Plant diversity and anthropogenic disturbances in the Sal (*Shorea robusta* C.F. Gaertn) forests of Bangladesh

A PHD THESIS

By

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Dedicated

To

My Beloved Parents

&

Daughter, Nuzhat Nueri

Preface

The core part of this thesis consists of four peer reviewed manuscripts submitted and partly published in four scientific journals, which are part of the appendix chapter of this thesis. The timeline and status of the publication process of all manuscripts is given at the end of this thesis. The initial text describes the research concept and the major findings of the work. A detailed description of the research methodology and findings can be found in the respective papers.

Acknowledgement

All praises are due to the Almighty Allah, Who is the Supreme Authority of this Universe and enabled him to complete his research work and writing up his PhD thesis for the fulfilment of the Doctor of Bodenkultur.

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The author

Plant diversity and anthropogenic disturbances in the Sal (*Shorea robusta* C.F. Gaertn) forests of Bangladesh

Abstract

Sal (*Shorea robusta* C.F. Gaertn) is a dipterocarpus tree species in Central Asia native to the southern slopes of Himalaya, and gregariously distributed in India, Nepal, Bangladesh, Bhutan and southern China. These tropical moist deciduous forests of Bangladesh are locally known as Sal or Gajari forests which cover 32% of the forested land. The uncontrolled growths of the population in Bangladesh lead to massive deforestation, a degradation of forests, wildlife and biodiversity. Both the Madhupur and Bhawal National Park occupy most of Sal forests of Bangladesh. They have a high socio-economical and ecological importance for the central part of Bangladesh but they are mostly unexplored and research is not well documented. Few studies on floral diversity (incomplete list of plants) can be found, but no systematic studies on the role of anthropogenic disturbances, their impact on plant diversity, structure and spatial diversity have been done so far. The aim of this research was to measure the biodiversity, the level of human disturbances, the effect of human disturbances on the plant diversity, and to find out the spatial characteristics of Sal. The study area in the Madhupur National Park was classified according to different levels of disturbances and protection. The core area of the Bhawal National Park was analysed on the basis of a changing intensity of recreational activities. Mature trees, seedlings, saplings, climbers and herbs were measured on 300 plots; beside descriptive statistics, biodiversity indices and neighbour-based variables were calculated to assess the spatial characteristics of the Sal forests. In total 134 plant species were identified in the Madhupur National Park, out of them 129 species were found in the core zone. A total of 43 plant species were enumerated in the core area of the Bhawal National Park. The diversity index and evenness decreased, and the concentration of dominance increased with rising disturbances. In most cases, the plant density and basal area of the mature trees showed a declining trend with the increase of disturbances. Sal grows comparatively faster than other associate species and tended to be more dominant over its natural associates from the low disturbed to the highly disturbed forests. The general dispersion of Sal is correlated to species mixture and its density. The core zone of the Bhawal National Park is a pure Sal forest where mostly mixed forests occur in the Madhupur National Park. The density of shrubs and climbers increased with the decreasing level of human disturbances. No coarse woody debris was found in the Bhawal National Park, whereas very few snags ($2.2ha^{-1}$) were found in the Madhupur National Park. The diameter and height class distributions indicate a mixture of very young to giant trees in the Madhupur National Park compared to the less diverse forests in the Bhawal National Park. In the highly disturbed and low protected forests of the buffer and peripheral zone the natural regeneration is in general endangered due to the cultivation of agricultural crops and introduction of exotic tree species. Additionally the picnic activities hamper the tree vitality substantially. Finally recommendations for further research activities about forest dynamics, the rate of deforestation and loss of biodiversity as well as measures for conservation management are given.

Key words: Diversity index, neighbour-based variables, evenness, spatial structure, coarse woody debris, deciduous forests, dominance, deforestation, exotic species

German

Pflanzenvielfalt und menschliche Beeinflussung in den Salbaum (*Shorea robusta* C.F. Gaertn) Wäldern von Bangladesch

Kurzfassung

Der Salbaum (*Shorea robusta* C.F. Gaertn) ist eine dipterocarpe Baumart in Zentralasien, welche an den südlichen Hängen des Himalayas beheimatet ist und zerstreute Vorkommen in Indien, Nepal, Bangladesch, Bhutan und dem südlichen China hat. Die feucht warmen tropischen Laubwälder in Bangladesch sind lokal unter der Bezeichnung Sal oder Gajari Wälder bekannt und bedecken rund 32% der Waldfläche. Das unkontrollierte Wachstum der Bevölkerung hat zu einer massiven Entwaldung, einer Degradation der Wälder sowie zum Verlust der Biodiversität geführt. Die Nationalparks in Madhupur und Bhawal machen den größten Teil der Salbaum Wälder in Bangladesch aus. Sie haben eine hohe sozio-ökonomische und ökologische Bedeutung jedoch gibt es bis dato noch wenig wissenschaftliche Erkenntnisse. Neben unvollständigen Arbeiten über die floristische Diversität wurden bisher noch keine systematischen Studien über die Bedeutung des menschlichen Einflusses auf die Planzenvielfalt, deren Struktur und räumliche Vielfalt durchgeführt. Das Ziel dieser Arbeit lag daher in der Analyse des menschlichen Einflusses auf die Biodiversität der Salbaum Wälder. Das Untersuchungsgebiet im Madhupur Nationalpark wurde nach dem Grad des menschlichen Einflusses und der Schutzzone eingeteilt. Die Kernzone des Bhawal Nationalparks wurde hinsichtlich wechselnder Einflüsse von Erholungsaktivitäten analysiert. Baum- und Strauchvegetation, Naturverjüngung, Kletterpflanzen und krautige Vegetation wurden auf insgesamt 300 Stichprobenpunkten erhoben; neben deskriptiver Statistik wurden Biodiversität Indizes und auf Nachbarschaftsbeziehungen beruhende Indikatoren für die Analyse der räumlichen Verteilung berechnet. Insgesamt wurden 134 Pflanzenarten im Madhupur Nationalpark identifiziert; davon kamen 129 Arten in der Kernzone vor. Nur 43 Arten konnten in der Kernzone des Bhawal Nationalparks identifiziert werden. Mit steigender Intensität von Störungen sinken der Diversitäts-Index und Evenness-Index, in den meisten Fällen nahmen dabei auch Pflanzendichte und Grundfläche der Baumvegetation ab. Das Wachstum des Salbaums ist im Vergleich zu den Begleitbaumarten rascher, die dominierende Rolle über die Begleitvegetation geht allerdings mit Abnahme der Intensität der Störungen zurück. Die räumliche Verteilung des Salbaums hängt dabei von der Baumartenmischung und der Stammzahl ab. In der Kernzone des Bhawal Nationalparks kommen vermehrt reine Salbaum Wälder vor, während im Madhupur Nationalpark Mischwälder auftreten. Die Dichte von Sträuchern und Kletterpflanzen nahm mit der Intensität des menschlichen Einflusses zu. Kein Totholz wurde im Bhawal Nationalpark erfasst, während wenig stehendes Totholz ($2.2 ha^{-1}$) im Madhupur Nationalpark festgestellt worden ist. Die Durchmesser- und Höhenverteilung wies auf die stark strukturierten Wälder im Madhupur Nationalpark im Vergleich mit den wenig strukturierten Salbaum Wäldern des Bhawal Nationalparks hin. In der stark beeinflussten und wenig geschützten Pufferzone der Nationalparks wird die Naturverjüngung durch landwirtschaftliche Maßnahmen und das Einbringen von nicht heimischen Baumarten gefährdet. Zusätzlich beeinflussen die Erholungsaktivitäten die Vitalität der Baumarten stark. Abschliessend werden in dieser Arbeit Empfehlungen für den Forschungsbedarf über die natürliche Dynamik der Salbaum Wälder, die fortschreitende Entwaldung und über die Abnahme der Biodiversität gemacht. Pflegemaßnahmen und Empfehlungen für die Erhaltung der Wälder werden gegeben.

Schlagwörter: Diversitäts-Index, Nachbarschafts-Indikatoren, Evenness-Index, räumliche Struktur, Totholz, Laubwälder, Dominanz, Entwaldung, nicht heimische Baumarten

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1. Introduction

Sal (Shorea *robusta* **C.F. Gaertn**) occurs gregariously on the southern slopes of the Himalayas and is distributed in Bangladesh, India and Nepal (Gautam and Devoe 2006). Its presence is also indicated in Bhutan and South China (Fu 1994, Zhao *et al.* 1994). It is evident that Sal forests are potential to yield other forest products, too. A Sal tree in addition to timber and fuelwood, produces fodder (Edwards 1996, Gautam 1990, Gautam and Devkota 1999, Pandey and Yadama 1990, Shakya and Bhattarai 1995), leaves for plates (Gautam and Devkota 1999, Rajan 1995,), seeds for the oil production (Sharma 1981), food (Sinha and Nath 1982), resin or latex from heartwood, tannin and gum from bark (Karnik and Sharma 1968). Besides, associates of Sal are known to produce edible fruits, fodder and compost, fibres, leaves for umbrellas, medicinal plants, thatch, grass, brooms and many other products depending on the species composition (Bhatnagar and Hardaha 1994, Chettri and Pandey 1992, Gautam 1990, Melkania and Ramnarayan 1998, Poudyal 2000, Sah 1996, Schmidt *et al.* 1993, Shakya and Bhattarai 1995, Webb and Sah 2003).

In Bangladesh, the Sal forests are one of the three major forest resources (other types are tropical evergreen and coastal forests) covering about 32% of the total forestland and 10% forest coverage (Hasan, 2004). The total area of Sal forests is 110 thousand hectares in Bangladesh, out of which 86% is in the central region and 14% in northern region. The Sal forest in the central region is known as 'Madhupur Garh', which is comprised of two National Parks: Madhupur and Bhawal National Park. Sal forests are scattered in the central and northern parts of Bangladesh, and the major forest lies in the districts of Gazipur, Mymensingh and Tangail. Madhupur National Park is situated in the district of Mymensingh and Tangail. The Bhawal National Park is located in the district of Gazipur and considered as suburbs of the highly populated mega city; Dhaka (the capital of Bangladesh). These forests have a high economical and ecological significance in the central part of Bangladesh. Sal forests have also ethnic and cultural values in Bangladesh as few ethnic communities (tribal people) live in these forests, and their livelihood and culture is directly related to these forests. Phytogeographically both the parks belong to same agro-ecological zone and classified under tropical moist deciduous forests. *Shorea robusta* is the dominant species of these forests and usually forms 75% to 25% of the upper canopy in the natural habitat (Alam 1995). Floristic compositions of different Sal forests indicate that these ecosystems have the richest diversity in Bangladesh. They are the habitats of different types of plants including tree, shrub, climber and herb (Alam 1995, Choudhury 2004). In past, both the parks were included within a continuous Sal (*Shorea robusta*) belt and consisted of same species composition (Alam 1995).

With geometric increasing of population both the park areas are facing tremendous human pressures. Human pressure is more severe in Bhawal National Park than the Madhupur National Park due to its location near to the capital of Bangladesh. The diversities of these ecosystems are unknown to the outsiders and not well documented. On the other hand, there is no information whether the species composition and diversity of both the park areas are remaining same like past or have been changed.

In Bangladesh, as elsewhere in the third world, the process of ecosystem destruction and the resultant environmental damages have been escalating alarming in recent years. The destruction of natural ecosystems goes hand in hand with a drastic reduction of biodiversity, which hampers the quality of life as well as economic development. The massive destructions of Sal forests of Bangladesh coincided with our limited knowledge on the composition, species richness, structure, regeneration pattern (Alam 1995) compared to India and Nepal. There are many studies on vegetation analysis of the Sal forests of Nepal and India (Murali *et al.* 1996, Pande 1999, Pandey and Shukla 2003, Pandey and Shukla 1999, Shankar 2001, Shankar *et al.* 1998, Singh *et al.* 1995, Sukumar *et al.* 1992, Timilsina *et al.* 2007, Webb and Sah 2003). A large-scale inventory about the plant diversity of Sal forests in Bangladesh is currently lacking. However, very few research activities focusing on the enlisting of the available plant species in the Sal forests of Bangladesh are available (Alam 1995, Choudhury 2004, Jashimuddin *et al.* 1999, Rashid and Mia 2001, Rashid *et al.* 1995). It is essential to know the plant diversities of these ecosystems to understand the diversity of these ecosystems comparing the status and diversity of Sal forests of other countries like India and Nepal.

Studies on forest biodiversity in Bangladesh, one of the world’s most densely populated countries, will be incomplete and incomprehensive ignoring the role of human impacts. The forests are subject to heavy pressures in terms of wood production and competing land-uses. Due to high population density and an uneven distribution of lands (60% people are landless), the natural resources are overexploited (World Bank 2004). The deforestation rate of Sal forests is 3.3% per year (BBS 2004). The Sal forests of Bangladesh are severely impacted by over-exploitation, deforestation, excessive litter collection, encroachment, indiscriminate collection of economically important plant species (i.e. medicinal, fodder etc), and other forms of human interference (Rasheed 1995, Salam *et al.*1999). Natural Sal forests are endangered due to the practices of shifting cultivation and the introduction of exotic species (Gain 1998). On the basis of previous and present anthropogenic disturbances the forests can be classified as (i) low disturbed (highly protected core zone, very small fragments of natural patches), (ii) medium disturbed (core zone but not too much protected and forest regenerated naturally after clear cutting), (iii) highly disturbed (buffer and peripheral zone consisting of agro forestation, woodlot plantation, rubber plantation, eucalyptus garden) and (iv) very highly disturbed (encroached, blank land, rice field, fellow land, mustard garden, banana garden, pineapple garden). On the other hand, the forests are classified into three zones on the basis of protection level of forest authority as (1) the peripheral zone: consisting of exotic tree stands on fringes, bordered by cropland and homesteads facing maximum human interference, there is no control of the forest security forces on this zone; (2) the buffer zone: forming the middle layer vegetation of the park with a mixture of natural and exotic species which also faces regular high disturbances, this zone are protected by forest authority but the local people have access there for agro-forestation in the gap; and (3) the core zone: characterized by natural vegetation facing low to medium disturbance. The recurrent anthropogenic disturbances in the Sal forests have rendered the system inhospitable for the regeneration and growth of wild plant associates, causing a net loss in plant diversity (Pandey 2000). In Bangladesh, no research was carried out earlier to measure the impact of human disturbance and the level of protection to the plant species composition and diversity of these ecosystems.

Along with all of these disturbances, the Bhawal National Park is disturbed by additional tourism activities. The core zone of this park is used as picnic spots. Picnic includes many activities like walking, gathering, cooking of fresh foods or warming cooked foods within the park by making holes into the soil with the burning of deadwood and fallen litter and finally eating the cooked foods being seated on the forest floor. Overseas, a range of direct and indirect impacts of recreational activities in protected areas on vegetation have been documented in both observational and experimental studies (Buckley 2004, Cole 2004, Leung and Marion 2000, Liddle 1997, Newsome *et al.* 2004, Newsome *et al.* 2002, Pickering and Hill 2007). But such studies have not been conducted in Bangladesh so far. In addition, studies on the impacts of specific picnic activities on the forest diversity and vitality of trees have not been done so far in the world as well.

Sal grows gregariously dominating over its associates in its stand (Troup 1986). Sal tends to regenerate as a mass of seedlings and forms more-or-less even-aged crops, which are relatively pure, or it forms the bulk of the stock in mixed stands (Rautiainen and Suoheimo 1997, Troup 1986). The behaviour of Sal in pure and mixed stand has not been determined anywhere. For a better understanding of the behaviour and ecosystem of Sal, it is essential to analyse the spatial diversity of the dominant species *Shorea robusta*. The structural diversity generally considers species composition, horizontal and vertical variation within the forests. On the other hand, spatial diversity considers these characteristics in space or arrangement of these dimensions in relation to each-others (Pommerening 2002). Single tree-based variables or neighbourhood-based parameters or ‘measure of surround’ (Gadow *et al.* 1998, Staupendahl 2001) provided a comprehensive description of the spatial structure of a forest in Europe (Pommerening 2002), Africa (Graz 2006) and in North America (Aguirre *et al.* 2003). This has been proved as the cheapest, easiest and most effective measure for measuring spatial diversity (Pommerening 2002). So, it is important to assess the applicability of these neighbourhood-based variables in the Sal forests for analysing the spatial diversity of the dominant species, Sal.

The main hypothesis investigated in this thesis can be summarized as follows:

- Madhupur and Bhawal National Park are important study areas for the analysis of forest diversity of Sal (*Shorea robusta*) forests of Bangladesh
- Species composition and community structure of the Madhupur and Bhawal National Park are unknown
- Anthropogenic disturbances and the level of protection have an influence on the plant diversity and vitality of Sal (*Shorea robusta*) forests of Bangladesh
- It is possible to describe the spatial structure of the dominating species Sal (*Shorea robusta*) by using European based neighbourhood analysis techniques.

2. Research Objectives

In the past the Madhupur and Bhawal National Park had a continuous belt of Sal forests with a comparable species composition. To observe the current species composition of the two national parks, species richness and contribution of different species in terms of abundance and dominance; different methods for data investigation should be considered in the core zone. The overall aim of this study was to investigate the plant diversity of Sal forests of Bangladesh and to enrich the scientific information about composition, species richness, structure and regeneration patterns under different levels of human disturbances and protection status.

The main objectives of this study based on the main hypothesis are given below:

1. To analyse the impacts of anthropogenic disturbances on the plant diversity of Madhupur National Park
2. To describe the impacts of picnic activities on the plant diversity and vitality of trees of Bhawal National Park
3. To analyse the differences in plant population structure based on the protection level in the buffer and peripheral zone of Madhupur National Park
4. To compare the species richness and community structure of the core zone of the Madhupur and Bhawal National Park
5. To measure the spatial structure of the dominating tree species, Sal by using European based neighbourhood analysis

These objectives have been considered in four peer reviewed manuscripts, which are part of this thesis in the appendix chapter.

To analyse the impact of anthropogenic disturbances on species richness, pattern of diversity, forest structure and regeneration of tree species in the Madhupur Sal forests of Bangladesh were the objectives of manuscript number 1. The species richness and abundance of different plant groups, distributions of diameter and tree height, the amount of coarse woody debris and regeneration status should be observed. In this study, a disturbance gradient from low to highly disturbed forest types based on the intensity of past and current anthropogenic impacts should be analysed (**Appendix 1**).

The role of picnic activities on forest diversity, structure, regeneration and vitality of tree species in the Bhawal National Park of Bangladesh is the core part of manuscript number 2. Diversity indices should be analysed according to different intensities of picnic activities.

Concentration of dominance, density and basal area as well as regeneration quantities should be observed along this gradient (**Appendix 2**).

To analyse the effects of zoning based on protection level, the plant community structure of buffer and peripheral zone of Madhupur National Park was the objective of the manuscript number 3. The study should focus on the species richness of trees, analysis of the diameter, tree height and social class distributions, as well as the regeneration status of natural tree species (**Appendix-3**).

To understand the effects of the dominating species Sal on management activities and man made disturbances it is essential to measure spatial diversity also. The study of the manuscript number 4 aimed to assess the applicability of neighbourhood-based variables (contagion or dispersion, aggregation or mingling, size dominance and size differentiation) in the Sal forests of Bangladesh. The analysis of the spatial diversity of Sal should help for a better understanding of the ecology of these forests (**Appendix 4**).

3. Materials and Methods

3.1 Characterisation of the study areas

The study was carried out in two Sal (*Shorea robusta*) dominating national parks of Bangladesh: Madhupur and Bhawal National park. The Madhupur National Park is located between $23^0 50^/$-$24^0 50^/$ N latitude and $89^0 54^/$-$90^0 50^/$ E longitude. The Bhawal National Park study area is located in 40 km north from the capital city Dhaka (24°01'N, 90°20'E). The forests are fragmented by an intricate network of depressions in a honeycomb pattern layout. The depressions are generally cultivated with paddy. Homesteads, cultivable land, and forests are mixed. Both the parks belong to the bio-ecological zone of Madhupur Sal Tract (Nishat *et al.* 2002). This tract represents highly oxidized reddish brown clay containing ferruginous nodules and manganese spots. According to Richards and Hassan (1988), the soils have a moderate to strong acidic reaction. The soils are also characterised by low organic matter and low fertility (Alam 1995). The topography of both parks is characterized by plain land or low hills rising 3.0-4.5 m above the surrounding paddy fields locally known as 'chalas', which are intersected by numerous depressions or 'baids'. Following Thornthwaite's principles, they are included in the humid region (Ismail and Mia 1973). The annual rainfall ranges from 2030-2290 mm and the annual temperature ranges from 10-34°C. The humidity varies between 60 and 86%, the duration of sunshine ranges from 5-9 hours and average maximum wind speed is 16KM/hour.

The Madhupur National Park was classified into low, medium and high disturbed sites according to human disturbance level (Appendix 1). It has been further zoned as core, buffer and peripheral zone in accordance with protection level assigned by the forest authority. On the other hand, the park was also classified as mixed and pure Sal forests according to relative abundance of the dominating species, Sal . The core area of Bhawal National Park is different from the Madhupur National Park, which has been being used as picnic spots. The rest area and human disturbances are alike of Madhupur National Park. The core area of Bhawal National Park was classified as non-used, occasionally used and frequently used area on the basis of picnic activities.Both the national parks are highly dominated by Sal (*Shorea robusta*). These national parks are located in the central region of Bangladesh (Figure 1). Detailed geographic locations, soil and climatic information are also given in Appendix 1&2.

Source: *Bangladesh Forest Department, 1999*

Figure 1: Map of study area (Madhupur and Bhawal National Park)

3.2 Sampling design

The study was carried out from 2006 to 2007. A total of 180 plots from Madhupur National Park and 120 plots from Bhawal National Park were on transects with a minimum distance of 100m from plot to plot, in most cases. The starting point of a transect walk in whole study area of Madhupur National Park and non-used area of Bhawal National was fixed on the road at 200m distance from the last intersection of two roads (Figure 2).

Due to the presence of depressions in the landscape, forest gaps, or bare land, it was not always possible to establish the plots in a regular distance. The plots on the transect were examined continuously at 100 m distance in areas with a more or less closed forest cover, but in cases of fragmentations the next plot was taken at 100m -200m distance.

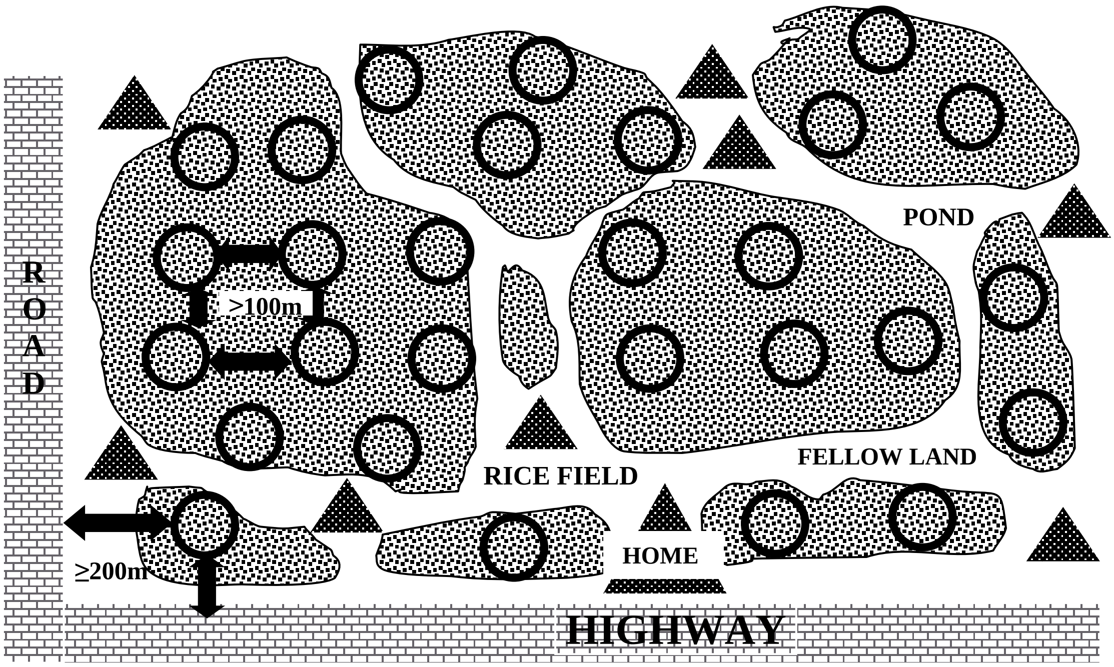

Figure 2: Topography of the study area and way of plot sampling

Forty plots in the frequently used area of Bhawal National Park were selected from the centre of 40 picnic spots. The plot in the occasionally used area of Bhawal National Park was selected at 100 m distance of each plot of frequently used area. The number of plots against different forest types is given in Table 1.

Table 1: Classification of study area and allocation of number of plots

National Park	Classification of Sites	Number of plots	Alternative classification	Number of plots
Madhupur	Low disturbed	60	Core Zone	120
	Medium disturbed	60		
	High disturbed	60	Buffer Zone	30
			Peripheral Zone	30
	Sub-total	180		180
Bhawal	Non-used area	40	Core zone	120
	Occasionally used area	40		
	Frequently used area	40		
	Sub-total	120		120

The area of each circular plot was 300m^2 (radius = 9.77m) and was considered for the data investigation of the mature trees (>10cm dbh), coarse woody debris (>5cm dbh and >1.37m height), saplings, climbers and herbs. But to capture more number of mature natural species from the buffer and peripheral zone of Madhupur National Park, a tree having more than 5cm dbh was considered as mature tree. To find out maximum number of regeneration, the whole 300m^2 area of a plot was considered in the buffer and peripheral zone. Within the 300m^2, a subplot of 100m^2 area (r=5.64m) was considered for the inventory of large and another subplot of 12.6m^2 area (r=2m) for small seedlings (Figure 3).

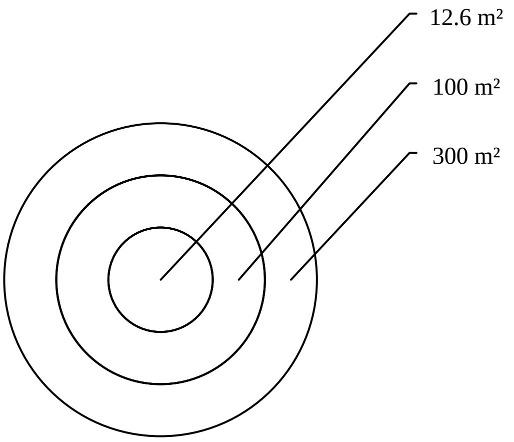

Figure 3: A sample plot

For measuring the spatial diversity, 60 plots were examined from the core areas of Madhupur National Park. In each plot, we selected 3 Sal trees from each plot termed as reference trees. To reduce biasness from the selection process of a reference tree, the first reference tree was taken as the nearest one from the centre, the second reference tree was taken as the nearest one from the middle point of the radius and finally the third reference tree was chosen as the most distant Sal from the centre of the plot (Figure 4).

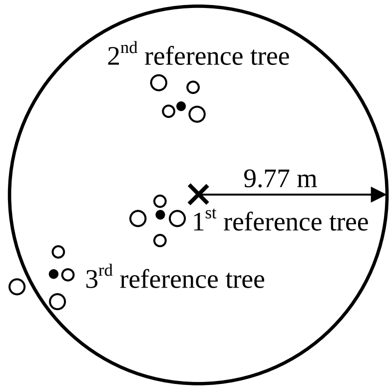

Figure 4: A sample plot with 3 reference trees and their neighbours

For each reference tree the four nearest neighbours were chosen for the neighbourhood analysis. In this context, the reference tree with its four neighbours was termed as ‘group of five’.

3.3 Biodiversity indices

3.3.1 Species-area curve

The size of a sample area needed to provide an accurate representation of the total diversity in tropical forests. Species area curves were produced from the total number of plant species found at different sample sizes to capture the maximum number of plant species from the study area. The number of sample plots was increased until and unless the number of plant species attains steady condition.

3.3.2 Species richness

Species richness is the number of different species in a given area. The species richness was calculated to determine the sensitivity of these ecosystems and their resident species. The actual number of species calculated alone is largely an arbitrary number.

3.3.3 Similarity Index (Community Coefficient)

The similarity index was measured to find out the species overlapping, similarity and contrarily dissimilarity among or between different forest sites or national parks. Jaccard Index (Jaccard 1912) and Sørensen index (Sørensen 1948) were calculated as

$$Jaccard\ \ Index = j/(a+b-j)$$

$$Sorensen\ Index = 2C/(A+B)$$

Where, j/C is the number of species common in both forests, *a/A* number of species in forest A and *b/B* the number of species in forest B.

3.3.4 Importance Value Index (IVI)

The Importance of Value Index of each tree species was measured to know the structural role and dominance of that species on the basis of relative frequency, abundance and dominance.The relative values of frequency, density and basal area for each single tree species were used to calculate the Importance Value Index (IVI) plot wise according to (Curtis 1959, Phillips 1959):

$$IVI = \text{relative frequency} + \text{relative density} + \text{relative basal area}$$

3.3.5 Shannon-Wiener Index (Diversity Index)

Diversity index was calculated to measure the species diversity and community composition in different forest sites and national parks as well. The Shannon-Wiener diversity index (Shannon and Wiener 1963) was calculated from the following formula given by Magurran (1988):

$$\underset{i=1}{\bar{H}} = -\sum^{s} p_i \ln p_i$$

Where, p_i is the proportion of the *i*th species and the number of all individuals of all species (n_i/N).

3.3.6 Simpson Index (The concentration of dominance)

In ecology, the concentration of dominance is often used to quantify the biodiversity of a habitat. It takes into account the number of species present, as well as the abundance of each species. Simpson’s index (Simpson 1949) measured the concentration of dominance (CD):

$$CD = -\sum_{i=1}^{s}(p_i)^2$$

Where, p_i is the same as for the Shannon-Wiener information function

3.3.7 The Evenness

Evenness is a measure of the relative abundance of the different species making up the richness of an area. Evenness was calculated by Pielou's index from the formula given by Magurran (1988):

$$E = \overline{H}/\ln S$$

Where, $\overline{H}$ is the Shannon-Wiener diversity index and S is the number of species

3.3.8 Neighbourhood-based indices

It considers species composition, horizontal and vertical variation within the forests and these characteristics in space or arrangement of these dimensions in relation to each-others. The contagion (Gadow *et al.* 1998, Staupendahl 2001), species mingling (Pielou 1977), size dominance (Hui *et al.* 1998) and size differentiation (Füldner 1995, Pommerening 1997, Pommerening 2002) were measured to determine the behaviour of the dominating species, Sal (*Shorea robusta*) to intra and inter species. The Indices were calculated as

Table 2: Formula of spatial indices

Indices	Formula	Where
Contagion	$W_i = \frac{1}{4}\sum_{j=1}^{4} w_{ij}$	$w_{ij} = \{1, if\ \alpha_j < \alpha_0; 0, otherwise\}$
Species mingling	$M_i = \frac{1}{4}\sum_{j=1}^{4} m_{ij}$	$m_{ij} = \begin{cases} 1, if\ species_j \neq Species_i < \alpha_0 \\ 0, otherwise \end{cases}$
Size dominance	$S_i = \frac{1}{4}\sum_{j=1}^{4} s_{ij}$	$s_{ij} = \{1, if\ DBH_j > DBH_i; 0, otherwise\}$
Size differentiation	$S_{ij} = 1 - \frac{\min(size_i, size_j)}{\max(size_i, size_j)}$	

3.4 Disturbance Index

The disturbances of the Madhupur National Park were classified as present and past disturbance. 6 disturbance elements were identified as present disturbance (logging, destruction of regeneration, litter sweeping, animal grazing, soil disturbances and shifting cultivation), where only logging could be identified as past disturbance. The intensity of each disturbance elements were categorized on the basis of qualitative assessments. Each category was weighted and average values were calculated.

Disturbance Index= Current disturbance Index + Past disturbance Index

$$CDI = \frac{1}{6}\sum_{i=1}^{6} W_i$$

Where, CDI is current disturbance index and W_i is the weight of *i*th (*i=1,2..6*) elements

$$PDI = W_p$$

Where, PDI is past disturbance index and W_p is the weight of past disturbance element (logging)

3.5 Classification of regeneration

The regenerations were classified as saplings (5- 10 cm dbh), large seedling (> 30 cm height and <5 cm dbh) and small seedling (< 30 cm height). The regeneration was also classified in liitle bit different way in the buffer and peripheral zone as 0- 30 cm height, 30- 130 cm height and >130 cm height having <5 cm dbh (Appendix 3) to capture more number of natural trees. Based on the presence of the different stages of the natural regeneration (small and large seedlings, saplings) and the number of species within a class the natural regeneration was categorized as good (small seedlings >> large seedlings >> saplings), fair (small seedling > large seedlings > saplings), poor (small seedling < large seedling < saplings), very poor (absence of one or two stages) and nil (absence of all stages of regeneration i.e. presence of mature trees only having no regeneration).

3.6 Quantifying social class

The social class is very important to know different tree layers and also the structural pattern of a stand. The social classes were classified as dominant, co dominant, suppressed and intermediate class on the basis of tree height, canopy length, side branching and general level of canopy crown.

Table 3: Classification of mature trees on the basis of crown length, side branching and trunk height

Class	Indication
Dominant	Trees with crown extending above the general level of the layer; somewhat taller than the co dominant trees, and has well developed crowns, which may be somewhat crowded on the sides.
Co-dominant	Trees with crowns forming the general level of the crown canopy; crown is generally smaller than those of the dominant trees.
Intermediate	Trees with crowns below, crown is generally smaller than those of the dominant trees.
Suppressed	Trees with crowns entirely below the general level of the crown canopy, or trees lost its crown by somehow, or crown of small trees

3.7 Quantifying vitality

The vitality is an important parameter for assessing the health condition of tree species and it was described according to four different classes (1 = very high vital, 2 = high vital, 3 = low vital and 4= very poor vital) on the basis of the parameters crown percentage of total height, crown development, trunk shape, root damage, bark damage, insect infestation and pathogen infection.

4. Results

4.1 Species richness and overlapping

Species-area curves indicated that the sampling protocol sufficiently captured the array of plant species in all forest sites of two national parks. A total number of 134 species were recorded in Madhupur National Park from which 70 were represented by tree species, 15 by shrub species, 26 by climbers and 23 by herbs. The total of number plant species in the core zone of Madhupur National Park is 129, from which 65 tree species and other plant groups (shrubs, climbers and herbs) are occurring in the whole study area. The Bhawal National Park inventory (only the core zone) yielded a total of 43 plant species, out of which 22 were represented in the tree group, 10 in the shrubs group, 6 in the climbers group and 5 in the herbs group. The number of plant species decreased from the core zone to buffer zone, buffer zone to peripheral zone; and with the picnic activities and other sorts of human disturbances. Species overlap between Bhawal and Madhupur National Park was high (75% of Bhawal National Park) and similarity index between two parks was 0.23 (Table 4). This indicated that 23% of all species existed in both parks.

Table 4: Species richness of Madhupur and Bhawal National Park and species overlapping between them

Plants	*Species richness*		*Species*	*Similarity*
	Madhupur	*Bhawal*	*overlapping*	*Index*
Mature tree	52	13	12	0.23
Sapling	29	10	6	0.18
Large seedling	45	18	13	0.26
Small seedling	57	12	11	0.19
Tree	65	22	19	0.30
Shrub	15	10	4	0.19
Climber	26	6	4	0.14
Herb	19	5	5	0.26
All Plants	129	43	32	0.23

4.2 Composition, diversity and population structure

The diversity index and evenness are higher in Madhpur than Bhawal National Park, whereas the concentration of dominance was higher in Bhawal than Madhupur National Park (Table 5). In almost all cases, the diversity index and evenness decreased and the dominance index increased with human disturbances.

Table 5: Biodiversity indices in the Madhupur and Bhawal National Park

Parameter	*Plant type*	*Madhupur*	*Bhawal*
Density(N/ha)	Mature tree	331	742
	Sapling	768	224
	Large seedling	1123	2048
	Small seedling	2613	968
	Shrub	3526	539
	Climber	163	40
Basal area(m^2/ha)	Mature tree	19.2	16.5
Diversity Index	Mature tree	1.99	0.09
	Sapling	1.47	0.40
	Large seedling	2.22	0.24
	Small seedling	2.99	1.12
	Shrub	1.53	1.11
	Climber	2.53	1.20
	Herb	1.72	0.59
Dominance Index	Mature tree	0.36	0.98
	Sapling	0.43	0.86
	Large seedling	0.23	0.93
	Small seedling	0.10	0.55
	Shrub	0.37	0.45
	Climber	0.13	0.42
	Herb	0.27	0.71
Evenness	Mature tree	0.50	0.03
	Sapling	0.44	0.17
	Large seedling	0.58	0.08
	Small seedling	0.74	0.45
	Shrub	0.57	0.48
	Climber	0.78	0.67
	Herb	0.50	0.37

Shorea robusta was the dominant species in the core area of Madhupur National Park followed by *Artocarpus chapalasha, Mallotus philippensis, Terminalia bellirica, Miliusa roxburghiana, Ficus benghalensis, Dillenia pentagyna, Lannea coromandelica* and *Bursera serrata*. The core area of Bhawal National Park was almost pure Sal forests (Table 6). With an increase of disturbances, the forests are becoming more pure Sal forest considering only natural species. In the peripheral zone, natural species were totally replaced by exotic species. The basal area (m^2/ha) of the mature trees was higher in the Madhupur than that of Bhawal National Park. Plant density and basal area (m^2/ha) of the mature tree decreased with human disturbances in almost cases.

Table 6: Importance Value Index (IVI) of Madhupur (M) and Bhawal (B) National Park

Botanical name	Relative dominance		Relative abundance		Importance Value Index	
	M	B	M	B	M	B
Abroma augusta	0.83		0.34		2.78	
Adina cordifolia	1.25	0.04	0.67	0.02	2.41	0.73
Albizia chinensis	0.21		0.17		0.47	
Albizia lebbek	0.00	0.26	0.00	0.42	0.00	4.71
Albizia marginata	0.63		0.34		1.98	
Alstonia scholaris	1.04		0.42		1.58	
Amoora rohituka	1.88		0.76		2.99	
Artocarpus chapalasha	1.46		0.59		16.02	
Artocarpus lakoocha	0.63		0.25		0.95	
Bauhinia variegata	3.75		1.68		6.91	
Bridelia retusa	0.63	0.04	0.25	0.02	0.95	0.73
Bursera serrata	3.75		1.76		9.13	
Callicarpa arborea	0.63	0.07	0.34	0.07	1.10	1.49
Cassia fistula	0.63	0.11	0.25	0.09	0.95	2.22
Cassia siamea	0.42		0.17		0.64	
Clerodendrum inerme	0.42		0.17		0.68	
Dillenia pentagyna	5.00	0.07	2.69	0.05	10.61	1.47
Diospyros cordifolia	0.21		0.08		0.39	
Dipterocarpus indicus	1.25		0.76		2.83	
Eugenia jambolana	0.63	0.26	0.25	0.25	1.03	4.54
Ficus benghalensis	0.42	0.04	0.17	0.08	10.81	0.79
Ficus benjamina	0.83		0.34		5.09	
Ficus carica	1.04		0.42		1.57	
Ficus glomerata	0.42		0.17		2.01	
Ficus hispida	0.21		0.08		0.30	
Garuga pinnata	0.42		0.17		0.82	
Grewia asiatica	0.21		0.08		0.30	
Grewia laevigata	0.83		0.34		1.29	
Grewia microcos	2.29		1.68		4.53	
Holarrhena pubescens	0.42		0.17		0.65	
Hymenodictyon excelsum	1.88		0.92		3.63	
Lagerstroemia parviflora	1.25		0.50		2.51	
Lannea coromandelica	5.00	0.07	2.35	0.07	10.19	1.49
Litsea glutinosa	0.21		0.08		0.31	
Litsea monopetala	0.83		0.34		1.48	
Madhuca longifolia	0.63		0.25		0.98	
Mallotus philippensis	7.29		5.80		15.02	
Miliusa roxburghiana	5.42	0.07	4.20	0.13	12.03	1.54

Milisua velutina	2.92	0.07	1.18	0.19	5.27	1.61
Oroxylum indicum	0.83		0.34		1.25	
Polyalthia longifolia	0.21		0.08		0.49	
Schleichera oleosa	2.92		1.09		4.83	
Semecarpus anacardium	4.17		2.10		7.66	
Shorea robusta	22.71	98.84	59.50	98.57	120.99	277.94
Spondias pinnata	0.63		0.25		1.08	
Sterculia villosa	0.42		0.25		0.73	
Stereospermum suaveolens	0.42		0.17		0.64	
Streblus asper	1.04		0.42		1.63	
Terminalia bellirica	7.08		3.78		14.48	
Toona ciliata	0.21		0.08		0.41	
Vitex glabrata	0.63		0.25		0.95	
Wrightia arborea	0.63		0.34		1.07	
Zanthoxylum rhetsa	0.42	0.04	0.17	0.04	0.62	0.75
Total	100.00	100.00	100.00	100.00	300.00	300.00

Out of the 65 tree species (including the tree species in the regeneration) in the Madhupur National Park, 59 tree species were found to be regenerating (94% of the total number of natural species), where 19 species out of 22 (86% of the total number of natural species) in the Bhawal National Park. The regeneration categories on the basis of the proportion of saplings, large seedlings and small seedlings are comparable between both parks (Table 7). No saplings and large seedlings were found in the highly disturbed forest type. In the peripheral zone no regeneration was found.

Table 7: Regeneration status in Madhupur and Bhawal National Park

Classification	*Madhupur*	*Bhawal*
Good	19(29%)	7(32%)
Fair	2(3%)	1(5%)
Poor	3(5%)	1(5%)
Very poor	37(57%)	10(45%)
Nil	4(6%)	3(14%)
Total	65(100%)	22(100%)

Clerodendrum serratum was the dominant species of the shrub species in the Madhupur National Park followed by *Glycosmis pentaphylla*, *Randia uliginosa* and *Barleria lupulina. Clerodendrum serratum* was also the dominant species in the Bhawal National Park followed by *Randia dumetorum*, *Dalbergia spinose* and *Ageratum sp. Mikania micrantha* was the dominant species of the climbers followed by *Smilax macrophylla, Scindapsus officinalis* and *Calamus tenuis*. In the Bhawal National Park, *Pothos scandens* was the dominant climber species followed by *Smilax macrophylla* and unknown species (local name: Nangollata). *Ageratum conyzoides* was the dominant herb species followed by *Imperata cylindrical* and

Oplismenus aemulus in the Madhupur National Park. On the other hand, *Cyperus rotundus* was the dominant herb species in Bhawal National Park followed by *Curcuma zedoaria* and *Oplismenus aemulus*. The number of agricultural crop species increased with human disturbance and protection level. Among the agricultural crops pineapple, banana, papaya, turmeric, ginger and cucurbits were more common in the high disturbed area.

No coarse woody was found in the Bhawal National Park. Only very few number of standing coarse woody debris (2.2 N/ha) were found in the Madhupur National Park. Lying coarse woody debris or logs was absent.

4.3 Diameter, height, social and vital class distributions

The diameter distributions based on the sampled trees of the individual plots of all forest types followed a reverse J-shaped distribution in both Madhupur and Bhawal National Park. With an increase of the diameters at breast height (DBH) the relative abundance of tree decreased. The maximum diameter of Bhawal National Park did not exceed 50 cm where, it exceeded 100 cm in Madhupur National Park (Fig. 5). The abundance of trees of higher diameter class increased with the naturalness and protection level. The tree height distributions showed a tendency towards a normal distribution in both parks. The height of mature trees in the Bhawal National Park did not exceed 30m, whereas the tree height in the Madhupur National Park exceeded 35m (Fig. 6). The proportion of taller trees also increase with the naturalness, but protection level seems not to have an influence on tree height. The proportion of dominant crown class increase with the protection level. The proportion of dominant tree was higher in the buffer zone than the peripheral zone.

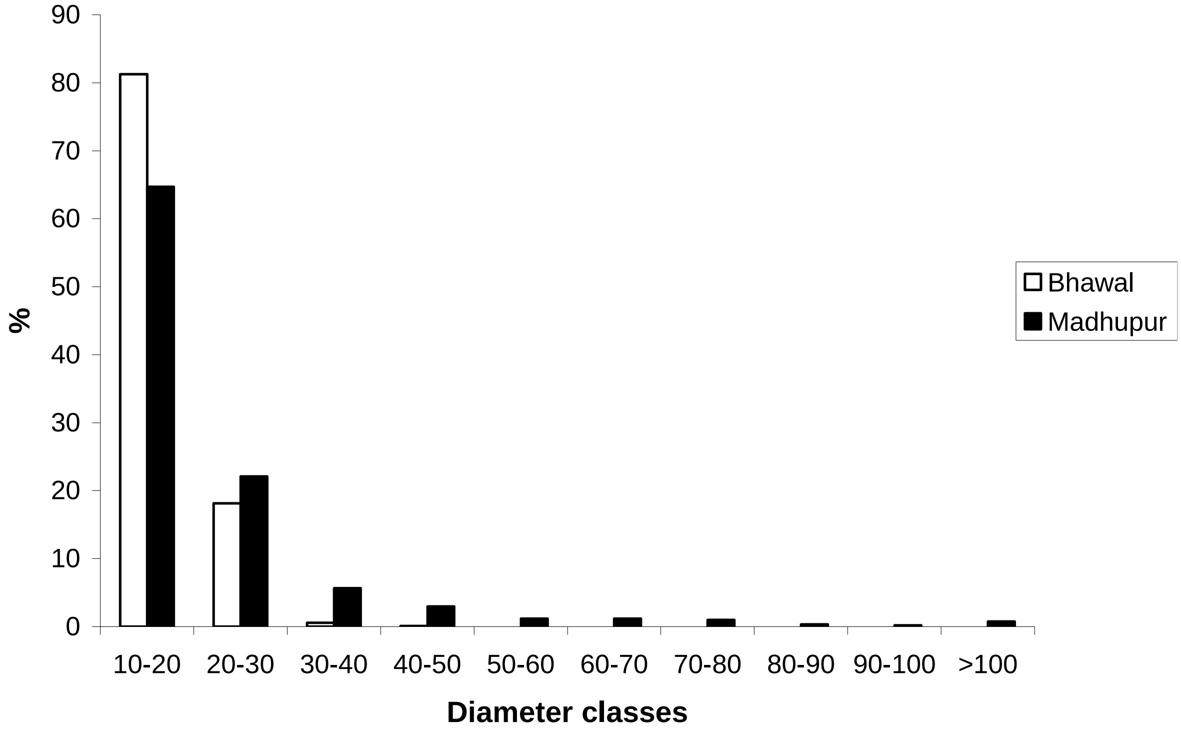

Figure 5: Diameter distributions in the Madhpur and Bhawal National Park

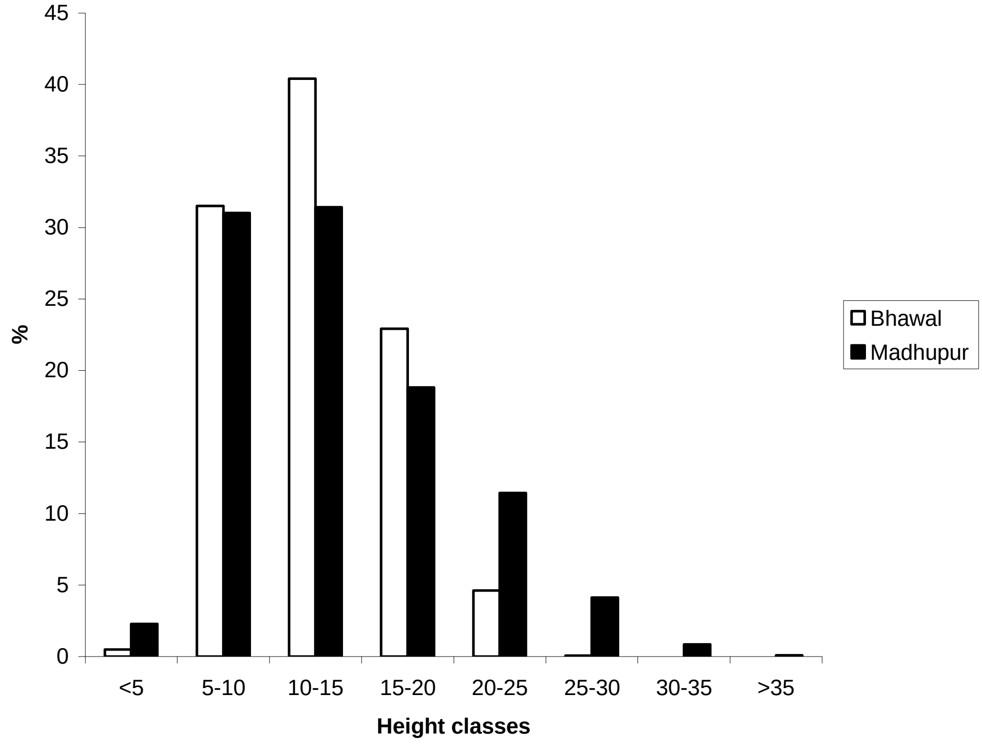

Figure 6: Height distributions in the Madhupur and Bhawal National Parks

The mean diameter and height of Sal was larger than Sal associates of same age. The size differentiation (diameter and height) was higher between Sal and other species than between the pairs of Sal and Sal. This indicates that the Sal-Sal diameter and height differentiation were more homogeneous than Sal-other species

Human disturbances played a vital role on the vitality of tree in the Sal forests. The proportion of trees having more vitality increased with the human disturbances like picnic activities.

4.3 Aggregation, dispersion, size dominance and size differentiation

The pure Sal forests showed lower 'degree of mingling' or higher 'aggregation' of Sal than the mixed stand. The species composition has a strong influence on the dispersion of the dominant species *Shorea robusta*. Sal is found as a dominant tree species in these ecosystems and the tendency for clumping is related to an increase in its density and subsequently the change of the dispersion occurs from 'random' to 'clumping'. There was a strong positive correlation($r=0.57$; $p=000$) between the value of density and contagion of Sal.

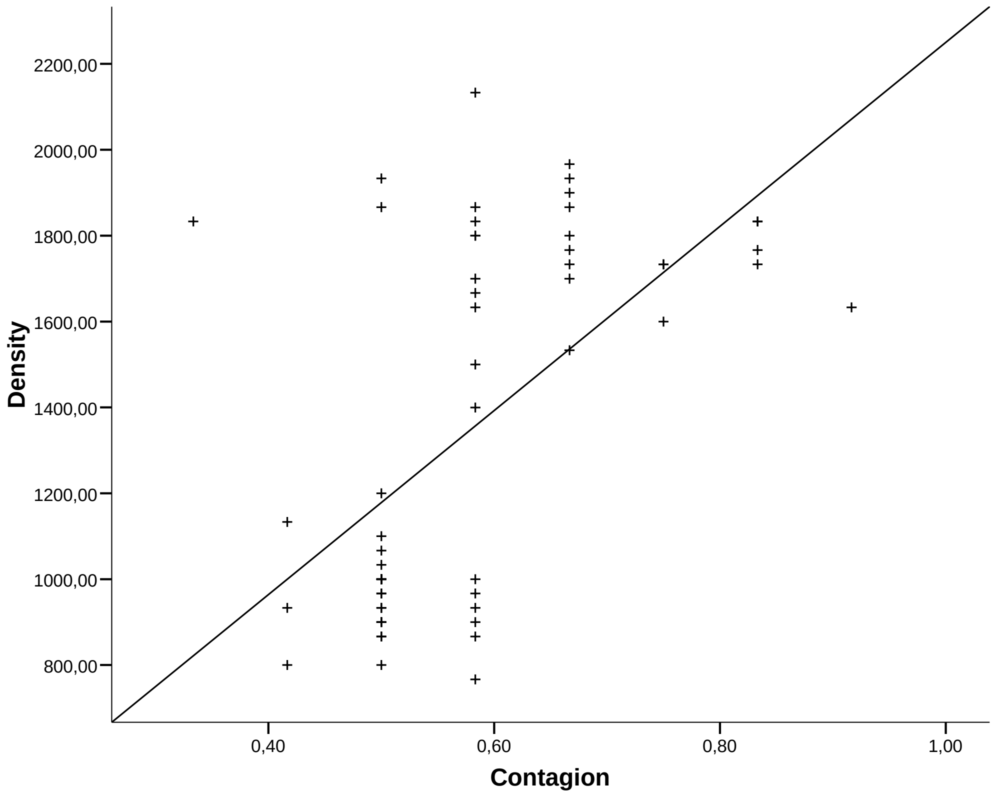

Figure 7: Linear regression between contagion and density of Sal tree (dbh ≥ 5cm)

On the other hand, with the increase of the proportion of Sal associates the dispersion changes from ‘clumping’ to ‘random’. There was a strong positive correlation(r=0.56; p=000) between the value of relative density and contagion of Sal.

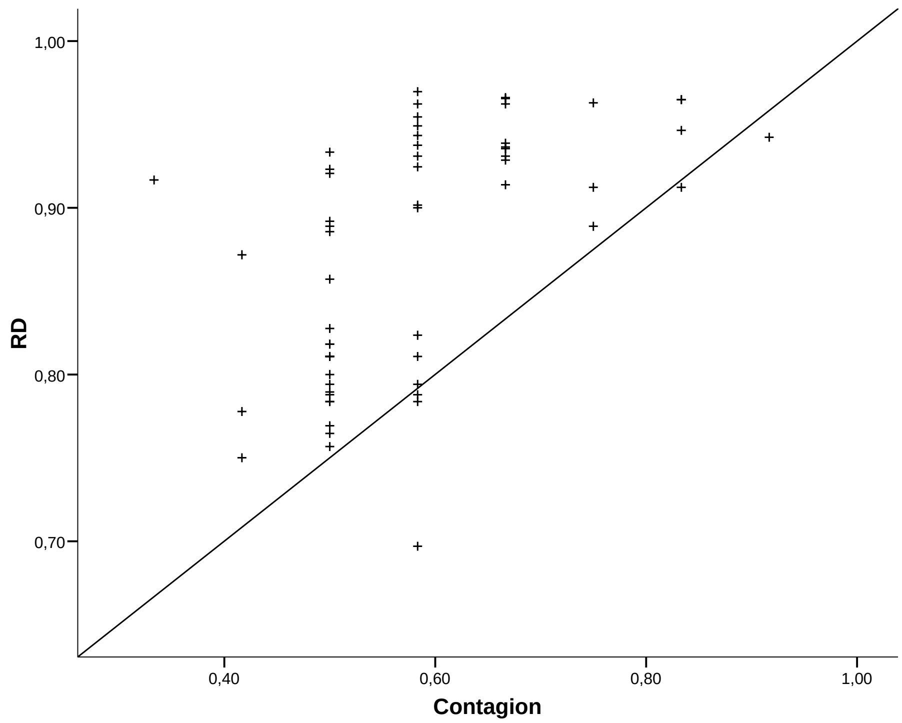

Figure 8: Linear regression between contagion and relative density (RD) of Sal

The mean diameter and height of Sal was larger than Sal associates of same age. The size differentiation (diameter and height) was higher between Sal and other species than between the pairs of Sal and Sal. The size dominance of Sal was slightly higher in mixed stand than pure stand.

Table 8: Size differentiation (Mean ±SD) among different tree species (dbh ≥ 5cm)

Forests	*Tree (N/plot)*	*Density of Sal(N/ha)*	*DBH of Sal (cm)*	*DBH of other sp.(cm)*	*Height of Sal(m)*	*Height of other sp.(m)*
Pure	56.7±4.3	1784.2±128.7	7.4±2.0	6.3±1.2	5.9±1.7	4.8±1.1
Mixed	35.2±2.6	956.7±99.8	7.3±2.3	6.9±4.0	5.6±2.0	4.9±1.7

5. Discussion

5.1 Anthropogenic disturbances in the Sal forests of Bangladesh

The Sal forests of Bangladesh are under constant human pressures due to encroachment and illegal removal of timber and fuelwood from the forests. These forests are located in the central part of the country which is most densely populated. They comprise only small patches intermingled with private agricultural lands. The main causes for the losses of forest land initiated in the 1950's were the ongoing urbanization and encroachment as well as activities for the change of the land use from forests to agriculture have started. The land degradation process has been further propagated by the activities around the Jamuna Multipurpose Bridge which attracted new investors and developers in the Madhupur Sal forest areas (UNEP 2001). The scarcity of land near to the capital of Bangladesh made forested areas highly demandable land. Industrialization like the establishing of garments industries, ceramic industries, poultry industries, and poultry feed industries enhanced the deforestation in the Bhawal Sal forest areas.

On the other hand, there is a huge pressure on the remaining forests because of the wide gap between the demand and supply of timber and fuelwood. The high prices for fuelwood and the potential high incomes from timber led to the existence of organised and professional groups of illegal loggers (Chowdhury 1994). Lacking an adequate number of forest staff, insufficient training of the forest guards, missing of an appropriate road network and check posts and poor infrastructure of the forest department makes it almost impossible to protect the forests. Moreover, the whole forest ecosystem is impacted by extensive and unregulated entrance of people who use the forests for fuel collection (tree, regeneration and shrubs), collecting non-wood products (shrubs, climbers and herbs) and other reasons (hiding, criminal activities). In addition, the ethnic communities locally known as ‘Garo’ or ‘Mandis’ and ‘Koch’ have been living in these forests for centuries. They are totally depended on the natural resources of the forests and they might cause some overuse of the forest according to the small remaining patches they are able to stay in. To combat the ongoing denudation of the Sal forests and to prevent further encroachment the forest department initiated agro-forestry programs. The beneficiaries could grow agricultural products altogether with exotic tree species. Consequently, the forests have lost their original character due to agricultural cultivation, which required tillage operations and intercultural operations. The tillage operations caused impacts on the soil by losing habitat for natural regeneration. The soils are disturbed by digging out stumps, collecting forest soils for household activities, digging ponds or the construction of roads and infrastructures. Domestic animals graze on the forest floor causing impacts on the species composition or number of species. The women of forest communities are professionally involved to sweep forest litter for their own needs or they sell it in the market to increase their income activities. Therefore, the forests are becoming non-fertile day by day due to scarcity of organic matter.

No single part of the Sal forests can be found as undisturbed natural forest. Logging, regeneration destruction, litter sweeping, animal grazing and soil disturbances are common in all zones and sites of both national parks. Recreational activities like picnics of 1.5 million people per year are an additional human pressure in the core zone of the Bhawal National Park. Type and intensity of the human disturbances in the Sal forests of the Madhupur and Bhawal Sal forests are not easily to be compared with other Sal forests of Central Asia. Firing, grazing, lopping and litter sweeping have been reported as the major human disturbances in Sal forests of Nepal and India (Gautam and Devoe 2006). Regeneration destruction and soil disturbances have not been considered as human disturbances in any studies in Asia so far. This study indicates that the impacts from these two disturbances will change the species composition from near natural to artificial forests and might cause further deforestation. Among all disturbances, soil disturbances seemed to be the most severe impact on these ecosystems. The digging out of stumps, tillage operations and the use of forest soils are hampering the natural habitat for plants in the Sal forests. In the buffer and peripheral zone these soil disturbances are out of control but in the core zone they are taking place at a minimum level. Therefore the buffer and peripheral zones can not be considered as national park areas in a strict sense.

To restore the forest land from encroachers, plantation of exotic species along with agroforestry have been going on in the buffer and peripheral zone. Especially exotic species affect the natural ecosystem and the natural regeneration processes (Alam *et al.* 2008). Major portions of buffer and peripheral zone are used as rubber plantation, and rice, mustard, cotton, pineapple and banana cultivation. As these areas were considered as very highly disturbed with no tree coverage, they were not investigated in this study.

However, the topography (plain-land), location (located in or near to highly populated areas), disputed land tenure system and the negligence of the forest authorities (mainly because of corruption) may be considered as key factors behind these unique human disturbances in Bangladesh.

5.2 Species richness, composition and community structure of Sal forests of Bangladesh

The species richness of the core zone of the Madhupur National Park (129 plant species: 65 trees, 15 shrubs, 26 climbers and 23 herbs) is comparable to other Sal forest regions in Central Asia. Webb and Sah (2003) enlisted 159 species (49 trees, 45 shrubs, 16 climbers and 42 herbs) in the Central Terai, Timilsina (2007) counted 131 species (28 tree, 10 shrub, 6 climber and 87 herb) in the Western Terai, Pandey and Shukla (2003) found 208 species (93 trees, 50 shrubs, 34 climbers and 31 herbs) in the Eastern Terai, and Shankar (2001) examined 87 species (≥10 cm gbh) in Darjiling Terai of Nepal and India. The Bhawal National Park appears poor in plant species richness (43 plant species: 22 trees, 10 shrubs, 6 climbers and 5 herbs) compared to other Sal forests region of South Asia. The overall species composition revealed that both the national parks are dominated by *Shorea robusta.* With the human disturbance the forest became more pure Sal forest. Both the national parks were supposed to be mixed natural forests with a total share of 75% to 25% by Sal (*Shorea robusta*) and the rest by other deciduous species like *Adina cordifolia, Albizia procera, Bombax ceiba, Butea monosperma, Lagerstroemia parviflora, Dillenia pentagyna, Garuga pinnata, Hymenodictyon orixensis, Semecarpus anacardium, Miliusa velutina, Schleichera oleosa* (Ismail and Mia 1973). The relative abundance of Sal (*Shorea robusta*) was 98.5% in the core zone of the Bhawal National Park, where 59.5% in the Madhupur National Park. The impacts of tourism and other human disturbances on Bhawal National Park are very much severe due to its location (40KM away from the centre of the capital) comparing to Madupur National Park (120 KM away from the capital). Tremendous human pressure caused the decreasing of the species richness and the relative proportion of natural Sal associates by increasing the relative proportion of Sal in Bhawal National Park. The outside area of this park is highly populated and anthropogenic disturbances are more severe than Maduhpur National Park. Urbanization and industrialization are being extended in this area day by day. Moreover, it is used as the recreational park for the people of the capital and other areas. Within each park, the relative abundance of Sal increased with human disturbance. So, the human pressure has an impact on the tree species composition. In peripheral zone no natural tree species were found. This reveals that with decreasing of protection level of the forest authority the natural species are logged out by the outside people. The natural species richness increases with naturalness and protection level (Appendix 1-3). The Madhupur National Park had a highly heterogeneous distribution of trees and can be considered as one of the highly diverse forests comparing to Bhawal National Park. However, a limitation of the study was that herbs covering less than

1% of the forest floor were not considered during data investigation due to the sampling design (to avoid a long time stay at the plot and probable threats from criminals). This fact could have a minor effect on the total of species found in the investigated study areas.

The stand density of the Madhpur National Park is well within the limits reported for other Sal forests of India and Nepal (Shanker 2001, Pandey and Shukla 2003, Webb and Sah 2003). The stand density of Bhawal National Park is comparable with Indian Sal forests reported by Shukla and Pandey (2000), Singh *et al.* (1995) and Rawal and Bhainsora (1999). The stand density of Bhawal National Park was higher than that of Madhupur National Park due to regeneration pattern. The Bhawal National Park has been regenerating by simple coppice system since 1934, where the trees of core zone of Madhupur National Park have been regenerating mostly by seeds. The mean basal area of the Maduhpur National Park is slightly higher than that Bhawal National Park due to presence of some giant trees. It is important to mention that the stand density and basal area of these parks do not represent the average forest characteristics. During data collection only the sample plots having minimum tree coverage were considered for data investigation and cleared areas were totally ignored.

The proportions of small seedlings, large seedlings and saplings in the core zones of both national parks indicate that the natural regeneration takes place adequately, but the highly disturbed forest type (buffer and peripheral zone of Madhupur National Park) is totally out of natural regeneration. Ploughing and clearing of ground vegetation for cultivation practices, firewood collection and grazing together with the below ground competition of mature trees and other plants may increase the mortality rate of seedlings and saplings in the highly disturbed forest type (Nath *et al.* 2005). Heavy soil disturbances from tillage operations, cultivation of agricultural crops in the forest rows and introduction of fast growing tree species degraded the habitat for the natural regeneration in the highly disturbed forest type (Appendix 3). The regeneration status in both parks decline with human disturbance (Appendix 1-2). In the past the medium disturbed forest type of Madhupur can be described as almost bare ground before 10 years. However, 30-40 years are required to return to a diversity level before the last clear cut in tropical forests (Webb and Sah 2003, Faber-Langendoen 1991, Webb and Fa'aumu 1999). Considering the regeneration status of medium disturbed forest type of Madhupur National Park, it is possible to restore that area towards a natural ecosystem if the destruction of natural regeneration can be protected (Appendix 1). The species richness and also the abundance of shrubs and climbers increased with naturalness (Appendix 1&2). It seemed that outside people collect shrubs for fuelwood and climbers to use as vegetables and medicines. In low protection level and in high disturbed site they have more access to enter than highly protected and low disturbed site. Agricultural operations and highly movement of picnic people are not also congenial for shrub and climber .Comparing the horizontal structure of both national parks appeared to exhibit a typical reverse-J shape pattern, typical for stable populations, typical admixtures of very young to old aged giant trees and characterized by a non-linear reduction in stem densities with increasing diameter (Hartshon 1978, Webb and Sah 2003, Swamy *et al.* 2000) in Madhupur than Bhawal National Park. The tree height distribution revealed that Madhupur had a more multilayered forest than Bhawal National Park. Without considering the exotic tree species in the high disturbed forest, proportion of larger trees decrease with human disturbances in both parks. The recreational activities like picnic have a negative impact on the tree vitality. Soil disturbances caused by different recreational activities and compaction of soil due to people movements, are the main reasons for deteriorating tree vitality.

No coarse woody debris was found in the Bhawal National Park. The coarse woody debris (CWD) level of Madhupur National Park was lower than any other tropical forests of India (Nath *et al.* 2005, Chandrashekara and Sibichan 2006). So far there is no reference level of CWD for the sub-continental tropical forests and even its status in tropical forests of the world has gone largely unreported (Grove 2001). Due to scarcity of fuelwood, the surrounding people cut the tree immediate after death. But in order to determine the degree of naturalness of a forest ecosystems CWD has become an important indicator (Grabherr *et al.* 1998). The amount of dead wood in natural forests may be so extensive – up to 30% of dead stems (Linder *et al.* 1997) or near about 40% volume of living trees (Rahman *et al.* 2008) in European temperate forests. But at least 5% of the stand basal area (or volume) should be dead for maintaining faunal biodiversity (Bütler *et al.* 2004). Along with lacking of CWD human disturbances caused disappearing or being red listed of most of the birds, mammals, reptiles or amphibians of this region (Kabir and Ahmed 2005, Sarker and Huq 1985, Alam *et al.* 2008)

5.3 Spatial diversity of Sal and the applicability of neighbourhood based-measures

Sal is gregarious and dominant in its stand (Champion and Osmaston 1962, Troup 1986). It was found that with the increase of the proportion or the density of Sal, the dispersion tended towards ‘clumping’ (Appendix 4). Tropical species with a low density tend to have relatively ‘uniform’ dispersion and those with high density have a ‘clumped’ dispersion (Krebs 1972). Sukumar *et al.* (1992) reported that with the increase of the abundance of deciduous species the clumping will increase. Rahman *et al.* (2007) found a ‘regular’ dispersion of Sal in highly mixed forest. Shankar (2001) reported that the clumping of Sal increased with its abundance. However, the behaviour of Sal was determined only in the successional or medium disturbed forest sites. It was mentioned that the relative proportion of Sal increases with human disturbance. On the other hand, with the increase of the relative proportion of Sal, the dispersion tends to be clumping. So, it can be assumed that the dispersion of Sal is correlated with the level of disturbances. Rahman *et al.* (2007) found a regular dispersion in natural or low disturbed forest sites of the Sal forest. It seems quite evident that Sal regenerates from seed origin in natural or low disturbed site but from sprouting in medium and highly disturbed sites.

The size differentiation was higher between Sal and other species than between the pairs of Sal and Sal, which indicates a relatively higher growth potential for Sal in the young stages of stand development compared to the other species. Some authors have also found that the growth of Sal is relatively faster than other species in the young development phases (Gautam and Devoe 2006). The mingling index of the neighborhood analysis can be used to describe the species composition of the Sal forests reasonably well. These neighbourhood-based variables and methods can be used in the field at low cost and less time to describe, compare and evaluate forest structures in a scientifically sound way. During field work, there is no need to consider the tree coordinates or the distances between trees to evaluate the basic spatial characteristics. Even only 1 reference tree having 4 neighbouring tree describe the spatial characteristics of Sal effectively.

6. Conclusions

The Sal forests are considered one of the richest ecosystems in regard to forest diversity in Bangladesh. However, the level of diversity is generally unknown to the scientific community, politicans, and local people and is, therefore, not well documented at all. The forests are facing a severe threat by anthropogenic disturbances cause by humans who directly or indirectly depend on forest resources for their social welfare. Since the value of these forests is currently not recognized, the increasing human population around the park is likely to threaten their very existence. The implementation of biodiversity conservation activities for the Bhawal National Park is challenging for being the nearest park with picnic facilities from the mega populated capital. Even in the low disturbed site, 75% of the species have become rare or very rare in Madhupur Sal forests. Both the parks warrant more attention in order to conserve their species richness. This study can serve as a baseline for the description of plant diversity in Bangladesh, giving an insight to the state of species richness at different disturbance intensities. Moreover, the findings of this study can provide information to managers describing the importance of a well balanced distribution of undisturbed Sal forests in order to formulate biodiversity conservation plans. A deeper understanding of the plant diversity of the Sal forest ecosystems will help the country implement international regulations, like the Convention on the Biological Diversity.

The surrounding people of the two National parks or people living inside are not fully aware of the importance of the conservation measure regarding the Sal forests. Besides the land resources, people living in and around the Sal forests heavily rely upon the forest products. In this context forest management efforts need to consider community-based forestry programmes involving local people in forest management activities. It was found that medium disturbed forest sites could be restored as natural ecosystem if human disturbances are minimised. Conservation management practices should therefore be focused on such sites. The continuing destruction of regeneration should be stopped otherwise many rare species even in the low disturbed forest site will be extinct. Gap filling with rare species in the low disturbed forest area will reduce the threat of being extinct. Additionally afforestation practices on bare lands could help the early successional species *Shorea robusta* to recover within a short period of time through its strong regeneration potentiality. Recreation management should consider the number and size of the picnic parties to be allowed. The number of picnic parties should not exceed the number of picnic spots to protect the occasionally used picnic spots from further disturbances. A recovery of highly disturbed sites in the peripheral zone might not be possible due to the large differences in species composition. In the buffer zone an *in- situ* conservation of seedlings, a protection from further logging of natural species, and stopping plantation of exotic trees and crop cultivations could be successful.

Socio-economic measures will help to decease the impacts on the Sal forest on a mid term basis. An alternative fuel energy source needs to be offered to the forest people or surrounding people in order to reduce the fuel wood collection. The income generating activities initiated by the government or NGOs through micro credit programme may minimise the tremendous human pressure on forest additionally. There is an urgent need for public awareness programmes to increase the understanding of the vulnerability of the environment and the importance of the maintenance of forest biodiversity. The professional illegal loggers and corrupted forest staffs should be brought under rule of law; otherwise, no measures should be effective to protect these biodiversity rich ecosystems.

In overall this study helped to improve our understanding of the plant diversity of the Sal forest ecosystems. However, after 10 years, the same research should be carried out on the same plots to determine the dynamics, rate of deforestation and the temporal loss of biodiversity in these parks. A comprehensive research is needed to measure the impact of picnic activities on soil characteristics and plants. Research on how the soil disturbances destroy the natural habitat for the ground flora including regeneration, is a crying need in these ecosystems. The future ongoing research activities will help to determinate the rate and spread of biodiversity losses in the Sal forests and will contribute to the rising awareness on the importance of these ecosystems.

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8. Appendix: Articles

8.1 Anthropogenic disturbances and plant diversity of the Madhupur Sal forests **(***Shorea robusta*** C.F. Gaertn)** ***of Bangladesh***

Anthropogenic disturbances and plant diversity of the Madhupur Sal forests (*Shorea robusta* C.F. Gaertn) of Bangladesh

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SUMMARY

This study examined the impact of anthropogenic disturbances on species richness, pattern of diversity, forest structure and regeneration of tree species in the Madhupur Sal (*Shorea robusta* C.F. Gaertn) forests of Bangladesh. The forest sites were classified as low, medium and highly disturbed based on the intensity of historic and current anthropogenic impacts. Plant species richness and biological diversity varied along a disturbance gradient in different forest types. A total of 134 plant species were identified in the study area. The highest plant species richness (125 species) was found in the low disturbed forest type, and the lowest species richness (19 species) was found in the highly disturbed forest type. Plant density (except herbs and sapling) and basal area of mature trees declined with an increase in disturbance intensity. Only a few snags ($4.4 ha^{-1}$) were found in the low disturbed forest type. The diameter and height distributions revealed that the low disturbed forest type comprised a mixture of very young to giant trees, while the medium and highly disturbed forest types contained only a young generation of trees. The relative abundance of the early successional species, *S. robusta,* increased with the intensity of human disturbances due to its regeneration potentiality. The highly disturbed forests can be no longer be considered natural habitats for natural plant species due to shifting cultivation and agroforestry. Recommendations for management practices for different levels of disturbance are given in order to maintain ecosystem stability and biological diversity.

Keywords: Disturbance index, human intervention, regeneration, species richness, structure

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INTRODUCTION

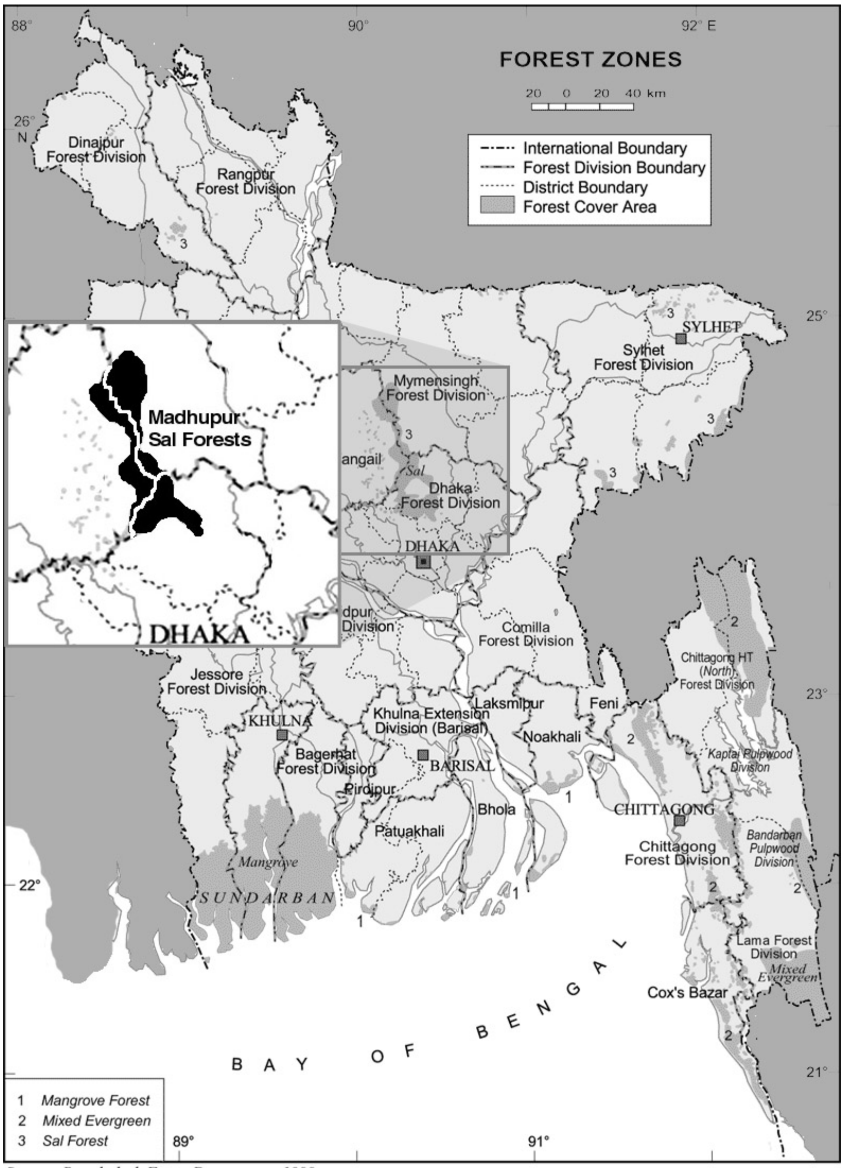
Forest ecosystems are characterized by a complex of various elementary factors: plant, animal, and micro-organism communities, abiotic factors (climate, abiotic soil substance), and humanity. Natural disturbances (fire, floods) are inherent key processes of forest ecosystems and major drivers of forest development in various forest biomes (Lorimer and White 2003; Peltzer *et al.* 2000). Besides evolutionary processes, human use and management have influenced landscapes and (forest) ecosystems in an intensive and sustainable way (Kumar and Ram 2005). Due to increasing human use there is an ongoing trend to shift from natural landscapes to ones developed and cultivated by man. The combination of direct and indirect uses of forest ecosystems by man, disturbance agents, and the impacts of climate change all contribute to changes in intra-specific variability, species diversity, and ecosystem variety (Mc Kinney 2002).

Studies on the biological diversity in Bangladesh, one of the world's most densely populated countries, are incomplete, incomprehensive, and ignore the role of human impacts. The forests are subject to heavy pressures in terms of wood production and competing land-uses. Due to high population density and an uneven distribution of lands (60% of the people are landless) the natural resources are overexploited (World Bank 2004). The forest coverage is 10% of the total area (FAO 2005) with a deforestation rate of 3.3% per year (BBS 2004). The Sal (*Shorea robusta* C.F. Gaertn) forests of Bangladesh have always been severely impacted by forms of human interference, such as: over-exploitation, deforestation, excessive litter collection, encroachment, and indiscriminate collection of economically important plant species (i.e. medicinal, fodder) (Salam *et al.*1999). More than 66% of these forests are under possession of encroachers today, who rely heavily on the provision of wood and non-wood products (Hasan 2004). Although the Madhupur Sal forests are protected, logging is a very common practice there (Alam *et al.* 2008). As a reaction to the conflicting land use interests, agroforestry programmes and the introduction of exotic species were initiated by the government in 1989 (Alam *et al.* 2008). Natural Sal forests became endangered due to the practices of shifting cultivation and the introduction of exotic species (Gain 1998). Based on the intensity of anthropogenic disturbances the forests can be classified as (i) low disturbed (highly protected core area, very small fragments of natural patches), (ii) medium disturbed (core area, but not too much protected and forest regenerated naturally after clear cutting), (iii) highly disturbed (agro-forestry, woodlot plantation, rubber plantation, eucalyptus garden), and (iv) very highly disturbed (change of forest coverage in bare unproductive land, rice field, fellow land, mustard garden, banana garden, pineapple garden).

The massive destruction of Sal forests of Bangladesh coincides with our limited knowledge of the composition, species richness, structure, regeneration pattern compared to India and Nepal. Sal occurs in various forest ecosystems on the southern slopes of the Himalayas in Nepal, India, and Bangladesh, extending from a few metres to 1500 m above sea level (Gautam and Devoe 2006). In India, Sal occupies the northern and central regions separated by the Gangetic Plain (Pandey and Shukla 2003). Terai (low land) is considered the main Sal growing region in Nepal (Timilsina *et al.* 2007; Webb and Sah 2003). The major portion of Sal forests in Bangladesh is located in the central part, which is described as a tropical moist deciduous forest (Alam 1995). There are many studies on vegetation of the Sal forests of Nepal and India (Pandey and Shukla 2003; Shankar 2001 Timilsina *et al.* 2007) which compare plantation forests with natural Sal forest vegetation (Shankar *et al.* 1998; Webb and Sah 2003). There are also studies on the role of human impacts (Murali *et al.* 1996; Shankar 2001). A large-scale inventory covering the plant diversity of plain-land Sal forest in Bangladesh is currently lacking, even though the ongoing human impacts are threatening these ecosystems. Some research activities focus on listing the available plant species in the Sal forests of Bangladesh (Alam 1995; Choudhury 2004; Rashid and Mia 2001) and on the horizontal structure of Sal forests in tropical forests (Pandey and Shukla 2003; Timilsina *et al.* 2007; Webb and Sah 2003). However, the creation of a comprehensive picture of the biological diversity of the Sal forests in continental Asia is essential since most of the studies of Nepal and India have been conducted on gentle to steep slopes at higher elevations. At present, a comprehensive study is missing on the plain-land Sal forest that focuses on the diameter and height distributions and on compiling a complete list of available plants. Coarse woody debris plays a vital role in the biological diversity and structure of forest ecosystems (Harmon *et al.*1986; Rahman *et al.* 2008). For a better understanding of the diversity in Sal forests it is important to analyse coarse woody debris as well. However, findings on the levels of coarse woody debris in tropical forests are limited (Chandrashekara and Sibichan 2006; Grove 2001). Thus, the present study describes plant diversity, the anthropogenic disturbances, as well as their impacts on the ecosystems of the Sal forests of Bangladesh. The objectives of the present study were: (i) to examine the species richness of these ecosystems (ii) to identify the impacts of different anthropogenic disturbances on the biological diversity (iii) to observe variations in different ecosystems characteristics (e.g. regeneration status, coarse woody debris level) along disturbance gradients.

STUDY AREA

The study was conducted in the Madhupur Sal (*S. robusta*) forests (locally known as Madhupur Garh), the largest belt of Sal forests in Bangladesh. These forests form a slightly elevated tract never exceeding 15 m in height above the surrounding floodplains. Sal is the dominant species and usually forms 25% to 75% of the upper canopy (Alam 1995). The Sal forests also contain many other natural valuable tree species, which are known as Sal associates (Hasan 2004). The area is located between $23^{0}50^{/}$-$24^{0}50^{/}$ N latitude and $89^{0}54^{/}$-$90^{0}50^{/}$ E longitude (Figure 1).



Source: *Bangladesh Forest Department, 1999*

Figure 1: Map of the study area (black shaded areas showing forest land)

The soil belongs to the bio-ecological zone of Madhupur Sal Tract (Nishat *et al.* 2002). This tract represents highly oxidized reddish brown clay containing ferruginous nodules and manganese spots. According to Richards and Hassan (1988), the soils have a moderate to strong acidic reaction. The soils are also characterised by low organic matter and low fertility (Alam 1995). Following Thornthwaite's principles, the Madhupur Sal growing region is included in the humid region (Ismail and Mia 1973). According to Bangladesh Meteorological Department (BMD 2008), over the past 30 years this region has exhibited the following attributes: annual rainfall from 2030-2290 mm, annual temperature from 10-34°C, humidity between 60 and 86%, duration of sunshine from 5-9 hours, and average maximum wind speed at 16 KM/hour. The forests are fragmented by an intricate network of depressions in a honeycomb pattern layout (Farooque 1997). The depressions are generally cultivated with paddy. Homesteads, cultivable land, and forests are mixed, which makes forest boundary demarcation and maintenance extremely difficult. Garo, an ethnic community (also called Mandis), have been living in these forests for centuries and are considered a forest people (Gain 1998). More than 66% of the Sal forests are cleared or under the possession of 88000 encroachers (Hasan 2004).

METHODOLOGY

The human disturbances in the Madhupur Sal forests are so multidimensional that a single parameter can not express the disturbance level properly. Pandey and Shukla (2003) developed a disturbance index based on the ratio of the number of trees that have been cut and the total number of individuals within a plot. Kumar and Ram (2005) considered mean canopy cover to estimate the human disturbance level. In this study the forests were classified as low, medium, and highly disturbed on the basis of historical and present human impacts. Only harvest activities (tree felling) were considered when assessing past disturbances. This was done by observing the density and basal area of the remaining mature trees. Other disturbance elements like grazing, litter sweeping or regeneration cutting, soil disturbances, shifting cultivation, along with logging have been identified as present disturbances. A disturbance index was determined by the qualitative assessment of the intensity of different disturbance elements found in the field (Table 1). All elements of the present disturbances were weighed equally important due to the fact that no study on the comparative impacts of those elements exists. Very highly disturbed plots - which had no tree coverage or no natural species at all - were not considered for data investigation. The study was carried out from 2006 to 2007. A total of 180 plots were selected on transects with a minimum distance of 100m from plot to plot, in most cases. The starting point of a transect walk was fixed on the road at 200m distance from the last intersection of two roads.

Table 1: Disturbance level and disturbance index for low, medium and highly disturbed forest sites of the Madhupur Sal forests (Shorea robusta C.F. Gaertn) of Bangladesh

Current disturbance				***Past disturbance***				***Disturbance Index(DI)***	
Elements	QC	W_c	CDI	Elements	QC	W_p	PDI	Equation	Range
L	Absent	0		Felling	No	0			0-140
SC	Very low	20	$CDI = \frac{1}{6}\sum_{i=1}^{6} W_i$		Partly	10	$PDI = W_p$	$DI = CDI + PDI$	
LS	Low	40			Medium	20	where, W_p is the		
AG	Medium	60	where, W_i is the		Heavily	30	weight of past		
SD	High	80	weight of *i*th		Clear	40	disturbance		
SF	Very high	100	(*i=1,2..6*) element				element		

L: Logging of mature tree and saplings, SC: Cutting of saplings and shrubs for fuelwood, LS: Litter sweeping, AG: Animal grazing, SD: Soil disturbances, SF: Shifting cultivation, QC: Qualitative classes of elements, Wc: Weighing of current elements, Wp: Weighing of past elements, CDI: Current Disturbance Index, PDI: Past Disturbance Index

Due to the presence of depressions in the landscape, forest gaps, or bare land, it was not always possible to establish the plots in a regular distance. The plots on the transect were examined continuously at 100 m distance in areas with a more or less closed forest cover, but in cases of fragmentations the next plot was taken at 100m -200m distance. At least 60 plots from each disturbance category (low – medium – high) were purposefully selected. The area of each circular plot was 300 m^2 (radius = 9.77 m) and was used for the data investigation of the mature trees (> 10 cm dbh), coarse woody debris (> 5 cm dbh and > 1.37 m height), saplings (5 – 10 cm dbh), climbers, and herbs. Within the 300 m^2, a subplot of 100 m^2 area (r = 5.64 m) was used for the inventory of large seedlings (> 30 cm height and < 5 cm dbh), and another subplot of 12.6 m^2 area (r = 2 m) for small seedlings (< 30 cm height). Coarse woody debris (CWD) were categorized as snags (standing CWD) and logs (lying CWD). The coverage of different herb species on the forest floor (minimum coverage ≥ 1% of the forest floor) was qualitatively assessed in categories. Mature trees were classified as dominant (> 20 individuals), common (10 - 20 individuals), rare (2 - 10 individuals), and very rare (1 individual) on the basis of abundance in each site. The natural regeneration was categorized as good (small seedlings >> large seedlings >> saplings), fair (small seedling > large seedlings > saplings), poor (small seedling < large seedling < saplings), very poor (absence of one or two stages), or nil (absence of all stages of regeneration i.e. presence of mature trees only having no regeneration) based on the presence of the different stages of natural regeneration (small and large seedlings, saplings) and the number of species within a class.

The diversity indices calculated here include: Species Richness, Important Value Index (Curtis 1959), Shannon-Wiener Diversity Index (Shannon and Wiener 1963), Concentration of Dominance or Simpson's Index (Simpson 1949), Evenness (Magurran 1988), and Similarity Index (Jaccard 1912).

Species area curves were produced from the total number of plant species found in different sample sizes.

RESULTS

Species richness, composition, and rarity

Species-area curves indicated that the data investigations in the three forest types with varying human impact (low disturbed – medium disturbed – highly disturbed) captured the full range of plant species within a different number of sample plots. In the low disturbed forest type the number of plant species continued to increase in up to 40 plots, in the medium disturbed forest type only a small number of additional plant species were identified after 30 plots, and in the highly disturbed forest type nearly no additional species were identified after a total of 20 plots (Figure 2).

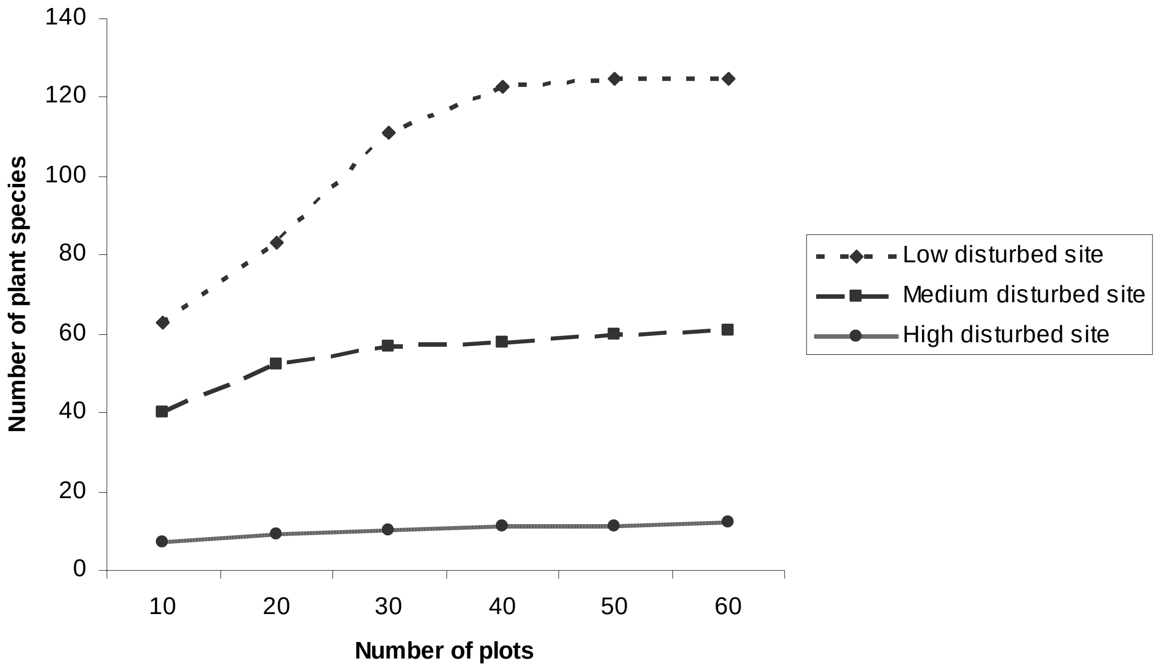


Figure 2: Species-area curve in three forest types

A total number of 134 species were recorded in the study, from which 70 were represented by tree species, 15 by shrub species, 26 by climbers, and 23 by herbs (Table 2). From the 57 mature tree species, only 2 species were common to all three categories.

Table 2: Similarity index and overlapping of plant species among three forest types (low-medium-highly)

Plants	***Species richness***				***Species overlapping***			***Similarity Index***		
	L	M	H	All	L-M	L-H	M-H	L-M	L-H	M-H
Mature tree	52	5	7*	57	5	2	2	0.10	0.04	0.20
Sapling	29	9	-	29	9	0	0	0.31	-	-
Large seedling	41	18	-	45	14	0	0	0.31	-	-
Small seedling	54	30	1	57	27	1	1	0.47	0.02	0.03
Tree	65	31	7	70	31	2	2	0.48	0.03	0.06
Shrub	15	6	1	15	6	1	1	0.40	0.07	0.17
Climber	26	10	1	26	10	1	1	0.38	0.04	0.10
Herb	19	14	3	23	10	1	1	0.43	0.16	0.13
All Plants	125	61	19	134	57	7	6	0.44	0.05	0.09

The number of mature natural tree species was greatest in the low disturbed forest type (52), followed by the medium disturbed (5), and then the highly disturbed forest type (2) (Table 3).

Table 3: Density (N/ha), basal area (m2/ha) and Important Value Index (IVI) of the enlisted mature tree species in three forest types (* indicates introduced species)

Botanical Name	***Local Name***	***Density(Mean±SD)***			***Basal area(Mean±SD)***			***IVI***		
		L	M	H	L	M	H	L	M	H
Abroma augusta (L.) L.f.	Olotkombol	1.7±7.3	0.6±4.3	-	0.48±2.19	0.13±1.05	-	2.34	9.68	-
Acacia mangium Willd.*	Mangium	-	-	0.6±4.3	-	-	0.01±0.10	-	-	5.00
Acacia moniliformis Griseb.*	Akashmoni	-	-	37.2±93.3	-	-	0.49±1.26	-	-	49.55
Adina cordifolia(Roxb.) Hook. f. ex Brandis	Haldu	4.4±15.6	-	-	0.19±0.88	-	-	2.77	-	-
Albizia chinensis(Osbeck) Merr.	Cheshara	1.1±8.4	-	-	0.03±0.27	-	-	0.54	-	-
Albizia marginata (Lam.) Merr.	Shirish	2.2±10.4	-	-	0.39±2.24	-	-	2.20	-	-
Alstonia scholaris(L.) R.Br.	Chatim	2.8±9.3	-	-	0.04±0.15	-	-	1.83	-	-
Amoora rohituka (Roxb.) Wight&Arn.	Roina	5.0±13.5	-	-	0.14±0.39	-	-	3.45	-	-
Artocarpus chapalasha Roxb.	Chapalish	3.9±10.8	-	-	5.36±16.39	-	-	17.05	-	-
Artocarpus lakoocha Roxb.	Dewa	1.7±7.3	-	-	0.03±0.12	-	-	1.10	-	-
Bauhinia variegata L.	Kanchon	11.1±19.1	-	-	0.57±1.34	-	-	7.91	-	-
Bridelia retusa (L.) A. Juss.	Katakhai	1.7±7.3	-	-	0.03±0.12	-	-	1.10	-	-
Bursera serrata Wall.ex Colebr.	Neor	11.7±19.2	-	-	1.39±4.23	-	-	10.26	-	-
Careya arborea Roxb.	Gadhila	2.2±10.4	-	-	0.05±0.25	-	-	1.27	-	-
Cassia fistula L.	Sonalu	1.7±7.3	-	-	0.03±0.12	-	-	1.11	-	-
Cassia siamea Lamk.*	Minjiri	1.1±6.0	-	-	0.02±0.11	-	-	0.74	-	-
Callicarpa arborea Roxb.	Bod	1.1±6.0	-	-	0.04±0.21	-	-	0.79	-	-
Dillenia pentagyna Roxb.	Ajuli	17.8±24.9	-	-	1.12±2.86	-	-	12.10	-	-
Diospyros cordifolia Roxb.	Tamal	0.6±4.3	-	-	0.04±0.29	-	-	0.44	-	-
Dipterocarpus indicus Bedd.	Garjan	5.0±19.2	-	-	0.32±1.63	-	-	3.24	-	-
Eugenia jambolana Lam.	Jam	1.7±7.3	-	-	0.06±0.27	-	-	1.19	-	-
Ficus benghalensis L.	Bot	1.1±6.0	-	-	3.92±21.37	-	-	11.41	-	-
Ficus benjamina L.	Pakor	2.2±8.4	-	-	1.50±6.75	-	-	5.48	-	-
Ficus carica L.	Dumur	2.8±9.3	-	-	0.04±0.14	-	-	1.82	-	-
Ficus glomerata Roxb.	Jagdumur	1.1±6.0	-	-	0.55±3.12	-	-	2.18	-	-
Ficus hispida L.f.	Kakdumur	0.6±4.3	-	-	0.005±0.04	-	-	0.35	-	-
Garuga pinnata Roxb.	Lalmoina	1.1±6.0	-	-	0.09±0.5	-	-	0.93	-	-
Gmelina arborea (L.) Roxb.*	Gamari		-	62.2±149.4	-	-	0.71±0.5	-	-	69.12
Grewia asiatica L.	Kapaija	0.6±4.3	-	-	0.004±0.04	-	-	0.35	-	-
Grewia laevigata Vahl.	Khailadamor	2.2±8.4	-	-	0.04±0.17	-	-	1.49	-	-

Grewia microcos L.	Datoi	11.1±29.2	-	-	0.21±0.71	-	-	5.29	-	-
Holarrhena pubescens (Buch.-Ham.) Wall. Ex G. Don	Kurchi	1.1±6.0	-	-	0.02±0.13	-	-	0.75	-	-
Hymenodictyon excelsum (Roxb.) Wall.	Bhutum	6.1±14.4	-	-	0.32±0.85	-	-	4.16	-	-
Lagerstroemia parviflora (L.) Roxb.	Shida	3.3±10.1	-	-	0.29±1.06	-	-	2.84	-	-
Lannea coromandelica (Houtt.) Merr.	Jiga	15.6±20.8	-	-	1.09±2.40	-	-	11.59	-	-
Litsea glutinosa (Lour.) C.B. Rob.	Kukurchita	0.6±4.3	-	-	0.01±0.05	-	-	0.36	-	-
Litsea monopetala (Roxb.) Pers.	Kharajora	2.2±8.4	-	-	0.12±0.63	-	-	1.70	-	-
Madhuca longifolia (L.) Macb.	Mohuya	1.7±7.3	-	-	0.04±0.18	-	-	1.13	-	-
Mallotus philippensis (Lamk.) Muell.-Arg.	Shindhuri	35.6±42.5	2.8±12.7	-	0.71±1.07	0.03±0.14	-	16.26	9.08	-
Melia azedarach L.*	Bokain	-	-	37.8±99.4	-	-	0.47±1.27	-	-	47.81
Miliusa roxburghiana (Wall. Ex Griff.) Hk.f.&Th	Bongajari	27.2±40.5	0.6±4.3	-	0.91±2.0	0.01±0.07	-	13.58	2.68	-
Miliusa velutina (Dunal) Hk.f.&Thoms.	Gandhigajari	7.8±14.2	-	-	0.45±1.07	-	-	6.01	-	-
Oroxylum indicum (L.) Vent.	Kanaidinga	2.2±8.4	-	-	0.03±0.13	-	-	1.46	-	-
Polyalthia longifolia (Sonn.) Thwaites	Debdaru	0.6±4.3	-	-	0.07±0.57	-	-	0.54	-	-
Schleichera oleosa (Lour.)Oken	Joina	7.2±13.8	-	-	0.32±0.79	-	-	5.54	-	-
Semecarpus anacardium L.f.	Behula	13.9±21.5	-	-	0.53±1.14	-	-	8.82	-	-
Shorea robusta Gaertn. f.	Sal	262.8±144.7	130.5±194.4	48.9±60.0	13.29±9.09	1.59±2.43	1.29±1.65	100.49	272.13	105.05
Spondias pinnata (L.f.) Kurz	Pahariamra	1.7±7.3	-	-	0.08±0.49	-	-	1.23	-	-
Sterculia villosa Roxb.	Udhal	1.7±9.6	-	-	0.02±0.14	-	-	0.86	-	-
Stereospermum suaveolens (Roxb.) DC.	Bonsonalu	1.1±6.0	-	-	0.02±0.12	-	-	0.74	-	-
Streblus asper Lour.	Sheora	2.8±9.3	-	-	0.06±0.26	-	-	1.88	-	-
Terminalia arjuna (Roxb. ex DC) Wight & Arn.*	Arjun	-	-	5.0±20.2	-	-	0.05±0.23	-	-	9.99
Terminalia bellirica (Gaertn.) Roxb.	Bohera	23.9±26.8	1.1±6.0	0.6±4.3	1.35±2.49	0.04±0.25	0.40±3.12	15.79	6.43	13.48
Toona ciliata M.J. Roem.	Rongi	0.6±4.3	-	-	0.05±0.35	-	-	0.47	-	-
Vitex glabrata R. Br.	Awal	1.7±7.3	-	-	0.03±0.14	-	-	1.10	-	-
Wrightia arborea (Dennst.) Mabb.	Koroch	2.2±10.4	-	-	0.04±0.24	-	-	1.25	-	-
Zanthoxylum rhetsa (Roxb.) DC.	Bajna	1.1±6.0	-	-	0.02±0.09	-	-	0.72	-	-

It was discovered that 59 of the 65 tree species in the low disturbed forest type (including the tree species currently being regenerated) undergo natural regeneration (93% of the total number of natural species). All tree species from the 31 tree species in the medium disturbed forest type were also regenerating (100% of the total number of natural species). In the low disturbed forest type fourteen species (24% of the total number of tree species) showed good regeneration, while only 2 species (6%) in the medium disturbed forest type showed such results. Only one tree species of the 2 natural tree species in the highly disturbed forest type showed very poor regeneration (50%). No saplings or large seedlings were found in the highly disturbed forest type. The percentage of rare and very rare species was higher in the medium (80%) than in the low disturbed forest type (75%). Out of two natural species, only one was labelled as very rare in the highly disturbed forest type. The linear regression showed that with an increase of the disturbance index the species richness decreased significantly (Table 4).

Table 4: Linear relationship between disturbance index and diversity indices

Relationship between	***R value for***						
	MT	Sapling	LS	SS	shrub	Climber	Herb
Disturbance Index(Y) Species richness(X)	-0.86^{***}	-0.55^{***}	-0.81^{***}	-0.67^{***}	-0.90^{***}	-0.87^{***}	-0.80^{***}
Disturbance Index(Y) Diversity index(X)	-0.87^{***}	-0.74^{***}	-0.78^{***}	-0.68^{***}	-0.85^{***}	-0.87^{***}	-0.73^{***}
Disturbance Index(Y) Dominance index(X)	0.86^{***}	0.79^{***}	0.78^{***}	0.68^{***}	0.83^{***}	0.85^{***}	0.65^{***}
Disturbance Index(Y) Evenness(X)	-0.12^{ns}	-0.89^{***}	-0.33^{**}	-0.14^{ns}	-0.03^{ns}	-0.16^{ns}	0.16^{ns}

*** (p=0.000), ** (p<0.01), ns (non significant)

Diversity

There was a highly significant negative correlation between the disturbance index and the Diversity Index for all plant groups. On the contrary, the disturbance index had a significant positive correlation with the dominance index. The linear regression indicated that with an increase of disturbances the evenness decreased significantly for saplings and large seedlings (Table 4).

The Least Significant Difference (LSD) indicated no significant difference for the diversity index of the mature trees between the medium and highly disturbed forest type. ANOVA and LSD showed that the dominance index varied significantly among all forest sites and for all plants except mature trees and herbs. The maximum evenness for all plant groups, except herbs, was found in the low disturbed forest type. The evenness of mature trees, saplings, large seedlings and herbs exhibited significant differences between the different forest types (Table 5).

Table 5: Average (arithmetic mean ± S.E) values of diversity indices and parameters of stand characteristics of three forest types (low-medium-high)

Parameters	***Plant group***	***Low***	***Medium***	***High***	***ANOVA***	
					F	p
Density(N/ha)	Mature tree	[a] 526±19	[b] 136±26	[b] 192±17	98.6	0.000
	Sapling	177±17	1359±51	0	596.4	0.000
	Large seedling	1908±114	337±35	0	219.4	0.000
	Small seedling	3197±225	2029±194	73±14	84.4	0.000
	Shrub	4481±269	2571±117	12±6	175.0	0.000
	Climber	247±14	78±5	4±2	208.6	0.000
BA (m^2/ha)	Mature tree	[a] 36.6±3.40	[b] 1.8±0.40	[b] 3.4±0.40	96.9	0.000
Diversity Index	Mature tree	[a] 1.52±0.06	[b] 0.05±0.03	[b] 0.06±0.02	450.6	0.000
	Sapling	0.89±0.07	0.38±0.03	-	26.5	0.000
	Large seedling	1.10±0.04	0.48±0.06	-	26.20	0.000
	Small seedling	1.16±0.08	0.78±0.08	0.00±0.00	38.16	0.000
	Shrub	1.35±0.04	0.55±0.07	0.00±0.00	57.43	0.000
	Climber	1.43±0.04	0.58±0.06	0.00±0.00	81.9	0.000
	Herb	1.10±0.04	0.87±0.03	0.17±0.00	57.6	0.000
Dominance Index	Mature tree	[a] 0.33±0.02	[b] 0.97±0.01	[b] 0.96±0.02	454.0	0.000
	Sapling	0.50±0.03	0.83±0.01	-	162.9	0.000
	Large seedling	0.44±0.02	0.69±0.04	-	20.2	0.000
	Small seedling	0.39±0.03	0.54±0.04	1.00±0.00	45.7	0.000
	Shrub	0.33±0.02	0.70±0.04	1.00±0.00	46.5	0.000
	Climber	0.28±0.01	0.62±0.04	1.00±0.00	58.9	0.000
	Herb	[a] 0.50±0.02	[a] 0.52±0.02	[b] 0.89±0.60	42.8	0.000
Evenness	Mature tree	[a] 0.79±0.02	[b] 0.57±0.01	[ab] 0.76±0.10	3.6	0.033
	Sapling	0.89±0.02	0.32±0.02	-	301.5	0.000
	Large seedling	0.82±0.02	0.92±0.02	-	6.7	0.002
	Small seedling	0.99±0.02	0.98±0.01	-	0.9	0.424
	Shrub	0.83±0.02	0.76±0.05	-	1.5	0.222
	Climber	0.94±0.01	0.96±0.01	-	1.3	0.281
	Herb	[a] 0.65±0.01	[a] 0.65±0.01	[b] 1.00±0.00	20.7	0.000
Disturbance Index		30.3±0.90	80.4±0.40	100.0±0.00	3955.8	0.000

Means within columns followed by the same letter or letters (a-c) are not significantly different (p <0.05), by LSD

Community structure and coarse woody debris level

Shorea robusta (IVI=100.49) was the dominant species in the low disturbed forest type, followed by *Artocarpus chapalasha, Mallotus philippensis, Terminalia bellirica, Miliusa roxburghiana, Dillenia pentagyna, Lannea coromandelica, Ficus benghalensis, Bursera serrata, Semecarpus anacardium,* and *Bauhinia variegate*. The medium disturbed forest type was almost pure, where *S. robusta* was highly dominant (IVI=272.13) followed by *M. philippensis* and *T. bellirica*. *S. robusta* was also dominant in the highly disturbed forest type, followed by the introduced species *Gmelina arborea, Acacia moniliformis,* and *Melia azedarach* (Table 3). The degree of disturbances caused significant differences in the density and basal area of the mature trees. The density (N/ha) and basal area (m^2/ha) of the mature trees was significantly higher in the low disturbed forest type than in the medium and highly disturbed forest types. The medium and highly disturbed forest types showed no significant differences (Table 5). The mean density (N/ha) of saplings was significantly higher in the medium disturbed forest type than in the low disturbed forest type. The ratio of the mean number of small seedlings, large seedlings, and the saplings revealed a good regeneration status in the low disturbed forest type. The ratio of large seedlings to saplings decreased in the medium disturbed forest type as compared to the low disturbed forest type.

Clerodendrum serratum was the dominant shrub species in all forest types. It was followed by *Glycosmis pentaphylla*, *Randia uliginosa*, *Barleria lupulina*, *Tabernaemontana divaricata, Ziziphus rugosa,* and *Mimosa rubricaulis* in the low disturbed forest type, and followed by *G. pentaphylla, Z. rugosa* and *Randia dumetorum* in the medium disturbed forest type (Table 6). *Smilax macrophylla* and *Calamus tenuis* were the dominant species of climbers in the low disturbed forest type, followed by *Scindapsus officinalis, Mikania micrantha*, and *Ficus scandens*. In the medium disturbed forest type, *M. micrantha* was the dominant climber species, followed by *Dioscorea bulbifera. M. micrantha* was the only climber species found in the highly disturbed forest type (Table 6). The species richness of herbs was highest in the low disturbed forest type, but the coverage (abundance) was low compared to the medium disturbed forest type. *Ageratum conyzoides, Imperata cylindrica,l* and *Oplismenus aemulus* were abundant in the medium disturbed forest type, while only *O. aemulus* was abundant in the low disturbed forest type. No species were abundant in the highly disturbed site.

Table 6: List of all shrub and climber species encountered and density (Mean±SD) in low, medium and high disturbed forest type

Botanical name	***Local name***	***Low***	***Medium***	***High***
Shrub				
Ageratum sp.	Fulkhari	31.7 ±132.1	-	-
Antidesma acidum Retz.	Chutkigota	15.0 ±86.0	-	-
Barleria lupulina Lindl.	Bishkathali	498.3 ±624.7	20.0 ±89.8	
Bauhinia malabarica Roxb.	Chokoi	100.0 ±177.5	-	-
Cassia sophera L.	Kalkeshundu	43.3 ±177.5	-	-
Clerodendrum serratum (L.) Moon	Bhite	1918.1±1213.7	1919.8±834.3	-
Glycosmis pentaphylla (Retz.) DC.	Mouhati	566.6 ±473.2	268.3 ±335.7	11.7 ±45.4
Jatropha curcas L.	Bonverenda	55.0 ±181.7	-	-
Mimosa rubricaulis Lam.	Teora	155.0 ±271.5	-	-
Phyllanthus reticulatus Poir.	Chitki	55.0 ±272.7	71.7 ±155.2	-
Randia dumetorum Lamk.	Monkata	500.0 ±413.7	128.3 ±234.4	-
Randia uliginosa DC.	Piralo	95.0 ±204.5	-	-
Tabernaemontana divaricata (L.) R. Br. Ex Roem. & Schult.	Tagor	233.3 ±424.1	-	-
Vitis negundo L.	Nishinda	15.0 ±68.5	-	-
Ziziphus rugosa Lamk.	Anaigota	200.0 ±234.3	163.3 ±214.7	-
Climber				
Asparagus racemosus Willd.	Shotomuli	6.1±20.8	-	-
Bauhinia vahlii Wight et Arn.	Bidipata	6.1±20.8	-	-
Caesalpinia bonducella F.	Nata karanj	2.8±9.3	-	-
Calamus tenuis Roxb.	Bet	31.1±50.9	-	-
Cissus adnata Roxb.	Paniyalata	5.0±12.0	1.1±6.0	-
Coccinia cordifolia (L.) Cogn.	Keoyakanthal	4.4±15.6	-	-
Coccinia grandis (L.) Voigt.	Telakucha	3.3±11.8	0.6±4.3	-
Dioscorea alata L.	Chuprialu	8.3±18.0	-	-
Dioscorea bulbifera L.	Metaalu	11.7±20.2	14.4±25.6	-
Dioscorea hispida Dennst.	Bishalu	3.3±10.1	-	-
Dioscorea pentaphylla L.	Jhumalu	5.6±13.9	-	-
Dioscorea tomentosa Koen. Ex Spreng.	Shuorialu	4.4±13.0	-	-
Ficus scandens Roxb.	Dumurlata	23.3±38.5	-	-
Ichnocarpus frutescens (L.) R. Br.	Kalidudhi	2.2±12.1	-	-
Melothria maderaspatana (L.) Cogn.	Patilalau	7.2±15.1	1.1±6.0	-
Mikania cordata (Burm. f.) B.L. Rob.	Germanlata	3.3±14.7	5.6±13.9	-
Mikania micrantha (L.) Kunth.	Assamlata	23.3±26.3	36.7±31.7	3.9±17.5
Piper chaba W. Hunter	Chai	7.8±18.8	-	-
Pothos scandens L.	Kalalata	1.7±7.3	-	-
Scindapsus officinalis (Roxb.) Schott	Pipul	28.3±35.3	4.4±11.4	-
Smilax macrophylla Roxb.	Kumarilata	31.1±44.2	6.7±13.4	-
Spatholobus parviflorus (Roxb. ex DC.) Kuntze	Goalialata	6.1±14.4	-	-
Thunbergia grandiflora Roxb.	Nillata	1.7±7.3	-	-
Tragia involucrata L.	Bishuti	0.6±4.3	-	-
Trichosanthes bracteata (Lam.) Voigt	Makal	12.2±20.3	6.7±13.4	-
Vitis quadrangularis (L.) Wall. ex Wight	Harjora	6.1±14.4	1.1±6.0	-

The diameter distributions of the sampled trees in all individual plots in all forest types followed a reverse J-shaped distribution. With an increase of the diameters at breast height (DBH) the tree density decreased. With few exceptions, the DBH of the medium and highly disturbed forest types ranged from 10 - 30 cm. Giant trees (DBH > 100cm) were found (5 trees/ha) only in the low disturbed forest type (Figure 3).

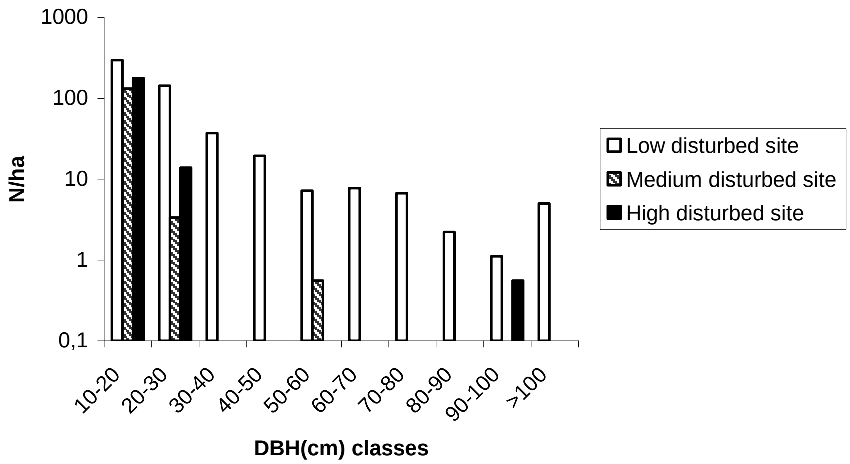


Figure 3: Diameter distribution of mature trees in three forest types

The tree height distributions showed a tendency towards a normal distribution. The height of mature trees in both the medium and highly disturbed forest types did not exceed 25 m, whereas the tree height in the low disturbed forest type exceeded 35 m (Figure 4).

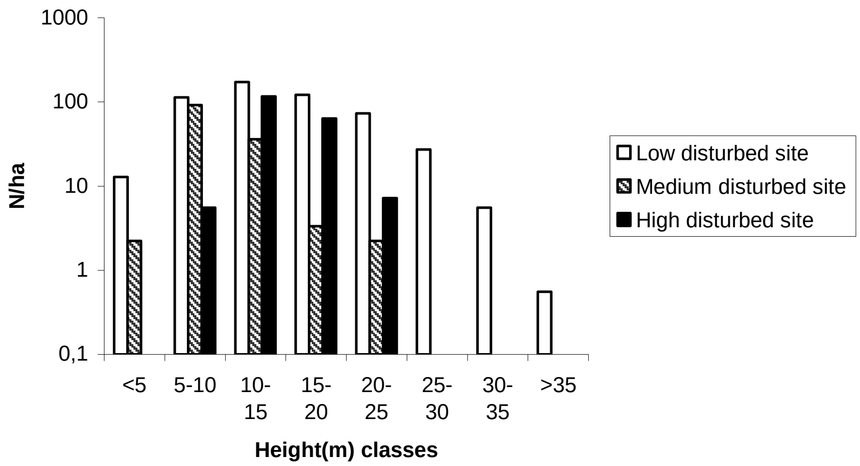


Figure 4: Height distribution of mature trees in three forest types

The density and basal area of the standing coarse woody debris in the low disturbed forest type was 4.4 N/ha and 0.14 m^2/ha, respectively. This was equal to 0.76 % of the density of the living trees and 0.004 % of the basal area. No lying coarse woody debris was found in the low disturbed forest type. The medium and the highly disturbed forest type had no coarse woody debris.

DISCUSSION

It is often observed that the increasing fragmentation of natural habitats by human disturbances leads to reduced species richness, and that many variables cause species loss along that gradient (Mc Kinney 2002). The species richness on the investigated study area of 5.4 ha (134 plant species: 70 tree, 15 shrub, 26 climber and 23 herb) was comparable to other studies on Sal forests of India and Nepal. Webb and Sah (2003) listed 159 species (49 trees, 45 shrubs, 16 climbers and 42 herbs) on 3.6 ha area in the Central Terai and Timilsina *et al.* (2007) counted 131 species (28 trees, 10 shrubs, 6 climbers and 87 herbs) in the Western Terai, Nepal. Pandey and Shukla (2003) found 208 species (93 trees, 50 shrubs, 34 climbers and 31 herbs) on 24 ha area in the Eastern Terai of India. Shankar (2001) examined 87 species (≥10 cm gbh) on 2 ha area in the Darjiling Terai, India. Swamy *et al.* (2000) listed 82 species (48 trees, 10 shrubs, 8 climbers and 16 herbs) on 0.3 ha of a low elevated (250-400m altitude), moist, deciduous forests in the Western Ghat of India. In this study all herbs having less than 1% forest floor coverage (< $3m^2$ cover of the forest floor) were not considered during data investigation due to the sampling design (to reduce the time of data collection and probability of threats from criminals). Otherwise, this might have increased the total number of herbal species.

The stand density of the low disturbed forest type was comparable with other Sal forests of India and Nepal, as reported by Pandey and Shukla (2003), Shanker (2001), and Webb and Sah (2003). The mean basal area ($36.6m^2$/ha) of the low disturbed forest type obtained in the present study was slightly larger than that of the Sal and moist deciduous forests reported by Pandey and Shukla (2003) and Webb and Sah (2003), and was close to the pan tropical average of $32m^2$/ha (Dawkins 1959). It is important to mention that the stand density and basal area of the low disturbed forest type did not represent the average forest characteristics. Most of the area between the small patches of low disturbed forests was bare land with no forest cover. During data collection only those sample plots having minimum tree coverage were considered for data investigation. Open areas were totally ignored. On the other hand, the presence of a few giant trees from *Ficus benjamina* and *Artocarpus chapalasha* increased the basal area of the low disturbed forest type substantially (Table 5). However, the basal area of *S. robusta*, the dominant species of the low disturbed forest type (13.3 m^2/ha), was almost similar to the results of the studies in the low disturbed and natural Sal forests ($11.8m^2$/ha) of the central Terai of Nepal (Webb and Sah 2003).

It was found that all disturbance types in this study were dominated by *S. robusta*. The species richness of Sal associates decreased with human activities, and consequently the forests became pure Sal forest. In the highly disturbed forest type, Sal was dominant over the one singular natural associate without bringing the introduced species into consideration. The medium disturbed forest type was heavily dominated by *S. robusta* and can be considered a pure Sal forest. The low disturbed forest type had a highly heterogeneous distribution of trees and can be considered one of the most highly diverse forests in Bangladesh. This diversity came about due to the restricted access of humans in comparison to the other two forest types (compare Hasan 2004).

The proportion of small seedlings, large seedlings, and saplings in the low disturbed forest type indicated that natural regeneration took place adequately despite the existing competition with shrubs, climbers, herbs, and the tree canopy closure. Gaps in the canopy created by thinning operations promoted a good regeneration status in the low disturbed forest type. The density of saplings was not satisfactory in the low disturbed forest type due to continuous cutting of Sal seedlings. Species with a nearly equal distribution of mature trees and trees in different stages of regeneration are expected to remain dominant in the near future. An abundance of only mature trees and an absence, or a very low number, of seedlings and saplings may cause local extinction of many species with time (Bhuyan *et al.* 2003). In the medium disturbed forest type, the presence of 30 different tree species in the category of small seedlings compared to 5 mature tree species indicated the high potential for natural regeneration. Although these sites were bare for many years, the seed dispersion from neighbouring mature trees of low or undisturbed forest types was sufficient to allow a highly diverse regeneration. However, the absence of organic matter due to frequent sweeping of forest litter, grazing, and cutting of seedlings might have restricted an adequate density of large seedling there (Troup 1986).

The coverage of herbs in the low disturbed forest type was comparatively lower than medium disturbed sites due to low insolation on the forest floor caused by the closed canopy cover (compare Nath *et al.* 2005). Webb and Sah (2003) reported the abundance of shrubs and climbers increased with the decrease of regeneration density and by creating gaps. But in this study, the density of shrubs and climbers was higher in the low disturbed forest type than the medium disturbed site. It seemed that in the medium disturbed forest type people cut more shrubs for fuelwood production, and collected more climbers to use as vegetables and medicines than in the low disturbed forest type. Tillage operations and other intercultural operations for agricultural crops were not congenial for growing ground flora like herb, shrub, regeneration, and climber in the highly disturbed forest type. Heavy soil disturbances from tillage operations, cultivation of agricultural crops between the forest plantations, and introduction of fast growing tree species degraded the habitat for the natural regeneration in the highly disturbed forest type (compare Rahman *et al.* 2007).

The coarse woody debris (CWD) level of the low disturbed forest type was lower than in other tropical forests of India (Chandrashekara and Sibichan 2006; Nath *et al.*2005). So far there is no reference level of CWD for the sub-continental tropical forests and even its status in tropical forests of the world has gone largely unreported (Grove 2001). Due to scarcity of fuelwood, the surrounding people cut trees immediately after their death. CWD has become an important indicator in determining the degree of naturalness of a forest ecosystems (Grabherr *et al.* 1998; Kowarik 1995). CWD is also an important component of forest ecosystems, reducing erosion and affecting soil development, storing nutrients and water, serving as a seedbed for plants, and is a major habitat for decomposers and heterotrophic organisms (Harmon *et al.*1986; Mccombe and Lindenmayer 1999). CWD provides nesting, roosting, feeding, loafing, and storage sites for birds, small mammals, reptiles, and amphibians (Rabe *et al.* 1998). The amount of dead wood in natural forests can be very extensive – up to 30% of dead stems (Linder *et al.* 1997), 25% of above-ground biomass (Nilsson et al. 2002), or about 40% of the volume of living trees (Rahman *et al.* 2008) in European temperate forests. But at least 5% of the stand basal area (or volume) can be considered relevant for maintaining biological diversity (Bütler *et al.* 2004). Along with the lack of CWD, human disturbances caused the disappearance or red-listing, of most of the birds, mammals, reptiles, and amphibians of this region (Alam *et al.* 2008; Kabir and Ahmed 2005).

In natural ecosystems, biotic succession increases the number of plant and animal species after a disturbance (Gibson *et al.* 2000). This is also true for habitats that remain undisturbed long enough for succession to occur (Mc Kinney 2002). Various studies have documented how succession increases species diversity in ruderal and managed communities (e.g. Crowe 1979). It is said that 30-40 years are required for tropical forests to return to a diversity level before the last clear cut (Webb and Fa'aumu 1999; Webb and Sah 2003). Judging by this information, it can be predicted that the medium disturbed site could return to the diversity level of the low disturbed site within the next 20 years. That is, of course, if the destruction of regeneration and the illegal logging of mature trees and saplings of Sal associates can be stopped. There would then have to be a sufficient number of patches of low or undisturbed forest types to allow a successful seed dispersion. Therefore, there is no realistic chance that the highly disturbed site will reach similar levels of plant diversity since it is a totally degraded habitat for natural regeneration. On the other hand, the variations in the level of disturbances could alter the successional pattern and subsequent composition, diversity, and structure of the forest (Busing 1995). The proportion of early successional species was higher in the medium disturbed forests than in the low disturbed forest sites. In contrast, the proportion of late successional species was higher in the low disturbed forest sites than in the medium disturbed forest sites. In the medium disturbed forest sites the relative abundance of early successional species, like *S. robusta*, was higher due to the regeneration potential created by the mass of seedlings produced and the coppicing from root suckers in complete overhead light conditions (compare Troup 1986). Converting a late successional habitat to an early successional habitat is likely to decrease the biological diversity by increasing the concentration of dominance (i.e. making common species more abundant and uncommon species absent) and possibly reducing richness. In this study, the regeneration potentiality of the early successional species, *S. robusta*, and the destruction of Sal associates caused lower diversity and richness in the medium disturbed site.

CONCLUSIONS

The Sal forests are considered one of the richest ecosystems in regard to forest diversity in Bangladesh. However, the level of diversity is generally unknown to the scientific community, politicans, and local people and is, therefore, not well documented at all. The forests are facing a severe threat by anthropogenic disturbances cause by humans who directly or indirectly depend on forest resources for their social welfare. Since the value of these forests is currently not recognized, the increasing human population around the park is likely to threaten their very existence. Even in the low disturbed site, 75% of the species have become rare or very rare. This indicates that Madhupur Sal forests warrant more attention in order to conserve their species richness. This study can serve as a baseline for the description of plant diversity in Bangladesh, giving an insight to the state of species richness at different disturbance intensities. Moreover, the findings of this study can provide information to managers describing the importance of a well balanced distribution of undisturbed Sal forests in order to formulate biodiversity conservation plans. A deeper understanding of the plant diversity of the Sal forest ecosystems will help the country implement international regulations, like the Convention on the Biological Diversity.

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8.2 Can picnic influence floral diversity and vitality of trees in Bhawal National Park of Bangladesh?

Can picnic influence floral diversity and vitality of trees in Bhawal National Park of Bangladesh?

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Abstract

This study examined the impact of picnic activities on forest diversity, structure, regeneration and vitality of tree species in the Bhawal National Park of Bangladesh. The study area was classified as a non-used, occasionally used and frequently used area on the basis of the intensity of the picnic activities. A total of 43 plant species were enumerated in the whole study area. The highest plant species richness (41 species) was observed in the non-used area whereas, the lowest species richness (11 species) in the frequently used area. The diversity index decreased with the increase of picnic intensity whereas, the concentration of dominance increased. Density of other plant groups except the density and basal area of the mature tree showed a declining trend from the non-used to frequently-used area. The frequently-used area exhibited very poor regeneration. Tree vitality decreased with the increase of picnic intensity. The relevance of this study as a basis for further research to determine the impact of tourism on biodiversity in Bangladesh is discussed.

Key words: Species richness, diversity index, concentration of dominance, regeneration, intensity

Introduction

Nature-based tourism and recreation in protected areas is increasing worldwide (Pickering and Hill, 2007). Tourism has long been considered a “clean industry”, without any negative effects on the environment worthy to be mentioned (Bundesamt für Naturschutz, 1997). However, this image is now outdated and with the rise in tourism numbers there follows an inevitable increase in negative environmental impacts (Whinam and Chilcott, 2003; Leung and Marion, 2000; Newsome et al., 2002a; Buckley, 2004). The impacts from recreation and tourism are influenced by factors such as the type of infrastructure provided, the location, type of activities, the behaviour of tourists and the season of use (Liddle, 1997; Cole, 2004). The use of protected areas is often zoned, with some areas highly developed and extensively modified through provision of infrastructure such as sealed roads, car parks, toilets, visitor centres, picnic areas, camping areas and accommodation. In contrast, other zones within the same protected areas may be classified remote (which can be designated as 'wildernesses) where there is limited access, no or few facilities, and only small numbers of visitors (Worboys et al., 2005). The recreational activities differ from place to place, region to region and country to country (Worboys et al., 2005). Picnic is very much popular in Bangladesh as recreation and tourism activity. Picnic includes many activities like walking, gathering, cooking of fresh foods or warming cooked foods within the park by making holes into the soil with the burning of deadwood and fallen litter and finally eating the cooked foods being seated on the forest floor. Overseas, a range of direct and indirect impacts of recreational activities in protected areas on vegetation have been documented in both observational and experimental studies (Pickering and Hill, 2007; Liddle, 1997; Leung and Marion, 2000; Newsome et al., 2002a; Buckley, 2004; Cole, 2004; Newsome et al., 2004). But such studies in Bangladesh have not been conducted so far. In addition, studies on the impacts of specific picnic activities on the forest diversity have not been done so far in the World as well.

There are eight national parks in Bangladesh, of which Madhupur National Park and Bhawal National Park are considered as Sal (Shorea *robusta* C.F. Gaertn.) dominating parks (Alam, 1995). Sal forests are distributed in Bangladesh, India and Nepal (Gautam and Devoe, 2006). There are many studies on the Sal forests of Nepal and India concerned with vegetation analysis of *Shorea* communities (Timilsina et al., 2007; Pandey and Shukla, 2003; Shankar, 2001; Singh et al., 1995; Pande, 1999; Pandey and Shukla, 1999), comparing plantation forests with natural Sal forest vegetation (Shankar et al., 1998; Webb and Sah, 2003) and impact of human disturbances (Sukumar et al., 1992; Murali et al., 1996; Shankar, 2001). Some studies focusing on the enlisting of available plant species are found in Bangladesh (Rashid and Mia, 2001; Jashimuddin et al., 1999; Rashid et al., 1995; Alam, 1995; Choudhury, 2004).

Bangladesh is one of the world's most densely populated countries and; as a consequence, forests are subject to heavy pressures in terms of both wood production and competing land-uses. Due to the high population density and sharply uneven distribution of lands (60% people are landless) natural resources including the forests are overexploited (World Bank, 2004). The human pressure on Bhawal National Park is the highest in Bangladesh as it is located only 40 Kilometre away from Dhaka, the fastest growing mega-city in the world with 12 million populations (density of 20,000-100,000/Square Kilometre, World Bank, 2008). The surrounding area of this park is also highly populated (density of 2505/sq Km; BBS, 2006). The forest area is reduced day by day for the demands of industrialization and urbanization. Meanwhile, most of the forests have either been clear felled or occupied by encroachers and only the remnants of natural patches exist (Gain, 1998). On an average 1.5 million people visit the Bhawal National Park every year for their picnic activities (official source). Therefore, it is important to know the effects of the different kinds of human impacts on the forest diversity of this park.

Hence this investigation was undertaken, to determine the impacts of picnic activities on the botanical richness, community structure, potentiality of regeneration and vitality of trees. The role of picnic activities on the forest diversity will help to determinate the overall status of the Sal forests in this park and give recommendations for further management.

Materials and methods

Study site

The study was conducted at Bhawal National Park of Bangladesh, which is locally known as Bhawal Sal (*Shorea robusta* C.F. Gaertn.) forest or Rajendrapur Gajari (Sal) forest (Figure 1). The study area is located in 40 km north from the capital city Dhaka (24°01'N, 90°20'E). It has been kept under IUCN management category as a protected landscape. Before this park was officially declared as national park in 1982 under the Bangladesh Wildlife Act, coppicing was introduced to manage these forests in 1925 and ‘taungya’ was initiated to plant other species of tree along with Sal in 1938. During the independence war these forests were hugely destroyed in 1971. Since then no management practices have been implemented except planting of some ornamental plants near forest roads for aesthetic purposes. Though no felling activities have been allowed after the declaration of the national park a number of human activities like illegal logging, cutting of regeneration, fuel wood collection, litter sweeping and soil disturbance are still common. In course of time Sal associates have been almost disappeared. Therefore, the park can be considered as semi-natural forests. The area of this national park is about 5,000 ha according to government master plan. The Dhaka-Mymensingh high way divides the park in two parts: east and west. The adjacent eastern part

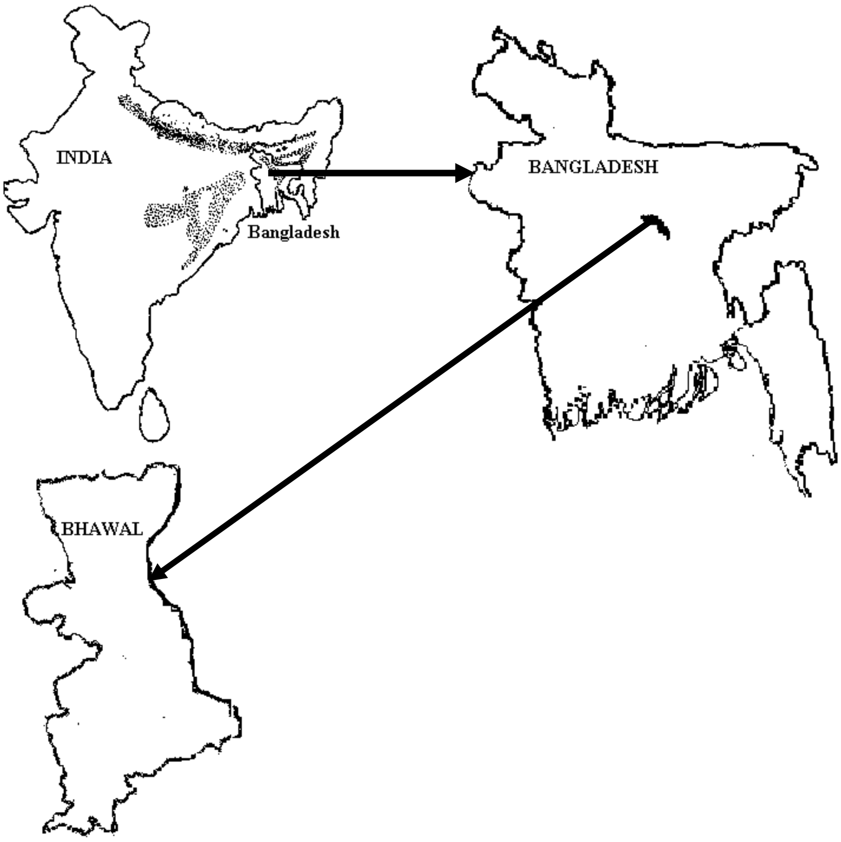

Figure 1: Map of the study area

from the high way is administered by 'Araishoprasad bit' (bit: small administrative unit), which is used as 'picnic spots'; whereas the adjacent west part is administered by the 'Bishoyakuribari bit', which is treated as 'wilderness area' compared to the eastern part. In the eastern side a lot of infrastructures were constructed like rest houses, cottages, parking areas, picnic spots, residential areas for the forest staff, mosque, children parks, lakes, carpeting roads, shops, tea stalls, benches and sun sheds. In total there are 50 'picnic spots' in this park which are used all the year round by the people for cooking, eating, playing and gathering. From October to February these spots remain fully occupied by different picnic parties keeping hugely crowded. Especially in the weekend (Friday and Saturday) these 50 spots are not sufficient at all to accommodate all picnic parties. The adjacent area of each picnic spot is used as picnic spot temporarily as well. From this consideration the study area was classified into three categories on the basis of the frequency of picnic activities taken place. The intensity of picnic activities was estimated qualitatively by observing the area and on the basis of the official map of the park (Table 1). The wilderness area was considered as non-used (N), the adjacent areas of picnic spots as occasionally used (O) and the picnic spots as frequently used (F) areas.

Table 1: Disturbance level in different stands

Stand	*Elements of disturbance*[a]	*Severity*	*Distance from the picnic spot(m)*	*Nature*	*LC*[b]*(%)*	*Other anthropogenic disturbances* [c]
N	H, C, Hm	Very high	0-50	Protected	10-20	L, RD, SD,LS
O	H, C, Hm	Medium-High	100-200	Protected	1-5	L, RD, SD,LS
F	Hm	Medium	200-1000	Protected	0	L, RD, SD,LS

[a]H: Digging holes for cooking, C: Cleaning of forest floor to be seated and to eat, Hm: Human trampling
[b]LC: Litter coverage of forest floor
[c]L: Logging, RD: Regeneration destruction, SD: Soil disturbance, LS: Litter sweeping

The present feature of the forest area is actually honeycombed with habitations and rice fields. The topography is characterized by low hills, which rise 3.0-4.5 m above the surrounding paddy fields locally known as 'chalas' which are intersected by numerous depressions or 'baids'. The dominant tree species is Sal (*Shorea robusta*) in this national park (Sarker and Huq, 1985). The soil belongs to the bio-ecological zone of Madhupur Sal Tract (Nishat et al., 2002) and this tract represents highly oxidized reddish brown clay containing ferruginous nodules and manganese spots. According to Richards and Hassan (1988) the soils are moderately to strongly acidic in reaction. The soils are characterised by a low organic matter and a low fertility (Alam, 1995). Following Thornthwaite's principles this region is included in the humid region (Ismail and Mia, 1973). The annual rainfall ranges from 2030-2290 mm and the annual temperature ranges from 10-34°C. The humidity varies between 60 and 86%, the duration of sunshine ranges from 5-9 hours and average maximum wind speed is 16KM/hour.

Sampling and data analysis

In total 40 plots were selected randomly near 40 picnic spots out of a total of 50, which were considered as frequently used (F) areas. Another 40 plots were selected within a minimum distance of 100 m from each plot of the F-areas, which were classified as occasionally used (O) areas. From the wilderness area 40 plots with a minimum distance of 100m from each other in any directions were selected randomly, which were called non-used (N) areas. However, due to the presence of depressions in the honey comb like huge gaps or bare land without forest cover it was not possible to establish the plots in a regular distance in the N-area. The area of each circular plot was 300 m^2 with 9.77 m radius. Within the 300 m^2 plot a subplot of 100m^2 area (r = 5.64 m) was considered for the inventory of large seedlings (< 5 cm dbh and > 30 cm height) and another subplot of 12.6 m^2 area (r = 2 m) for small seedlings (the seedlings of < 30 cm height according to Sagar and Singh, 2005). The whole area (300 m^2) was considered for measuring the mature trees (> 10 cm dbh), saplings (5 – 10 cm dbh), climbers and herbs. The percentage of forest floor occupied by the different species of herbs (≥ 1 % forest floor) was approximated. With this exception each stem was counted as an individual. Regeneration included small seedlings, large seedlings and saplings. The regeneration was categorized in relation to the occurrence of the seedling categories as good (small seedling >> large seedlings >> saplings), fair (small seedling > large seedlings > saplings), poor (small seedling < large seedling < saplings), very poor (general absence of individuals in one or two stages) and nil (absence of regeneration in all stages). The vitality of each tree was assessed on the basis of the parameters crown percentage of total height, crown development, trunk shape, root damage, bark damage, insect infestation and pathogen infection (Table 10).

Table 10: Classification of tree vitality

Class	**Indication**
VC-1 (very high vitality)	a) vigorous crowns with a length of 55 per cent or more of the total height, well developed, b) trunk straight, insect free, disease free, damage or injury free c) no damage or injury in root system; d) bark intact; e) leaf vigorous, no infestation or infection of pests
VC-2 (high vitality)	a) moderately vigorous crowns with a length from 30 to 55 per cent of total height, medium developed; b) trunk nearly straight; c) few roots were damaged or injured; d) bark almost intact; e) initial infestation or infection caused by insects or disease
VC-3 (low vitality)	a) fair to poor crowns with a length from 10 to 30 per cent of total height, weakly developed; b) trunk little bit wavy shaped c) many roots were damaged or injured; d) some portions of trunk were debarked; e) advanced infestation or infection caused by insects or disease
VC-4 (very low vitality)	a) very short, less than 10 per cent of the total height; sometimes merely a tuft at top of tree or dieback occurred or crownless; b) trunk fully wavy shaped c)root system almost destroyed ; d) most of the portion of the trunk was debarked; e) foliage or trunk was severely infested or infected by insects or disease

The relative values of frequency, density and basal area for each single tree species were used to calculate the Importance Value Index (IVI) plot wise according to (Phillips, 1959; Curtis, 1959):

$$IVI = \text{relative frequency} + \text{relative density} + \text{relative basal area} \quad (1)$$

The similarity index (community coefficient) among different areas was calculated according to Sorenson (1948):

$$SI = 2C/(A+B) \qquad (2)$$

Where, C is the number of species common to both forests, a number of species in forest A and b the number of species in forest B (compare 2).

The Shannon-Wiener diversity index (Shannon and Wiener, 1963) was calculated from the following formula given by Magurran (1988):

$$\bar{H} = -\sum_{i=1}^{s} p_i \ln p_i \qquad (3)$$

Where, p_i is the proportion of the ith species and the number of all individuals of all species (n_i/N) (compare 3).

Evenness was calculated by Pielou's index from the formula given by Magurran (1988):

$$E = \overline{H}/\ln S \qquad (4)$$

Where $\overline{H}$ is the Shannon-Wiener diversity index and S is the number of species

Simpson's index (Simpson 1949) measured the concentration of dominance (CD):

$$CD = -\sum_{i=1}^{s} (p_i)^2 \qquad (5)$$

Where, p_i is the same as for the Shannon-Wiener information function (compare 5).

Species area curves were produced from the total number of floral species found at different sample sizes. Data were analysed by an ANOVA and linear regression analysis to find out the relation between the degree of disturbance and the stem density, basal area, diversity index, concentration of dominance and evenness. All statistical analyses were done using the SPSS package (SPSS, 2006).

Results

Species richness and diversity

The inventory on the 3.6 ha tropical wet deciduous forest yielded a total of 43 plant species. Species richness was biggest (41) in the N-areas followed by O-areas (27) and F-areas (11). Out of 43 species were recorded in the whole area, 22 were represented in the tree group, 10 in the shrubs group, 6 in the climbers group and 5 in the herbs group (Table 4). Species-area curves indicated that the number of sampling plots sufficiently captured the array of plant species available at this site (Figure 2).

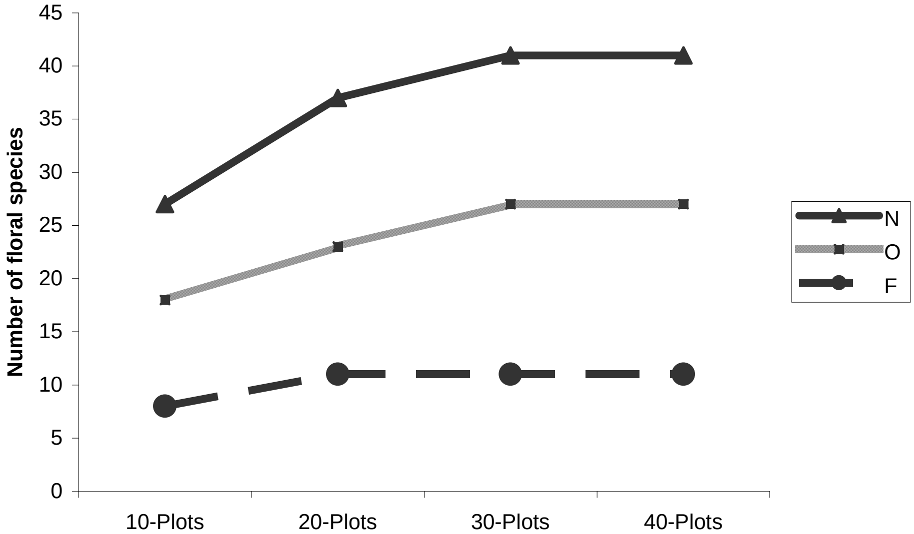

Figure 2: Species richness-area curves for all three picnic categories (N, O, F)

The number of mature tree species was 13 in the whole area. The highest number of mature tree species was found in the N-areas (12) followed by O-areas (6) and F-areas (3). Only Sal (*Shorea robusta*) was common to all three areas (Table 5).

Table 4: Similarity index of floral species for all three picnic categories (N, O, F)

Plants	Species richness				Species overlapping			Similarity Index		
	N	O	F	All	N-O	O-F	F-N	N-O	O-F	F-N
Mature tree	12	6	3	13	5	1	3	0.56	0.22	0.40
Sapling	10	6	3	10	6	3	5	0.75	0.67	0.77
Large seedling	17	6	2	18	5	2	2	0.43	0.50	0.21
Small seedling	12	8	4	12	8	4	4	0.80	0.67	0.50
Tree	20	15	7	22	13	6	7	0.74	0.55	0.52
Shrub	10	6	1	10	6	1	1	0.75	0.29	0.18
Climber	6	5	2	6	5	2	2	0.91	0.57	0.50
Herb	5	1	0	5	1	0	0	0.33	0.00	0.00
Plant	41	27	11	43	25	10	11	0.74	0.53	0.42

Considering all plants together the highest similarity index was observed between N-O areas (0.74) followed by O-F areas (0.53) and F-N areas (0.42). Diversity index was highest in the N-areas followed by O-areas and F-areas for all plant groups (mature tree, sapling, seedlings, shrub and herb). On the contrary, dominance index was highest in the F-areas followed by O-areas and N-areas. Except the category of large seedlings all other tree groups (mature tree, saplings and small seedling) exhibited the highest evenness in the F-areas followed by O-areas and N-areas (Table 2).

Table 2: Diversity indices for all three picnic categories according to different components of the Sal forests

	Diversity Index			Dominance Index			Evenness		
classes	N	O	F	N	O	F	N	O	F
Mature tree	0.15	0.06	0.04	0.96	0.98	0.99	0.06	0.03	0.03
Sapling	0.67	0.28	0.14	0.75	0.90	0.95	0.29	0.16	0.13
Large seedling	0.41	0.15	0.09	0.87	0.95	0.96	0.14	0.09	0.13
Small seedling	1.20	1.10	0.82	0.53	0.54	0.59	0.48	0.53	0.59
Shrub	1.14	1.01	0.00	0.50	0.50	1.00	0.50	0.57	-
Climber	1.63	0.98	0.47	0.22	0.51	0.70	0.91	0.61	0.68
Herb	0.92	0.00	-	0.51	1.00	-	0.57	-	-

Table 5: Density, basal area and Important Value Index (IVI) of the enlisted mature tree species all three picnic categories (N, O, F)

Botanical Name	*Local Name*	*Density(N/ha)*			*Basal area(m^2/ha)*			*IVI*		
		N	O	F	N	O	F	N	O	F
Adina cordifolia (Roxb.) Hook. f. ex Brandis	Haldu	0.8	-	-	0.01	-	-	2.2	0.0	0.0
Albizia lebbek (L) Benth.	Koroi	3.3	2.5	-	0.08	0.13	-	9.1	9.2	0.0
Bridelia retusa (L) A. Juss.	Katakhai	-	0.8	-	-	0.01	-	0.0	2.9	0.0
Careya arborea Roxb.	Gadhila	1.7	-	-	0.04	-	-	4.5	0.0	0.0
Cassia fistula L.	Sonalu	1.7	-	0.8	0.03	-	0.02	4.5	0.0	3.2
Dillenia pentagyna Roxb.	Ajuli	1.7	-	-	0.03	-	-	4.4	0.0	0.0
Eugenia jambolana Lam.	Jam	2.5	-	3.3	0.07	-	0.06	6.8	0.0	9.7
Ficus benghalensis L.	Bot	0.8	-	-	0.04	-	-	2.4	0.0	0.0
Lannea coromandelica (Houtt.) Merr.	Jiga	0.8	0.8	-	0.02	0.02	-	2.3	2.9	0.0
Miliusa roxburghiana (Wall. Ex Griff.) Hk.f.&Th.	Bongajari	0.8	0.8	-	0.03	0.03	-	2.3	3.0	0.0
Miliusa velutina (Dunal) Hk.f.&Thoms.	Gandhigajari	0.8	0.8	-	0.02	0.08	-	2.2	3.3	0.0
Shorea robusta C.F. Gaertn.	Sal	725.8	745.0	728.3	18.03	16.28	14.62	257.0	278.7	287.2
Zanthoxylum rhetsa (Roxb.) DC.	Bajna	0.8	-	-	0.02	-	-	2.3	0.0	0.0

Composition, community structure and tree vitality

The Important Value Index of the mature tree showed that the whole study area is highly dominated by Sal (*Shorea robusta*). The dominance of Sal was the highest in the F-areas (IVI: 287.2) followed by O-areas (IVI: 278.7) and N-areas (IVI: 257) compared among the three areas (Table 5).

There was no significant differences in density (N/ha) of the mature trees among the three areas, but the density of saplings, large seedlings, small seedlings, shrubs, climbers and herbs were significantly at highest in the N-areas followed by O-areas and F-areas. The basal area of the mature trees was significantly highest in the N-areas followed by O-areas and F-areas also (Table 3).

Table 3: Mean values (Mean±SD) of the densities (N/ha) and basal area (m2/ha) for all three picnic categories (N, O, F) according to different components of the Sal forests

Parameter	Flora	N	O	F	ANOVA	
					F	p
Density (N/ha)	Mature tree	741.7±109.1[a]	750.8±154.3[a]	732.5±141.3[a]	0.18	0.835
	Sapling	240.8±116.1[a]	253.3±100.9[b]	176.7±90.0[c]	6.4	0.002
	Est. seedling	4552.5±1321.8[a]	1450.0±572.4[b]	140.0±243.7[c]	288.7	0.000
	Ephemeral	1790.5±1015.4[a]	795.8±697.9[b]	318.3±434.0[c]	39.7	0.000
	Shrub	1305.8±298.8[a]	264.2±112.1[b]	46.7±73.5[c]	506.9	0.000
	Climber	63.3±45.2[a]	37.5±33.9[b]	18.3[c]	15.8	0.000
B. area(m^2/ha)	Mature tree	18.4±2.9[a]	16.5±5.0[b]	14.7±4.1[c]	8.3	0.000

Means within columns followed by the same letter or letters (a-c) are not significantly different (p <0.05), by LSD

Randia dumetorum was the dominant shrub in the O-areas and it is the only species found in F-areas, whereas *Clerodendrum serratum* was the dominant species followed by *Randia dumetorum* in the N-areas (Table 7).

Table 7: Density (N/ha) of shrubs in all three picnic categories (N, O, F)

Botanical Name	Local Name	N	O	F
Ageratum sp.	Fulkhari	52.5	5.0	-
Ardisia humilis Vahl.	Bonjam	9.2	2.5	-
Clerodendrum serratum (L.) Moon.	Bhite	890.0	21.7	-
Dalbergia spinosa Roxb.	Anantakata	39.2	47.5	-
Glycosmis pentaphylla (Retz.) DC.	Mouhati	20.0	9.2	-
Holarrhena antidysenterica Wall. Ex A. DC.	Kuteshwar	19.2	-	-
Lantana Camara L.	Lantena	30.0	-	-
Mimosa pudica L.	Lojjaboti	16.7	-	-
Randia dumetorum Lamk.	Monkata	215.8	178.3	46.7
Urena lobata L.	Ghaghra	13.3	-	-

Among the climber species, *Pothos scandens* was the dominant species in all three areas (Table 8).

Table 8: Density (N/ha) of climbers in all three picnic categories (N, O, F)

Botanical Name	*Local Name*	*N*	*O*	*F*
Asparagus racemosus Willd.	Shotomuli	5.8	-	-
Ficus scandens Roxb.	Dumurlata	4.2	1.7	-
Pothos scandens L.	Kalalata	20.8	25.8	15.0
Smilax macrophylla Roxb.	Kumarilata	15.8	3.3	-
Spatholobus roxburghii Benth.	Mongolilata	5.8	0.8	-
Unknown	Nangollata	10.8	5.8	3.3

Considering the average area of forest floor occupied by herbs the overall abundance of herbs was most frequent in the N-areas, whereas occasional in the O-areas and absent in the F-areas (Table 9).Only *Cyperus rotundus* was common to both N and O-areas.

Table 9: Abundance of herbs in all three picnic categories (N, O, F)

Botanical name	*Local Name*	*N*	*O*	*F*
Adhatoda vasica Nees.	Bashok	Rare	Absent	Absent
Curcuma zedoaria (Christm.) Roscoe	Shoti	Occassional	Absent	Absent
Cyperus rotundus L.	Mutha	Frequent	Occassional	Absent
Nicotiana plumbaginifolia Viv.	Bontamak	Rare	Absent	Absent
Oplismenus aemulus (R.Br.) Roem. & Schult.	Basket	Occassional	Absent	Absent
Total		Frequent	Occassional	Absent

Out of the 20 tree species in the N-areas 18 were found to be regenerating, whereas 15 species out of 15 in the O-areas and 7 species out of 7 in the F-areas (Table 6).

Table 6: Classification of the natural regeneration at all three picnic categories (N, O, F)

Classification	N	O	F
Good	7(35%)	1(7%)	-
Fair	1(5%)	-	-
Poor	1(5%)	1(7%)	-
Very poor	9(45%)	10(67%)	7(100%)
Nil	2(10%)	3(20%)	-
Total	20(100%)	15(100%)	7(100%)

7 species (35% of total tree species) exhibited good regeneration in the N-areas, whereas 1 species (7%) in the O-areas. 7 species out of 7 in the F-areas showed very poor regeneration (100%).

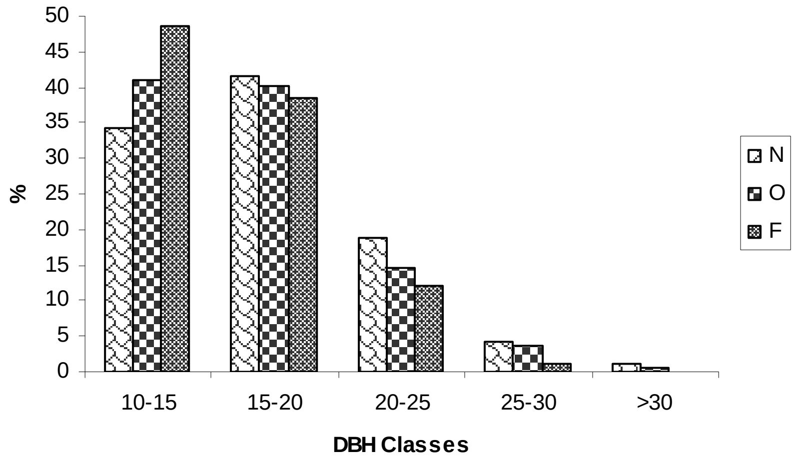

Figure 3: Diameter distributions of the mature trees in all three picnic categories (N, O, F)

Except in the N-areas the diameter distribution of the mature trees in all areas showed a reverse J-shaped pattern (Figure 3), and an approximately normal distribution of tree height in the three areas (Figure 4). The proportion of comparatively larger trees in terms of diameter and tree height increased from F-areas to O-areas and O-areas to N-areas.

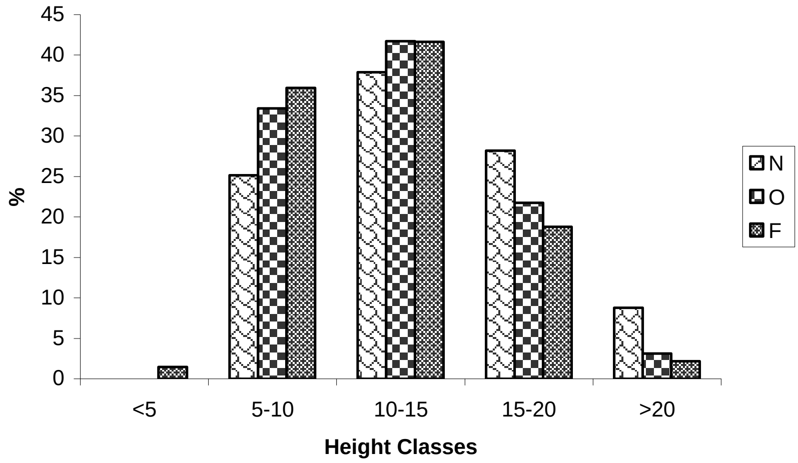

Figure 4: Tree height distribution in all three picnic categories (N, O, F)

The vitality class-4 (very low vitality) had the highest proportion considering the stem number within the O (33.9%) and F-areas (61.7%), whereas only 13.7% of all trees were classified with a very low vitality in the N-areas. The proportion of the vital class-1 (very high vitality) was 14.7%, 9.1% and 1.3% within the N, O and F-areas respectively (Figure 5).

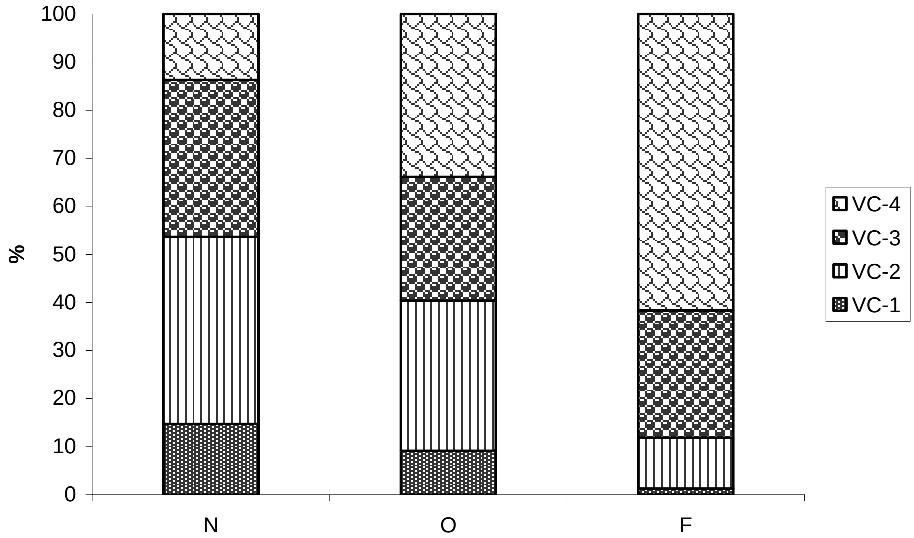

Figure 5: Distribution of the vitality classes of the mature trees in all three picnic categories (N, O, F)

Discussion

The Bhawal National Park dominated by Sal appears poor in plant species richness (43 plant species: 22 trees, 10 shrubs, 6 climbers and 5 herb) comparing to other Sal forests region of the World. Rahman et al. (2008) counted 134 species (70 trees, 15 shrubs, 26 climbers and 23 herbs) from the Madupur National Park, which is also dominated by Sal and located in the same agro ecological zone. Webb and Sah (2003) enlisted 159 species (49 trees, 45 shrubs, 16 climbers and 42 herbs) from the Central Terai, whereas Timilsina et al. (2007) counted 131 species (28 trees, 10 shrubs, 6 climbers and 87 herbs) from the western Terai of Nepal. Pandey and Shukla (2003) found 208 species (93 trees, 50 shrubs, 34 climbers and 31 herbs) in the eastern Terai, and Shankar (2001) examined 87 species (≥ 10 cm dbh) in the Darjiling Terai of India. Swamy et al. (2000) listed 82 species (48 trees, 10 shrubs, 8 climbers and 16 herbs) from a low elevated (250-400 m altitude) and moist deciduous forest in the Western Ghat of India. The species richness of mature trees (> 10 cm dbh) was low when compared with the range across the tropics, 20 species ha^{-1} in Varzea forest of Rio Xingu, Brazil

(Campbell et al. 1992) to as high as 307 species ha^{-1} in Amazonian Ecuador (Valencia et al. 1994). Compared to various moist tropical forests in the neighbouring countries of Bangladesh (Chandrashekara and Ramakrishnan, 1994; Parthasarathy and Karthikeyan, 1997; Ganesh et al., 1996; Kadavul and Parthasarathy, 1999), this study site represents the lowest forest diversity according to species richness. The diameter and height distributions indicated that the park is scarce of old and merchantable timbering trees as Sal may be 45 m tall and 8 m girth (Troup, 1986). On the other hand, the Sal forests in this region are supposed to be a mixed natural forests with a total share of 75% to 25% by Sal (*Shorea robusta*) and the rest by other deciduous species like *Adina cordifolia, Albizia procera, Bombax ceiba, Butea monosperma, Lagerstroemia parviflora, Dillenia pentagyna, Garuga pinnata, Hymenodictyon orixensis, Semecarpus anacardium, Miliusa velutina, Schleichera oleosa* (Ismail and Mia, 1973). The relative abundance of Sal ranged from 98% to 99% among the three study sites in this study which indicates that most of the associates of Sal have been almost lost. The impacts of tourism and other human disturbances on this park are very much severe due to its location (40KM away from the centre of the capital). Tremendous human pressure caused the decreasing of the species richness and the relative proportion of natural Sal associates by increasing the relative proportion of Sal in this forest. The outside area of this park is highly populated and other disturbances like logging, regeneration cutting, litter sweeping and animal grazing are severely prominent here along with tourism. It is comparatively difficult for the illegal loggers to sell Sal timber on the local market due to vigilance of the law enforcing agencies and the easy identification of the species compared to other species. The natural associated species of Sal grow often in the homesteads too, but Sal is the only species which grows in the forest only. Rapid urbanization and industrialization in that area may be other causes of being species poor forest.

Nevertheless, the anthropogenic disturbances are similar in the whole study area but the intensity of picnic activities varies from one site to another. Within the study area the species richness of all plant groups tended to be decreasing from the wilderness area to the picnic spots. At the same time the vegetation composition and cover also differed between the plots at the roadside compared to the more undisturbed areas at some distance. The proportion of bare ground increased with the decrease of naturalness (compare also Johnston and Johnston, 2004). The density of plant groups except the number of the mature trees increased with the distance from the picnic spot to the wilderness area as well. Picnic spots are not a congenial habitat for natural regeneration of Sal associates due to the continuous human movements. Small seedlings of Sal associates could not attain the size of large seedlings, saplings and mature trees. But Sal was able to compete with its continuing regeneration even within picnic spots because of the strong coppicing character (Suoheimo, 1999). The intensity of picnic activities decreased the vitality of the mature trees. People damage the bark and branches unnecessarily just for fun. The disturbances by man on the forest floor in passing by have a negative impact on the vegetation (Hill and Pickering, 2006). With the increasing distance from the road the level of humus, nutrient supply, pH values and electrical conductivity may increase (Johnston and Johnston, 2004). On the other hand the picnic activities cause strong compactness to the soil (Buckley and Pannell, 1990; Pickering and Buckley, 2003; Donaldson and Bennet, 2004; Worboys et al., 2005). The construction of infrastructures near to picnic spots may degrade the soils including erosion, sedimentation and pollutant runoff at picnic spots (Buckley and Pannell, 1990; Spellerberg, 1998; Newsome et al., 2002a). Compaction can reduce the growth rate of trees by reducing the size or extent of root systems and the number of fine roots. As a consequence the oxygen uptake of roots is reduced, thereby decreasing the absorption of water and nutrients as well as impeding water movement through soils. Extensive soil compaction may significantly reduce a site's capability for timber productivity through degraded reforestation potential, rate of tree growth, and stand health in the long-term. Direct damages to the roots of trees occurred due to activities in digging holes for cooking and disposing of human or other waste (compare Newsome et al., 2002b; Phillips and Newsome, 2002; Smith and Newsome, 2002; Bridle and Kirkpatrick, 2003).

The most obvious impacts on the vegetation are caused by camping and walking including the effects on the vegetation being crushed, sheared off, and uprooted (Stone and Elioff, 2000; Newsome et al., 2002a). These impacts may result in changes to the vegetation including loss of height, biomass, reproductive structures (e.g. flowers, fruit), reduction in cover, damage to seedlings and change in species composition (Hill and Pickering, 2006; Growcock, 2005; Whinam and Chilcott, 1999). Moreover, the litter coverage increased with the decreasing of picnic activities. The maintenance of the soil organic pool in tropical ecosystems is achieved by the high and rapid circulation of nutrients through the fall and decomposition of litter (Ola-Adams and Egunjobi, 1992). The litter on the forest floor acts as an input-output system of nutrients (Das and Ramakrishnan, 1985). It is particularly important in the nutrient budget of tropical forest ecosystems on nutrient-poor soils, where vegetation depends on recycling of nutrients contained in the plant detritus (Singh, 1968).

All the man made impacts observed during the study have direct and indirect effects on the species composition and species richness of trees, ground vegetation and climbers. That’s why the Sal dominated national park appears poor in plant species richness compared to other

Sal forests. The tourist activities very much represent "a double edged sword for the socio-environmental movement, in that it is an activity which is both reviled and revered. It has become a focus of criticism for its impacts and a focus of promotion for achieving sustainable development" (Mowforth and Munt, 1998). Tourism will therefore have a specific position in policies aimed at the conservation of biodiversity as the level of acceptance in the general public is of great importance. Conservation measures will be more "sustainable" if they are widely accepted and supported, and especially if large parts of the society are directly aware of the benefits they derive from the protection of biodiversity for themselves. The implementation of biodiversity conservation activities for the Bhawal National Park is challenging for being the nearest park with picnic facilities from the mega populated capital. But obviously the impacts can be minimised to some extend. Park managers should have legislative requirements to manage recreation in ways that mitigate impacts and ensure that activities are ecologically sustainable. Recreation management should consider areas where particular picnic activities are allowed to be conducted and areas where the focus should be on a limitation in number and size of the picnic parties. The number of picnic parties should not exceed the number of picnic spots and a balanced number of occasionally used picnic spots may lead to near to wilderness areas. However, further comprehensive research activities are needed to measure and monitor the impact of tourists on soil characteristics and plants to understand the role of these damages for ecosystem processes.

Nevertheless, it is very difficult to control negative human impacts in the context of an overpopulated region and the rising demands for recreational purposes. There is an urgent need for public awareness programmes for visitors to increase the understanding for the vulnerability of the environment and the importance for the maintenance of forest biodiversity.

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8.3 Comparison of structural diversity of tree-crop associations in Peripheral and Buffer zones of Gachabari Sal forest area, Bangladesh

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Comparison of structural diversity of tree-crop associations in Peripheral and Buffer zones of Gachabari Sal forest area, Bangladesh

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Abstract: The structural diversity of different tree-crop associations were studied at Gachabari Sal forest area of Madhupur Garh on Buffer and Peripheral Zone during 2006. The total density, basal area of trees in the Buffer and Peripheral Zone were 155.5 trees·hm^{-2}, 795.4 trees·hm^{-2} and 3.9 m^{2}·hm^{-2}, 5.8 m^{2}·hm^{-2}, respectively. No regeneration and natural trees were found in Peripheral Zone and the Zone is totally occupied by exotic species where the Buffer Zone comprised of both natural and exotic trees. The Peripheral Zone belonged to younger and smaller trees whereas the Buffer Zone belonged to mixture of smaller, taller, younger and mature trees simultaneously. For the practicing of different agroforestry systems both Zones have lost their original characters of Sal forest.

Keywords: Structural diversity, Tree-crop associations, Sal, Peripheral and Buffer Zone.

Introduction

The traditional Sal forests of Bangladesh belong to the category of tropical moist or dry deciduous forest (Rashid *et al.* 1995). Available information suggests that currently only 10% of the 120 000 hm^{2} of Sal forests are covered with Sal trees (Gain 1998). The Madhupur Sal forest is the largest patch, which plays a vital role in maintaining ecological balance at the centre of the country. But unfortunately this forest area is degraded, denuded and encroached to such an extent that it has lost the main features of the original Sal (Rashid and Mia 2001). The worst destruction of wildlife and biodiversity has also taken place in the Sal area. Traditional Sal forest has now becoming a history for introducing commercial cultivation and adoption of exotic plant species. In the core zone of Mahupur Sal forest some natural species can be found but it is declining day by day and after few decades it will be a funny story. Now –a-days the Buffer and Peripheral Zone of Madhupur Sal forests have become a history of natural Sal forest. The recurrent anthropogenic disturbances have rendered the system inhospitable for the regeneration and growth of wild plant associates, causing a net loss in plant diversity (Pande 1999). Being a land-hungry country, Bangladesh cannot preserve her forest areas due to severe pressure on forest land by overpopulation. Agroforestry has become an effective tool to replenish degradation of forest as it offers direct benefits to the local community from its early stage of establishment. Government of Bangladesh and Non-Government Organizations launched several agroforestry projects throughout the country including Madhupur Sal Forest.

Most of the studies on Indian Sal forests are concerned with vegetation analysis of *Shorea* communities (Gupta and Shukla 1991; Singh *et al.* 1995; Pande 1999; Pandey and Shukla 1999). In Bangladesh there are some lists of plants found in Sal Forest areas (Alam 1995; Choudhury *et al*, 2004; Rashid and Mia 2001). No detailed studies on plant diversity of Sal forests in Bangladesh are also available (Alam 1995). The present study was, therefore, undertaken to assess the structural diversity with emphasis on stand structure including vertical and horizontal structure of Peripheral and Buffer Zone and to compare the degree denudation of natural trees between these two zones.

Materials and methods

The study was conducted at Gachabari area under Madhupur Garh, Bangladesh. The area is located between 23°50'–24°50' North latitude and 89°54'–90°50' East longitude with 15 m altitude and the climate of the region is moderate. The annual rainfall ranges from 1500 to 2100 mm and the temperature ranges from 10 to 34°C. The soil is red brown terrace with low organic matter content and moderately to strongly acidic in reaction (Richards and Hassan 1988). The study was carried out during November/2006. The Gachabari Sal forest area may be classified in three zones: (1) the peripheral zone, consisting of exotic tree stands with different field crops (2) the buffer zone, consisting of few natural Sal-exotic tree stands with different field crops and (3) the core zone, consisting of coppiced Sal.

For the present study we have established 30 circular plots of 300 m^{2} area in the Peripheral and Buffer Zone respectively. Plots of Peripheral Zone were established randomly from different sites and plots from Buffer Zone were established continuously at 100

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m interval in any directions. For the purpose of describing the stand structure the diameter at breast height (DBH), height and trunk height of each tree (≤ 5cm d.b.h. and ≤1.37 m height) were measured for each individual on each plot. The vegetation was quantitatively analyzed by frequency, density and basal area of trees following Curtis and McIntosh (1950). The relative values of frequency, density and abundance were determined as per Phillips (1959). These values were summed to represent IVI (Importance value Index) of individual species (Curtis 1959). Diameter of tree populations was classified as ≥5–10 cm, 10.1–15 cm, 15.1–20 cm, 20.1–25 cm and >25 cm where height was classified as ≥1.37–5 m, 5.1–10 m, 10.1–15 m, 15.1–20 m and 20.1–25 m. Each tree was classified according to its status as a dominant, co dominant, intermediate and suppressed tree on the basis of crown length, tree height, side branching and general level of canopy crown.

Results

Phytosociology

In the Peripheral Zone only exotic tree species (04 species) and no natural tree species was found. In the Buffer Zone 02 natural tree species and 03 exotic tree species were found (Table 1). In both zones different agroforestry systems were observed. Therefore 05 crop species in the Buffer Zone and 07 crop species in the Peripheral Zone had various associations with tree species (Table 1). The mean density per hectare of individuals of ≥5 cm d.b.h. was maximum for Sal (97.8), followed by Mangium (40.5), Acacia (10.8), Arjun (6) and Bohera (0.6) in the Buffer Zone the maximum was found for Acacia (304.4), followed by Gamari (276.6), Bokain (193.3) and Mangium (21.1) in the Peripheral Zone (Table 2). Considering all tree species Buffer Zone indicates a density of 155.7 trees·hm^{-2} which was 20% of Peripheral Zone (795.4 trees·hm^{-2}) (Table 3). Total basal area of Buffer Zone was 3.9 m^2·hm^{-2} which was 67% of Peripheral Zone (5.9 m^2·hm^{-2}) (Table 3). In the Buffer Zone, the natural tree species Bohera belonged to 0.7% relative density though its relative basal area is 20.7%. Considering density and basal area of trees of both Zones it can be concluded that within the Buffer Zone mature trees with higher diameter and in the Peripheral Zone younger trees with lower diameter exists. Among all natural tree species, Bohera in the Buffer Zone had the highest basal area. The maximum Important Value Index was found for Acacia (108.5) in Peripheral Zone and for Sal (171.5) in Buffer Zone (Table 2). Sal was found to be present as the main associated species in the Buffer Zone while Acacia in the Peripheral Zone. Regeneration of Sal (146.7 seedlings·hm^{-2}) was found only in Buffer Zone and no regeneration was observed in Peripheral Zone (Table 2). No saplings (>30cm height) were found in the Buffer Zone.

Table 1. Different tree-crop associations (agroforestry systems) found in the study area

Aspect	Tree-Crop Associations	No. of natural tree species	No of exotic tree species	No. of crop species
Buffer Zone	1. Sal+Acacia—Pineapple+ Mustard	02	03	05
	2. Sal+Acacia—Pineapple+Papaya			
	3. Sal+Acacia— Pineapple+Banana			
	4. Sal+Acacia— Pineapple+Banana+Papaya			
	5. Sal+Mangium— Pineapple+Papaya			
	6 .Sal+Mangium— Pineapple+Banana			
	7. Sal+Mangium— Pineapple+Banana			
	8. Sal+Mangium+Acacia— Pineapple+Banana			
	9. Sal+Mangium+Acacia— Pineapple+Papaya			
	10.Sal+Mangium+Acacia— Pineapple+Banana+Papaya			
	11. Sal+Arjun+Acacia—Cotton			
	12.Sal+Bohera+Acacia+Manjium— Pineapple+Banana+Papaya			
Peripheral Zone	1.Acacia—Pineapple	0	04	07
	2.Acacia—Pineapple+Turmeric			
	3.Gamari—Pineapple			
	4.Gamari—Pineapple+Turmeric			
	5.Acacia+Gamari—Pineapple			
	6.Acacia+Gamari—Pineapple+Turmeric			
	7.Acacia—Bitter gourd			
	8.Acacia—Kachu+Ginger			
	9.Acacia—Banana+Papaya			
	10.Acacia—Banana			
	11.Bokain+Mangium+Acacia— Pineapple+Turmeric			
	12. Bokain+Mangium+Acacia— Pineapple+Ginger			
	13. Bokain+Mangium+Acacia— Pineapple+Turmeric+Ginger			

Diameter distributions of tree populations

Diameter class distribution of Buffer Zone indicated that 46.2 % of the total number of trees was of the size ranging from ≥ 5cm cm to 10.0 cm in diameter followed by 15.1 cm to 20 cm diameter (32.6%), and in the Peripheral Zone 65.4% trees was of the size ranging from ≥ 5 cm to 10.0 cm in diameter followed by 10.1 cm to 15 cm diameter (31.8%) (Fig. 1). 7.6% of all individuals belong to the diameter class 10.1–15cm in the Buffer Zone and 2.7% of all individuals belong to the diameter class 15.1–20 cm in the Peripheral Zone. 13.1% population of Buffer zone was of the diameter class 20.1–25 cm whereas only 0.1% population of Peripheral Zone was of that diameter class. Within the range of ≥5–15 cm diameter 53.8% population of Buffer Zone and 97.2% population of Peripheral Zone were found.

Table 2: Frequency (F), relative frequency (RF), density (D), relative density (RD), basal area (BA), relative basal area (RBA) and Important Index Value (IVI) of different tree species in Buffer Zone and Peripheral Zone of Gachabari Sal Forest area

Species		Aspect	F (%)	RF (%)	D (tree·hm^{-2})	RD (%)	BA (m^2·hm^{-2})	RBA (%)	IVI
1. natural	Sal	Buffer Zone	96.7	42.3	97.8	38.3	2.6	66.4	171.5
	Bohera		3.7	1.6	0.6	0.4	0.8	20.7	22.7
2. Exotic	Arjun		14.8	6.5	6	3.9	0.1	3	13.4
	Mangium		76.7	33.5	40.5	26	0.3	7.8	67.3
	Acacia		36.7	16.1	10.8	6.9	0.1	2.1	25.1
Regeneration									
1. 0–30cm height Sal			70	100	146.7	100	-----	------	-------
2. 30.1–130cm height			------	-----	------	------	-----	------	-------
3. >130cm height(<5cm dbh)			------	-----	------	------	-----	------	-------
1. Natural		Peripheral Zone							
2. Exotic	Gamari		36.7	26.2	276.6	34.7	2.2	38	98.9
	Mangium		20	14.3	21.1	2.7	0.1	2	19
	Acacia		50	14.3	304.4	38.3	2	34.5	108.5
	Bokain		33.3	35.7	193.3	38.3	1.5	25.5	73.6
	Regeneration		------	-----	--------	------	------	------	-------

Table 3. Mean of density and basal area of all tree species in Buffer and Peripheral Zone

Aspect	Mean density	Mean basal area	Ratio of Density (Buf: Peri)	Ratio of basal area (Buf: Peri)
Buffer Zone	155.7	3.9	0.2	0.67
Peripheral Zone	795.4	5.8		

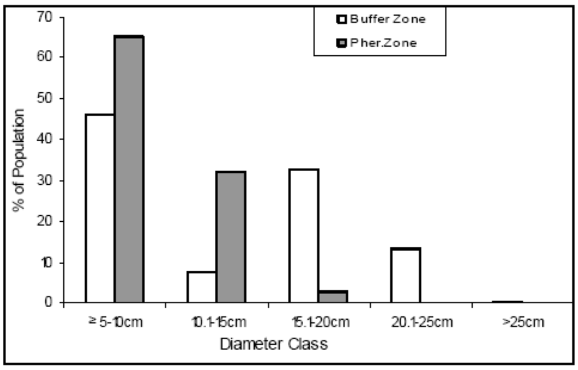

Fig. 1 Diameter class distribution of tree populations of the study area

Height class distribution

The height class 15.1–20 m belonged to maximum population (38.5%) followed by 5.1–10 m height class in the Buffer zone where 5.1–10 m height class belonged to maximum population(53.1%) followed by 10.1–15.1 m height class in the Peripheral Zone(Fig. 2). 15.1–20 m height class in the Peripheral Zone contained 6.5% population and 10.1–15.1 m height class in the Buffer Zone contained 18.5% population. 7.1% population was of the height class 20.1–25 m in the Buffer zone whereas no population found in that height class in the Peripheral Zone. Within the range 15.1–25 m height only 6.5% was found in Peripheral Zone where 45.6% population found in Buffer Zone.

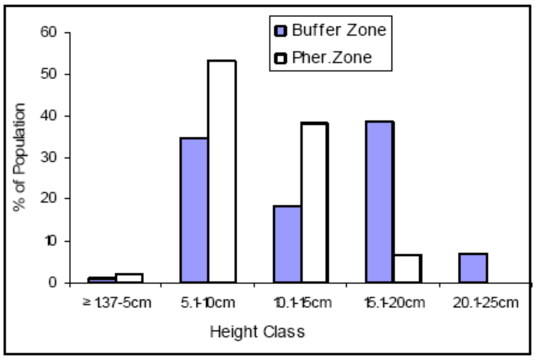

Fig. 2: Height class distribution of tree population in the study area

Crown class distribution

46.8% of all trees in the Buffer Zone have been assed as dominant, followed by co dominant (23.9%), intermediate (19%) and suppressed (10.3%). 33.2% of total trees in the Peripheral Zone have been assessed as dominant, followed by co dominant (31.1%), intermediate (23.6%) and suppressed (12.1%) (Fig. 3).

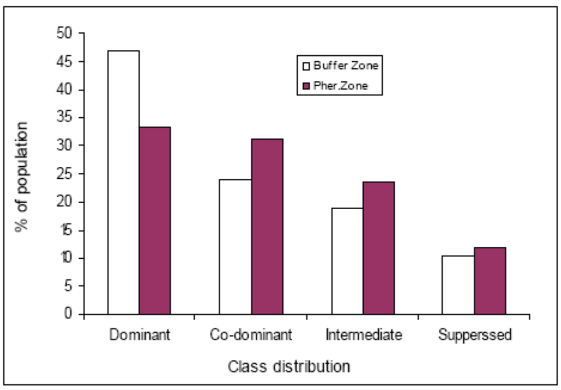

Fig. 3 Crown class distribution of tree populations in the study area

Discussion

All natural species were totally removed and exotic tree species occupied the Peripheral Zone. With the practicing crop productions in the forest areas, both the zones have lost their original characteristics. The results showed that Peripheral Zone has a less density of tree species than the Buffer Zone. Webb and Sah (2003) recorded average densities of 252.5 Sal trees·hm^{-2} for natural forests and 778.3 Sal trees·hm^{-2} for successional Sal forests in Nepal where Pandey and Shukla (2003) recorded the mean density of 304 Sal trees·hm^{-2} in a managed Sal forest in India. Jashiruddin *et al* (1999) reported 1353 Sal stems·hm^{-2} for the coppiced Sal forest in Bangladesh. The density of Sal trees in Buffer Zone appeared to be very scarce for denudation and degradation. Bhuiyan (1994) found 614 exotic trees·hm^{-2} in alley cropping where we found 795.4 exotic trees·hm^{-2} in the Peripheral Zone.

The result showed that the Peripheral Zone belongs to no longer suitable condition for regeneration and the Buffer Zone belongs to few saplings. The seedlings in the Buffer Zone may not attain the size of saplings due to high degradation and cultivation of crops within the tree space. Webb and Sah (2003) recorded average densities of 1 763 saplings·hm^{-2} for natural forests and 1 326 saplings·hm^{-2} for successional Sal forests in Nepal. Nath et al (2005) reported that in the highly disturbed stand, ploughing and clearing of ground vegetation for cultivation practices, firewood collection and grazing together with the below ground competition of mature trees and other plants increase the mortality rate of seedlings and saplings. Peripheral Zone was denser than that of Buffer Zone but in the Peripheral Zone all natural species, regeneration and natural conditions have been disappeared. The basal area of trees of Buffer Zone was greater than that of Peripheral Zone considering density of trees.

The Peripheral Zone indicated J-shaped pattern in which number of stems decrease with the increase of diameter, on the other hand, in the Buffer Zone the d.b.h. class is not J-shaped (Fig. 1). The diameter class distribution indicated that almost trees in Peripheral Zone were younger and a big portion of populations (47.2%) of Buffer Zone were mature and larger in size. For the presence of few natural trees the Buffer Zone belongs to many mature trees. The height class distribution showed that almost trees were smaller in height in the Buffer Zone where Buffer Zone comprised of smaller and taller trees (Fig. 2). Exotic trees in both zones were younger, which were shorter than natural trees of Buffer Zone. In both Zones the crown class distribution follow J-shaped pattern (Fig. 3). The number of dominant trees in Buffer Zone is greater than that of Peripheral Zone due to the presence of higher natural trees.

Conclusions

The Buffer Zone is highly degraded and denuded as only few natural tree species exist there. Crop cultivations within the forest enhanced losing of the original characters of Sal forest in both zones though few decades ago they were natural forests. The Peripheral Zone was comprised of only exotic species of younger and smaller in size whereas the Buffer Zone comprised of both natural and exotic tree species of mixture of younger, mature, taller and smaller trees simultaneously. In Buffer Zone few seedlings of Sal were found which could not attain saplings due to probably soil disturbances and crop cultivations. Recovery of Peripheral Zone could not be possible but the Buffer Zone could be by adopting *in- situ* conservation of seedlings, protecting further denudation; stopping plantation of exotic trees and crop cultivations.

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8.4 Analysis of spatial diversity of sal (Shorea robusta **Gaertn.f***) forests using neighbourhood-based measures*

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Analysis of spatial diversity of sal (*Shorea robusta* Gaertn.f) forests using neighbourhood-based measures

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Keywords: Aggregation, Dispersion, Homogeneity, Reference trees.

Abstract: The study presents an analysis of spatial and structural diversity of Sal (*Shorea robusta*), the dominant species of sal forests in Bangladesh by using a neighbourhood analysis approach. The simple field method permits relatively unskilled persons to collect data. Most of the indices can be calculated in the field and the data analysis is comparatively easy. Therefore, the applicability of the method was tested by using different setting of reference trees compared with the full sampling for each plot in the Madhupur sal forests. The results indicate that a group of one reference tree and its four neighbours can be used efficiently to describe the spatial and structural diversity in homogeneous young forests at low costs and in short time. The indices can be easily interpreted allowing quantitative comparisons between different types of forest stands. Sal can be considered as the dominant and comparatively faster growing species than other associate species.

Introduction

The sal forests of Bangladesh belong to the category of tropical moist or dry deciduous forest (Gain 1998). In Bangladesh, it is one of the three major forest resources (other types are tropical evergreen and coastal forest), which covers about 32% of the forested land (Banglapedia 2006). Sal (*Shorea robusta*, Dipterocarpaceae) is the dominant species of these forests, which are comprised of pure and mixed stands (Ismail and Mia 1973). These forests have a high economical and ecological significance in the central part of Bangladesh. Sal forests have also ethnic and cultural values in Bangladesh as ethnic communities (tribal people) live in these forests and, their livelihood and culture are directly related to them. Few studies on floristic diversity (incomplete list of plants) can be found, but no systematic studies on structural and spatial diversity have been done so far (Alam 1995, Rahman et al. 2007a).

Spatial stand structure is an important factor in determining habitat, species diversity and management practices. The structural diversity generally considers species composition, horizontal and vertical variation within the forests and on the other hand, spatial diversity considers these characteristics in space or arrangement of these dimensions in relation to each other. The structural diversity can be assessed by the spatial diversity as well. In the past, studies relating to spatial aspects were not comprehensive, cost effective or easy. Lund pair correlations involve tree coordinates (Stoyan and Stoyan 1992, Pretzsch 2001, Pommerening 2002) requiring large databases which may not always be available. Distant dependant indices proposed by Clark and Evans (1954) or Pielou (1977) can give a snap shot of the forest structure by describing the variety of spatial arrangements (Zenner and Hibbs 2000). Single tree-based variables or neighbourhood-based parameters or 'measure of surround' (Gadow et al. 1998, Staupendahl 2001) can be used to provide a comprehensive description of the spatial structure of a forest. The neighbour-based variables can be used in quick assessment of large forests (Pommerening 2002, Graz 2006). These parameters are used to quantify the regularity of neighbours position, size and interspersion with reference trees. Other than European scientists, Graz (2006) used these variables in dry savana woodland of Africa and Aguirre et al. (2003) experimented in Mexican forests successfully for assessing spatial diversity. Recent studies evaluated the applicability or the advantages of using neighbourhood-based variables for the analysis of structural diversity. However, a study on the sample size (suitable number of reference trees and neighbouring trees) and the importance of choosing an appropriate setting for the study design for assessing the spatial diversity has not been tested so far. Our study aims to assess the applicability of these neighbourhood-based variables in the sal forests of Bangladesh, to analyse the spatial diversity of the dominant species for a better understanding of the ecology of these forests and finally to find out a suitable setting for the neighbourhood analysis.

Materials and methods

Study sites

The study was carried out at Madhupur, the largest area of sal forests in Bangladesh during November 2006 – January 2007. These forests are intercepted by numerous depressions in the form of long and narrow valleys called 'Baid' locally, which are cultivated for agricultural crops, especially rice. For the presence of this 'Baid', continuous cover forests cannot be found in this region. Geographically it is located at 23°50'-24°50' North latitude and 89°54'-90°50' East longitudes. The soil belongs to the bio-ecological zone of Madhupur sal Tract, which is above the normal flood level (Nishat et al. 2002). The soils are moderately to strongly acidic in reaction (Richards and Hassan 1988), the annual rainfall is 2030-2290 mm while the maximum temperature is 34°C and minimum is 11°C (Islam et al. 2007). Webb and Sah (2003) classified sal forests as natural, successional (forest regenerated naturally after clear cutting) and plantation sal. We selected two stands for this study in the successional forests of the same age. One stand was at Rasulpur and the other stand at Rajabari area in the Madhpur sal forests. Both forests are highly dominanted by sal.

Sampling

Due to the presence of 'Baid', it was not possible to establish all plots on a regular grid. Therefore, the plots were randomly selected on transects with a minimum distance of 100 m between them. Thirty circular plots were established in Rasulpur as well as in Rajabari. The area of each plot was 300 m^2 having 9.77 m radius. In each plot, we selected 3 sal trees termed as reference trees. To reduce bias from the selection process of a reference tree, the first reference tree was taken as the nearest one from the centre, the second reference tree was taken as the nearest one from the middle point of the radius and finally the third reference tree was chosen as the most distant sal from the centre of the plot (Fig. 1). For each reference tree, the four nearest neighbours were chosen for neighbourhood analysis. In this context, the reference tree with its four neighbours was termed as 'group of five' (G5).

In each plot, we recorded all trees (dbh ≥ 5 cm) according to species name, dbh and height of each trees. For the neighbourhood variables, we measured dbh and height of each reference tree and four neighbouring trees. We classified the angle between every two neighbours in clock-wise direction in the field whether this angle was smaller or bigger than 90°.

Data analysis

For characterizing spatial diversity, we calculated four indices for each reference group and for each plot. For the subsamples of the 3 groups (1G5 or 5 trees, 2G5 or 10 trees and 3G5 or 15 trees per plot), the indices were calculated separately. SPSS® was used to analyze the correlations among different variables and to test the mean values for significant differences at a significance level of 5%.

Contagion

The contagion (Gadow et al. 1998, Staupendahl 2001) describes the degree of regularity of the spatial distribution of the four trees nearest to a reference tree i (Fig. 2). W_i is based on the classification of the angles α_j between each pair of the four neighbours. Assuming complete regularity of the positions of the four nearest neighbours around a reference tree, the expected standard angle α_0 would be equal to 360°/4 = 90°. In case of neighbours, w_{ij} can be visually assessed in the field by comparing α_j with α_0. A quick decision can be made in the forest on whether α_j is smaller than or equal to 90° or not.

$$W_i = \frac{1}{4}\sum_{j=1}^{4} w_{ij} \qquad W_i \in [0,1]$$

$$w_{ij} = \{1, \text{ if } \alpha_j < \alpha_0; 0 \text{ otherwise}\}$$

$W_i = 0$ indicates that the neighbouring trees are positioned in a regular manner, whereas $W_i = 1$ indicates an irregular or clumped distribution. With four neighbours, there are five possible values (0, 0.25, 0.50, 0.75 and 1) that W_i can assume. The average contagion value may be classified as 'regular', 'random' and 'clumped' (Gadow et al. 1998). The mean contagion value greater than 0.6 can be considered as 'clumped', those with values between 0 and 0.5 indicate 'regular' tree distributions, and between 0.5 and 0.6 are 'random' (Albert 1999).

Species mingling

The corresponding single tree variable to Pielou's coefficient of segregation, known as mingling (M_i), gives the proportion of the $n = 4$ nearest neighbours j ($j = 1 \ldots n$) of the ith reference tree which do not belong to the same species as the reference tree i:

$$M_i = \frac{1}{4}\sum_{j=1}^{4} m_{ij} \qquad M_i \in [0,1]$$

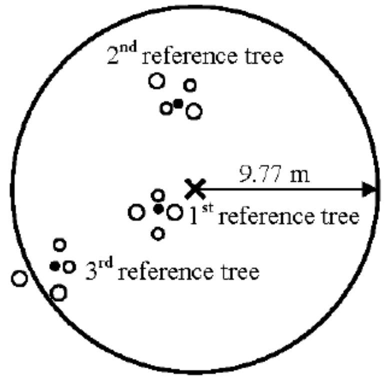

Figure 1. A sample plot with 3 reference trees and their neighbours.

m_{ij} = {1, if reference tree *i* and neighbouring tree *j* are of different species; 0, otherwise}. In case of 4 neighbours, M_i can assume 5 possible values (0.0, 0.25, 0.50, 0.75 and 1.00). The arithmetic mean of M_i for a particular species of reference tree (M_{Sp}) provides a measure of the degree of interspersion of the species in the area. Values close or equal to 1 indicate a high degree of mingling, i.e., trees of the reference species do not occur in a clumped manner. On the other hand, values near or equal to 0 indicate a low degree of mingling and a high aggregation, i.e., reference tree and all neighbours are of the same species. 1-M_{Sp} approximates the proportion, *P* of that species in the stand.

Size dominance

In addition to the mingling of species described above, the interspersion of tree dominance in size is quantified on the basis of diameter (D_i) and height (H_i) using the 'measure of surrounding' described by Hui et al. (1998), which is applied analogously to the mingling index:

$$S_i = \frac{1}{4}\sum_{j=1}^{4} s_{ij} \qquad S_i \in [0,1]$$

s_{ij} = {1, if tree *j* is thicker/higher than the sample tree *i*; 0, otherwise}. With four neighbours, five possible values (0, 0.25, 0.50, 0.75 and 1) can be calculated for S_i. The average value of S_i=0 indicates that all 4 neighbouring trees are smaller in size than the reference tree where the value 0 indicates that all neighbouring trees are taller or have a larger diameter than the reference trees.

The size dominance S_i is interpreted as diameter dominance D_i and height dominance H_i in a similar way.

$$D_i = \frac{1}{4}\sum_{j=1}^{4} d_{ij} \qquad D_i \in [0,1]$$

d_{ij} = {1, if tree *j* is thicker than the sample tree *i*; 0, otherwise}

$$H_i = \frac{1}{4}\sum_{j=1}^{4} h_{ij} \qquad H_i \in [0,1]$$

h_{ij} = {1, if tree *j* is higher than the sample tree *i*; 0, otherwise}

Size differentiation index

The singletree diameter differentiation variable, S_{ij}, gives the size difference of neighbouring trees on a continuous scale and describes the spatial distribution of tree sizes (Füldner 1995, Pommerening 1997, 2002). For the *i*th reference tree and its *n* = 4 nearest neighbour *j* (*j* = 1…n) the diameter differentiation S_{ij} is defined as:

$$S_{ij} = 1 - \frac{\min(size_i, size_j)}{\max(size_i, size_j)} \qquad S_i \in [0,1]$$

The value of S_{ij} increases with increasing average size difference between neighbouring trees. S_{ij} = 0 means that neighbouring trees have an equal size. This index is based on pairs of reference trees - first, second, third or fourth nearest neighbour tree. The size differentiation can be classified as diameter differentiation D_{ij} and height differentiation H_{ij}:

$$D_{ij} = 1 - \frac{\min(dbh_i, dbh_j)}{\max(dbh_i, dbh_j)} \qquad D_i \in [0,1]$$

$$H_{ij} = 1 - \frac{\min(height_i, height_j)}{\max(height_i, height_j)} \qquad H_i \in [0,1]$$

Size differentiation values can be interpreted as follows (Pommerening 2002):

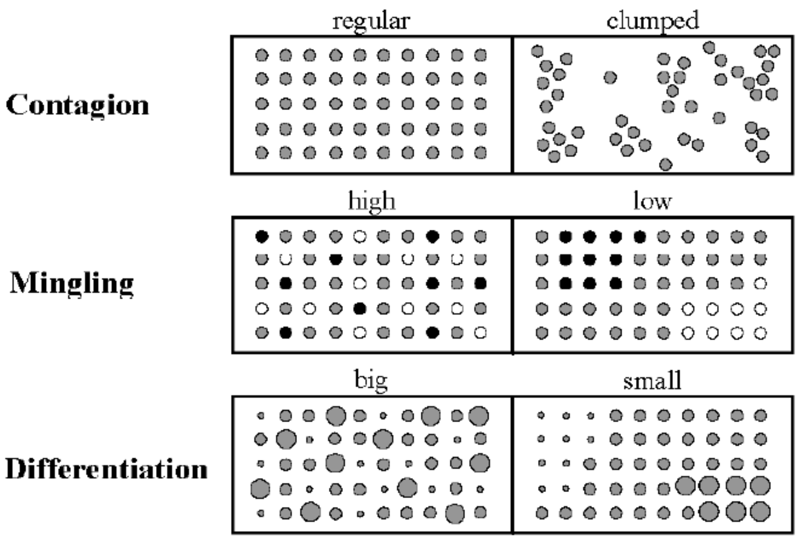

Figure 2. Aggregation, dispersion and size differentiation of trees in a forest.

Small differentiation: Comprises average values 0.0-0.3 (the average size of a neighbour is 0-30% larger or smaller than that of a reference tree)

Average differentiation: Comprises average values 0.3-0.5 (the average size of a neighbour is 30-50% larger or smaller than that of a reference tree)

Big differentiation: Comprises average values 0.5-0.7 (the average size of a neighbour is 50-70% larger or smaller than that of a reference tree)

Very big differentiation: Comprises average values 0.7-1 (the average size of a neighbour is 50-70% larger or smaller than that of a reference tree)

Results

Contagion and mingling

The mean contagion values of Rajabari stand across 1G5 (5 tree), 2G5 (10 tree) and 3G5 (15 tree) per plot were 0.67, 0.66 and 0.66, respectively, indicating a 'clumped' dispersion of trees in all 3 cases; whereas at Rasulpur, the contagion values were 0.50, 0.50 and 0.51 respectively, indicating a 'random' dispersion of trees (Table 2). The number of reference trees per plot did not affect the results and interpretation of tree dispersion significantly at both stands.

The mean mingling values were 0.04, 0.05 and 0.05, respectively, using 1G5, 2G5 and 3G5 per plot at Rajabari. Each of the mean values was near to 0 indicating a very low 'degree of mingling' or 'very high aggregation' of sal. At Rasulpur, the average mingling values for the 1G5, 2G5 and 3G5 per plot were 0.18, 0.20 and 0.22, respectively, indicating a low 'degree of mingling' or 'high aggregation' of sal as well (Table 2). To find out the proportion of sal from the mingling within the stand we calculated the value of 1-M_{Sal}. The mean values of 1-M_{Sal} of Rajabari forest were 0.96, 0.95 and 0.95, respectively, using 1G5, 2G5 or 3G5 per plot. Considering all trees within a sample plot, the average proportion of sal was 0.94 at Rajabari stand. For Rasulpur, the mean values of 1-M_{sal} were 0.82, 0.80 and 0.78, respectively, where the proportion of sal was 0.81 considering all trees from the plots. There was no significant difference of the proportion of sal across different sample sizes (Table 2). There was a positive linear correlation found between the total density of sal or the proportion of sal and the contagion value. With the increase of the stem number of sal trees and the overall proportion of sal, the value for the contagion index increased (Table 4).

Size dominance and size differentiation

The mean values of the diameter dominance were 0.43, 0.45 and 0.49 respectively for the 1G5, 2G5 and 3G5 samples, which indicated that 43%, 45% and 49% of the neighbours had a larger diameter at breast height than the reference trees at Rajabari. Similarly, 46%, 46% and 43% of the neighbours were larger at Rasulpur (Table 2).

Using the indices based on the 1G5, 2G5 and 3G5 per plot the height dominance was calculated as 0.45, 0.44 and 0.47 for Rajabari, where 0.36, 0.42 and 0.38 for Rasulpur (Table 2). The mean diameter differentiation of Rajabari forests were 0.15, 0.16 and 0.16, indicating a 'small' differentiation using 1G5, 2G5 and 3G5 per plot, where the mean diameter differentiation was 0.16, 0.17 and 0.17 indicating a 'small' differentiation also at Rasulpur. Similarly, the height differentiation was 'small' at both stands across different sample sizes (Table 2). The sal-sal diameter and height differentiation were more homogeneous in both stands than sal-other species (Table 3). There was no statistically significant difference found for the mean size dominance and differentiation for 1G5, 2G5 and 3G5 per plot in each stand (Table 2).

The mean diameter and height of sal were larger than those of the other species at both stands (Table 1). The diameter distributions were more homogeneous across different sample sizes (Fig. 4) than the height distributions (Fig. 5). No noticeable changes occurred in both diameter and height distributions across different sample sizes (Figs. 4-5).

Homogeneity or heterogeneity of the distribution of indices within and between the forest stands for using different sample sizes

There were no statistically significant differences in mean values for any of the indices calculated within each

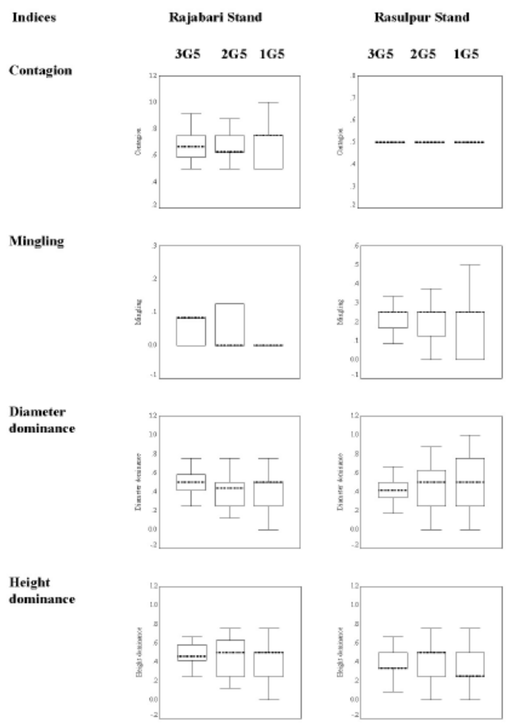

Figure 3. Boxplots showing medians, quartiles, maximum and minimum values of major indices across different sample sizes in Rasulpur and Rajabari forest stands.

Table 1. Basic information (Mean ±SD) of the investigated forests based on data from the full sampling of all trees per plot.

Stand	Tree (N/plot)	Density of Sal(N/ha)	DBH of Sal (cm)	DBH of other sp. (cm)	Height of Sal (m)	Height of other sp. (m)
Rajabari	56.7±4.3	1784.2±128.7	7.4±2.0	6.3±1.2	5.9±1.7	4.8±1.1
Rasulpur	35.2±2.6	956.7±99.8	7.3±2.3	6.9±4.0	5.6±2.0	4.9±1.7

Table 2. Mean values and standard error of mean (SE) of neighbourhood based indices. Statistical tests were performed for the indices across different sample sizes. In all cases there were no significant differences across the different sample sizes (One-way ANOVA, p=0.05).

Indices	Rajabari						Rasulpur					
	All	3G5	2G5	1G5	F	Sig.(p)	All	3G5	2G5	1G5	F	Sig.(p)
Mingling	-	0.05±0.01	0.05±0.01	0.04±0.02	0.24	ns(0.79)	-	0.22±0.01	0.20±0.01	0.18±0.03	0.83	ns(0.44)
Proportion(1-M_{Sal})	0.94±0.003	0.95±0.01	0.95±0.01	0.96±0.02	0.32	ns(0.81)	0.81±0.009	0.78±0.01	0.78±0.01	0.82±0.03	0.95	ns(0.42)
Diameter dominance	-	0.49±0.03	0.45±0.04	0.43±0.05	0.52	ns(0.60)	-	0.43±0.02	0.43±0.02	0.46±0.05	0.22	ns(0.80)
Height dominance	-	0.47±0.01	0.44±0.03	0.45±0.04	0.12	ns(0.87)	-	0.38±0.03	0.38±0.03	0.36±0.05	0.50	ns(0.61)
Diameter differentiation	-	0.16±0.01	0.16±0.01	0.15±0.01	0.10	ns(0.88)	-	0.15±0.01	0.15±0.01	0.14±0.02	0.09	ns(0.92)
Height differentiation	-	0.17±0.007	0.17±0.007	0.16±0.01	0.26	ns(0.77)	-	0.19±0.01	0.19±0.01	0.18±0.02	0.09	ns(0.91)
Contagion	-	0.67±0.02	0.66±0.02	0.66±0.03	0.05	ns(0.95)	-	0.51±0.008	0.51±0.008	0.50±0.02	0.10	ns(0.90)

All= all tree, 3G5=15 trees, 2G5=10 trees and 1G5=5 trees from of a plot

Table 3. Size differentiation (Mean ±SD) among different species, based on 1G5 (5 trees/plot).

Stand	DBH differentiation		Height differentiation	
	Sal-Sal	Sal-other species	Sal-Sal	Sal-other species
Rajabari	0.15 ±0.10	0.18 ±0.09	0.16 ±0.10	0.20 ±0.12
Rasulpur	0.15 ±0.13	0.13 ±0.08	0.17 ±0.15	0.23 ±0.11

Table 4. Relationships (Y = a + bX) between aggregation and dispersion of sal.

Between	*a*	*b*	*r²*	*p*
Sal density$_{all\ tree}$–Contagion$_{5\ tree}$	571.61	1369.4	0.25	0.00
Sal proportion$_{all\ tree}$-Contagion$_{5tree}$	0.75	0.22	0.21	0.00

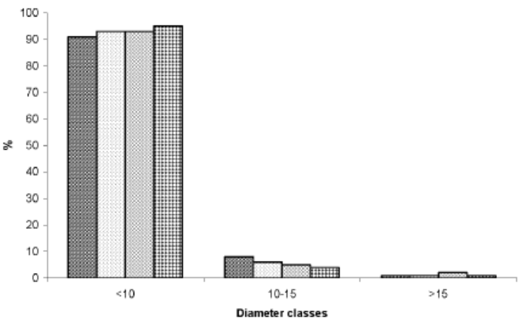

Figure 4. Diameter distributions of trees of both forests across different sample sizes.

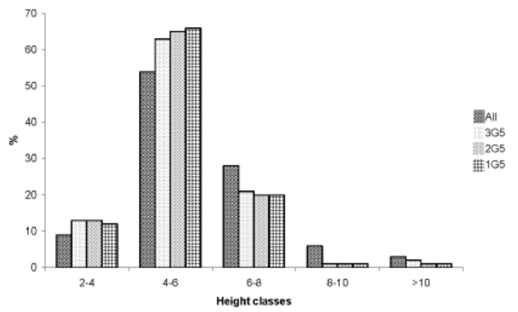

Figure 5. Height distributions of trees of both forests across different sample sizes.

stand in testing different sample sizes (Table 2) but there were some differences in median, quartiles, minimum and maximum values of indices observed across different sample sizes in both stands (Fig. 3). The highest standard error of mean was found in 1G5 followed by 2G5, 3G5 and the full sampling of all trees (Table 2). The boxplots also showed that the distribution of indices around the median values were most homogeneous in 3G5 followed by 2G5 and 1G5. These plots indicate that with an increase of the number of sample trees the lower and upper quartiles of the calculated indicators has a tendency towards the median (Fig. 3).

Discussion

One objective of this contribution was to analyse the spatial diversity of the dominant tree species *Shorea robusta* for a better understanding of the ecology of the Madhupur sal forests. It was found that the mean value of mingling for sal indicated a high level of 'aggregation' of sal at both Rajabari and Rasulpur forests. A 'clumped' dispersion of trees was observed at Rajabari forest, while a 'random' dispersion was found at Rasulpur forest. With the increase of the proportion or the density of sal, the dispersion tended towards 'clumping' (Table 4). Tropical species with a low density tend to have relatively 'uniform' dispersion and those with high density have a 'clumped' dispersion (Krebs 1972). Sukumar et al. (1992) reported that with the increase of the abundance of deciduous species the clumping will increase. Rahman et al. (2007b) found a 'regular' dispersion of sal in forests existing 'lower aggregation' of sal. Shankar (2001) reported that the clumping of sal increased with its abundance. Sal is known as a dominant tree species in most of the forest ecosystems (Champion and Osmaston 1962, Troup 1986) and the tendency for clumping is related to the increase of its density and subsequently the dispersion changes from 'regular' to 'random' and 'random' to 'clumping'.

The size differentiation was higher between sal and other species than between the pairs of sal and sal, which indicates a relatively higher growth potential for sal in the young stages of stand development compared to the other species. Some authors have also found that the growth of sal is relatively faster than other species in the young development phases (Gautam and Devoe 2006).

Measures based on the nearest-neighbour concept allowed us to find no significant differences among different sample sizes according to both forest stands analyzed. However, dissimilarities were found for median, quartiles, minimum and maximum values. As the comparison of the neighbour-based spatial parameters are based on arithmetic mean values and some sort of scaling (Pommerening 2002), it is possible to find non significant differences across different sample sizes in both forest stands, although the median and quartiles of the single values indicate some small differences. Considering the mean values the least sample size (5 trees/plot) measured unique spatial characteristics in both stands.

The study aimed to assess the applicability of neighbourhood analysis in the sal forests of Bangladesh and to find out a suitable setting for the design of the fieldwork of the structural analysis based on the number of reference trees. It was found that using 5, 10 and 15 trees from each plot has no significant effect on the results based on mingling, size dominance, size differentiation and contagion. The proportion of sal obtained from the mingling values across 5, 10 and 15 tree per plot, showed similar results compared to the full sampling of all trees on the plot. So, it can be assumed that using the mingling index of the neighborhood analysis can be used to describe the species composition of the sal forests reasonably well. Single G5 (5 trees/plot) approach could be used to measure the horizontal and vertical structure of a forest instead of 3G5 (15 trees/plot). However, the number of individuals in lower height classes would be overestimated. This fact might also be linked to the problem that some neighbouring trees for the third or the most distant reference tree came from outside of the plot area, which may not have been part of the full sample on the circular plot. However, a single G5 (5 trees) from each plot may be efficiently used to measure structural (composition, horizontal and vertical structure) and spatial (dispersion, aggregation and size differentiation) parameters of a forest, saving money and time simultaneously.

According to the selection process for the reference tree, we adopted a new approach. We took 3 reference trees on the basis of the distance from the centre of the 300 m^2 circular plot (first: the nearest from the centre, second: the nearest from the middle point of the radius and the third: the most distant from the centre). This procedure allowed reducing a bias from the effect of selecting a reference tree. It would be difficult to examine many reference trees with their neighbours, maintaining an equal distance from the centre of a circle of 300 m^2 area to each neighbours.

These neighbourhood-based variables and methods can be used in the field at low cost and less time to describe, compare and evaluate forest structure in a scientifically sound way. During field work, there is no need to consider the tree coordinates or the distances between trees to evaluate the basic spatial characteristics. The two young forests considered in this study were more or less homogeneous and highly sal dominant. Further research is needed for more heterogeneous and highly mixed forests to justify the applicability of these neighbourhood indices. However, considering its simplicity, we can recommend adopting the method with one "group of five" (G5) to measure the structural and spatial diversity of young and homogeneous sal forests of Bangladesh in the context of an inventory based on a regular grid or transects.

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8.5 Timeline of publications

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Paper I	17 February 2009 International Journal of Biodiversity Science and Management	Major revision	-
Paper II	09 February 2009 Forestry Studies in China	Minor revision	07 April 2009
Paper III	30 December 2006 Journal of Forestry Research	Minor revision	21 January 2007
Paper IV	31 January 2008 Community Ecology	Major revision	20 October 2008

9. Curriculum Vitae

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- Bachelor of Science in Agriculture from Bangladesh Agricultural University obtaining first class in 1995 (Examination held in 1999)
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Occupation

Assistant Secretary, The Government of the People's Republic of Bangladesh (May 2003 to till now)

Conference and workshop proceedings

Rahman MM, Frank G, Ruprecht H and Vacik H (2007) Deadwood of three oak dominated forest associations in a Natural Forest Reserve in Austria. In: University of Cambridge (Eds.), Student Conference for Conservation Science , 8th Student Conference for Conservation Science, 27-29 March 2007, University of Cambridge, Cambridge, UK

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