequent in HDF. There was one species (52%) found very frequently in HDF at > 150 cm ht class. All together 33 species were found rare and very rare in NNF, whereas 20 species in MDF and 16 species in HDF.

Discussion

In the present study 91 species were found in the Kassalong Reserve Forest (North Forest Division) of which 81 species belong to 35 families. However, from a previous inventory in 1961 it was reported that more than 100 species were found (Anon, 1970). In comparison, 41 tree species were recorded from the reserve forest of Khagrachari district in a sample area with around 600 m^2 (Hossain, 2007). It is difficult to apply an appropriate sample size for an accurate representation of species richness in the tropics. Different arguments for an appropriate size of the sample area in tropical forests are discussed (Ashton, 1963; Riswan, 1985; Richard, 1996; Wilkie et al., 2004; Rahman et al., 2009). According to Ashton (1963) 2–5 ha sample area is sufficient for species richness but Wilkie et al. (2004) proved that 15 ha might not be enough for measuring species richness. On the contrary, it was reported that species richness is almost steady within the area of 1.2 to 1.8 ha in the moist deciduous forest of Bangladesh (Rahman et al., 2009). In the present study, the total sample area comprising 45 sample plots was 1.35 ha. The Kassalong Reserve Forest had high species numbers compared to other reserve forests of the country (Nath et al., 2000; Hossain et al., 1997). In the reserve Arunachal Pradesh Nath et al. (2005) reported 94; in the reserve Darjeeling Shankar (2001) recorded 87 tree species, whereas Kadavul (1999) and Parthasarathy (1999) estimated 80 species in Eastern Ghats and 122 in Western Ghats. However, tree species richness declines (NNF-63, MDF-54, HDF-14) with the increase of disturbances in the study area. The same declining trends along a disturbance gradient were observed in different studies of Eastern Himalayas and the moist deciduous forest of Bangladesh (Bhuyan et al., 2003; Rao et al., 1990; Webb, Sah, 2003; Rahman, Vacik, 2009; Rahman et al., 2009).

Median stand density varies from 533 (HDF) to 233 (MDF) stems/ha according to human interference. It seems reasonable that HDF had the highest stems/ha compared to the other forests because of artificial regeneration. However, it had been observed from different studies in India that stand density decreased with increasing disturbances (Bhuyan et al., 2003; Nath et al., 2005; Parthasarathy, 1999). A reverse J shaped diameter distribution was observed in the NNF. From the study of Kadavul (1999) and Hossain et al. (1997), the same diameter distribution was observed in their studies on natural forests. MDF showed no regular declining trend of individuals with increasing diameter classes compared to NNF, but trees with high diameter classes. The same relation was also found from the study of Nath et al. (2005). On the contrary, the HDF had limited diameter class range (< 10–60 cm) compared to others. The basal area of the Sitapahar Reserve Forest was reported with 55.23

m^2/ha (Nath et al., 2000) which is quite higher than the Kassalong Reserve Forest, where the MDF had the highest median value of basal area (37.2). However, it has to be considered that the value of density and basal area of the present study only represents the existing coverage of the sampled forest. Because some potential plots from HDF and MDF were ignored during the data investigation, as most of the trees were temporarily or permanently felled for cultivation or settlement purposes, the basal area and density could be lower.

According to chemical status, it was observed that natural decomposition was higher in NNF followed by MDF, and HDF showed the lowest decomposition. Interestingly, the amount of potassium and phosphorus was higher in MDF, which could be explained by the cultivation with different crops or using chemical fertilizer. However, the site conditions were comparable for drawing a conclusion on species richness.

It is observed that diverse communities are more stable then ecosystems with less diversity (Ralhan et al., 1982; Elton, 1958; Odum, 1971). In the present study, the Shannon–Wiener index of the mature trees shows a value ranging from 2.18 to 4.08. Among them the highest species diversity were found in NNF (4.08), which was quite higher than the Shannon index value (2.98) found in the Sitapahar Reserve Forest in Bangladesh (Nath et al., 2000). It might be concluded that the Kassalong Reserve has still a high potential to recover from past human disturbances. However, species diversity of the forest decreases with increasing disturbances. The same trend was found in the wet evergreen forests of India (Bhuyan et al., 2003; Rao et al., 1990). In the HDF, a comparatively higher dominance and less even distribution was found among the species compared to the other two forest types. The result is in line with the study of Rao et al. (1990) and Webb, Sah (2003) where high dominance and low equitability was observed in disturbed forest and vice-versa in undisturbed forest.

In the present study, *Tetrameles nudiflora* had the highest IVI (30.85) in the NNF whereas Nath et al. (2000) found the highest IVI (53.15) for *Dipterocarpus turbinatus* in the Sitapahar Reserve Forest. But the Bamu reserved forest of Bangladesh *Bursera serrata* recorded the highest IVI of 18.91 (Hossain et al., 1997). *Dipterocarpus turbinatus* in the Kassalong Reserve had the 3rd highest IVI of 17.69, and in the Sitapahar Reserve Forest *Tetrameles nudifora* had a very low IVI (2.04). It can be observed that the dominancy of species varies among different reserve hill forests of Bangladesh, which could be explained by past impacts of human and water drainages leading to bad site conditions (Keel, Prance, 1979; Jacobs, 1988; Richard, 1996 and Kadavul, 1999). In the NNF of the present study, the recorded numbers of rare and very rare species (59) were higher compared to the findings (41) by Nath et al. (2005) in the undisturbed forest of the Arunachal Pradesh. According to disturbances, the number of rare and very rare species decreased, whereas still 54 species were recorded in MDF and 11 species recorded in HDF. The same decreasing trend of rare and very rare species with disturbances was also described by Nath et al. (2005). Rare species constitute 67% of all individuals in the NNF in the present study. This share is much higher compared to results obtained in the wet evergreen forest of Arunachal Pradesh (50%) and Darjeeling district (36%) (Nath et al., 2005; Shankar, 2001). The densities of tree seedlings at a lower height class (< 30 cm ht) were higher in the MDF than in the NNF and the HDF. In MDF the density of mature trees is low, which provides larger gaps suitable for natural regeneration. But quite the opposite results were observed from the study of Nath et al. (2005), where the density of seedlings found low in disturbed forest compared to the undisturbed forest. Interestingly, at higher height classes (31–150 cm and > 150 cm ht) the density of seedlings were similar in NNF and HDF. It could be possible that logging activities supported the sprouting from teak stumps, which increased the total density of regeneration.

It was found that species richness in the regeneration is linked to human disturbances independently from different development stages. The number of species was higher at the classes < 30 cm ht and 31–150 cm ht compared to the > 150 cm ht class in MDF. However, in HDF the number of species was comparatively less throughout all development stages. Local human interventions in relation to a reduction of the cultivation cycle could serve as an explanation for that finding. Considering the present level of species richness in regeneration in relation to the level of species richness of the mature trees, there is quite a chance to reach a near to natural level. From different studies, it was observed that for the recovery of species richness a range of 20–40 years is necessary for forest communities to return to pre-cut diversity levels (Webb, Sah, 2003; Webb, Fa'aumu, 1999). However, regeneration potential is related to human activities (Bhuyan et al., 2003; Kadavul, 1999). Specially, during shifting cultivation all regeneration is uprooted to allow the growth of cultivated species. So, according to the species richness in the MDF, it could be hypothesized that if succession is allowed without human interventions, species richness at MDF could reach the state of the NNF throughout the natural development of the forest. Considering the conservation of species diversity, human impacts should be minimized to a certain level in order to allow an undisturbed development.

Conclusion and policy implications

The Kassalong Reserve Forests contain high species diversity beside the different kinds of human disturbances. As the level of diversity has not been well documented in general, the local people and politicians are not aware of the potential threats. The forests are facing a severe pressure by anthropogenic disturbances of humans who directly or indirectly depend on the forest resources for their social welfare. The introduction of species caused an adverse effect on the botanical diversity of the forests, as species richness declined with increasing human interference. The findings of the present study indicate the necessity to take further initiative at a management level to protect the species diversity of the Kassalong Reserve before introducing plant species. From the historical point of view, forest conservation activities in India and Nepal very often transferred forests under strict protection as reserves and excluded rural people living near the forest area from utilizing the natural resources in a sustainable way. In accordance with the National Forest Policy of Bangladesh, the biodiversity of existing degraded forests should be enriched by conserving the remaining natural habitats of birds and animals utilizing conservation in nature reserves and protected areas. Through the participation of the local people, the illegal occupation of the forestlands and the illegal tree felling and hunting of wild animals should be prevented (Islam, 2003). In the case of the Kassalong Reserve, a non-participatory process was followed. There would have been a strong need to involve local people in the management of forests in order to stop the decline of the forest cover along with species diversity, and an increase in the level of acceptance for conservation activities. Moreover, current teak plantations with a poor botanical diversity will not provide the necessary non-timber forest products to local people. In order to protect forests from destruction and to conserve their diversity, parts of the Kassalong forests should be managed in a participatory way. The demands of the local community will have to be considered to allow the conservation of these forests. Some parts which still contain some natural forests could be managed as protected forest and other parts, considering accessibility for frequent monitoring purposes, could be managed as commercial forest with mixed timber species (leguminous and indigenous timber quality species), instead of monocultures with teak only. The present findings provide general information to researchers about the status of the present and possible pathways for future development of the forests. The results will help conservation officials of natural forests in Bangladesh to promote the value of biodiversity for the country. However, further studies are necessary to observe the forest ecosystems' structures at a spatial level, to quantify the socio-economic conditions of the forests and describe the long-term effects of human interventions on forest diversity.

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