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

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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. The highest plant species richness (125 species) was found in the low disturbed forest type, and the lowest species richness (19 species) in the highly disturbed forest type. Plant density (except herbs and saplings) 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 young trees. The relative abundance of the early successional species, S. robusta, increased with the intensity of human disturbances due to its regeneration potential. Highly disturbed forests can no longer be considered natural habitats for natural plant species due to shifting cultivation and agroforestry.

Keywords: disturbance index; human intervention; regeneration; species richness; structure

Introduction

Natural disturbances (e.g. fire, floods) are inherent and key processes in forest ecosystems and major drivers of forest development in various forest biomes (Peltzer et al. 2000; Lorimer and White 2003). Besides evolutionary processes, human use and management have influenced landscapes and (forest) ecosystems in both intensive and sustainable ways (Kumar and Ram 2005) and, as human uses increase, there is an ongoing shift from natural landscapes to those developed and cultivated by man. The combination of direct and indirect uses of forest ecosystems by humans, disturbance agents and the impact of climate change all contribute to changes in intra-specific variability, species diversity and ecosystem variety (McKinney 2002).

Studies on biological diversity in Bangladesh, one of the world’s most densely populated countries, are incomplete, not comprehensive and ignore the role of human impacts. The forests are subject to heavy pressure in terms of wood production and competing land uses. Due to the high population density and uneven distribution of land (60% of people are landless), natural resources are overexploited (World Bank 2004). Forest cover is 10% (FAO 2005), with a deforestation rate of 3.3% per year (BBS 2004). The Madhupur Sal (Shorea robusta C.F. Gaertn) forests of Bangladesh have long 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 and fodder plants) (Salam et al. 1999). Natural Sal forests have become endangered due to the practices of shifting cultivation and introduction of exotic species (Gain 1998). More than 66% of the total area of these forests is currently in the possession of encroachers, who rely heavily on the provision of wood and non-wood products (Hassan 2004). Although the Madhupur Sal forests are protected, logging is common (Alam et al. 2008). As a reaction to the conflicting land-use interests, in 1989 the government initiated agroforestry programmes and the introduction of exotic species (Alam et al. 2008).

The massive destruction of these forests coincides with our limited knowledge of their composition, species richness, structure and regeneration pattern compared to those in India and Nepal. Sal occurs in various forest ecosystems on the southern slopes of the Himalaya 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). The Terai (lowlands) is the main Sal growing region in Nepal (Webb and Sah 2003; Timilsina et al. 2007). Sal forests in Bangladesh are mainly located in the central part of the country, and described by Alam (1995) as tropical moist deciduous forest. There are many studies on the vegetation of the Sal forests of Nepal and India (Shankar 2001; Pandey and Shukla 2003; 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).

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However, most of studies of Nepal and India have been conducted on gentle to steep slopes at higher elevations. For Bangladesh, a large-scale inventory of the plant diversity of Sal forests of the lowland plains is unavailable, even though ongoing human impacts are threatening these ecosystems. Past research has focused on listing the available plant species in these forests (Alam 1995; Rashid and Mia 2001; Choudhury et al. 2004) and on their horizontal structure (Pandey and Shukla 2003; Webb and Sah 2003; Timilsina et al. 2007). There has been no comprehensive study on Sal forest of the lowland plains, focusing on diameter and height distributions and on compiling a complete list of plant presence. Coarse woody debris plays a vital role in the biological diversity and structure of forest ecosystems (Harmon et al. 1986; Rahman et al. 2008). Thus, for a better understanding of the diversity of Sal forests, it is also important to analyse coarse woody debris. However, findings on the levels of coarse woody debris in tropical forests are limited (Grove 2001; Chandrashekara and Sibichan 2006). Taking these research gaps into consideration, the present study describes the plant diversity and anthropogenic disturbances, as well as their impacts, on ecosystems of the Sal forests of Bangladesh. The objectives of the study were: (i) to examine species richness of these ecosystems; (ii) to identify impacts of different anthropogenic disturbances on biological diversity; and (iii) to observe variations in different ecosystem characteristics (e.g. regeneration status, coarse woody debris level) along disturbance gradients.

**Study area**

The study was conducted in the Madhupur Sal forests (locally known as Madhupur Garh), the largest belt of Sal forests in Bangladesh. These forests are found on slightly elevated areas, never exceeding 15 m above the surrounding floodplain. Sal is the dominant species and usually forms 25%–75% of the upper canopy (Alam 1995). The forests also contain many other valuable natural tree species, known as Sal associates (Hassan 2004). The area is located between 23°50’–24°50’ N and 89°54’–90°50’ E (Figure 1). The soil is a highly oxidized, reddish brown clay containing ferruginous nodules and manganese spots, belonging to the bio-ecological zone of the Madhupur Sal Tract (Nishat et al. 2002). The soils have a moderate to strong acidic reaction (Richards and Hassan 1988) and are characterised by low organic matter and low fertility (Alam 1995). Following Thorntwaite’s principles, the Madhupur Sal growing region is included in the humid region (Ismail and Mia 1973). According to the Bangladesh Meteorological Department (BMD 2008), the climatic characteristics of this region over the past 30 years are: annual rainfall from 2030–2290 mm; annual temperature from 10–34°C; humidity between 60 and 86%; daily sunshine of 5–9 h; average maximum wind speed of 16 km/h.

The forests are fragmented by an intricate network of depressions, creating a honeycomb pattern (Farooque 1997). The depressions are generally cultivated for 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 have been cleared or are in the possession of 88,000 encroachers (Hassan 2004).

**Methodology**

The human disturbances in the Madhupur Sal forests are so multidimensional that a single parameter cannot adequately express the disturbance level. 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 human disturbance level. In the present study, the forests were classified as low, medium and highly disturbed on the basis of historical and present human impacts. These classes are defined as follows: (i) low disturbed – highly protected core area, very small fragments of natural patches; (ii) medium disturbed – core area, but not much protected and forest regenerated naturally after clearcutting; and (iii) highly disturbed – agroforestry, woodlot plantation, rubber plantation and eucalyptus plantation.

Only harvesting 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, such as 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 considered as equally important as no study on the comparative impacts of those elements exists. Very highly disturbed plots, which had no tree cover or no natural species at all, where the forest had been converted into bare unproductive land, rice fields, fallow land, mustard garden, banana garden or pineapple garden, were not considered for investigation.

The study was carried out in 2006 and 2007. A total of 180 plots were selected on transects, each starting on the road at a distance of 200 m from the last intersection of two roads. Due to the presence of depressions in the landscape, forest gaps or bare land it was not always possible to establish plots at a regular spacing. In areas with more or less closed forest cover, plots were examined every 100 m, but in fragmented forest, the next plot was from 100 to 200 m along the transect. At least 60 plots from each disturbance category (low–medium–high) were purposefully selected. The area of each circular plot was 60 plots from each disturbance category (low–medium–high) were purposefully selected. The area of each circular plot was 300 m² (radius = 9.77 m) and was used for investigation of mature trees (>10 cm dbh), coarse woody debris (>5 cm dbh and >1.37 m height), supplings (5–10 cm dbh), climbers and herbs. Within the 300 m², a subplot of 100 m² (radius = 5.64 m) was used for the inventory of large seedlings (>30 cm height and <5 cm dbh), and another subplot with a
Figure 1. Map of the study area (black shaded areas are forest land).
Table 1. Disturbance level and disturbance index for low, medium and highly disturbed forest sites of the Madhpur 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 CDI $= (1/6) \sum_{i=1}^{6} W_i$ | Felling No 0 PDI $= W_p$ | $DI = CDI + PDI$ | 0–140 |
| SC Very low 20 where, $W_i$ is the weight of | Partly 10 weight of past | |
| LS Low 40 $i$th ($i = 1, 2 \ldots 6$) element | Medium 20 disturbance element | |
| AG Medium 60 | Heavily 30 | |
| SD High 80 | Clear 40 | |
| SF Very high 100 | | |

Note: 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, $W_c$: Weighing of current elements, $W_p$: Weighing of past elements, CDI: Current disturbance index, PDI: Past disturbance index.

Results
Species richness, composition and rarity
Species–area curves indicated that the investigations in the three disturbance categories 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 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 20 plots (Figure 2). A total of 134 species were recorded: 70 tree species, 15 shrub species, 26 climber species and 23 herb species (Table 2). Of the 57 mature tree species, only two were common to all three categories. The number of mature natural tree species was greatest in the low disturbed forest type (52), followed by the medium disturbed (five) and then the highly disturbed forest type (two) (Table 3).

Of the 65 tree species in the low disturbed forest type (including tree species currently regenerating), 59 undergo natural regeneration (93% of the total number of natural species). All of the 31 tree species in the medium disturbed forest type were also regenerating. In the low disturbed forest type, 14 species (24% of the total number of tree species) showed good regeneration, while this was only true for two species (6%) in the medium disturbed forest type. Only one of the two natural tree species in the highly disturbed forest type showed very poor regeneration. 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%), and only one natural species 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).
and basal area (m²/ha) of mature trees was significantly higher in the low disturbed forest type, followed by the medium disturbed forest type. The density (N/ha) of mature trees and the basal area of standing coarse woody debris in the highly disturbed forest type exceeded 35 m (Figure 4). The tree height distributions showed a tendency towards normal distribution. The height of mature trees in both the medium and highly disturbed forest types ranged from 10 to 30 cm. Giant trees (DBH > 30 cm) were found (5 trees/ha) only in the low disturbed forest type (Figure 3). The tree height distributions showed a tendency towards normal distribution. The height of mature trees in both the medium and highly disturbed forest types did not exceed 25 m, whereas tree height in the low disturbed forest type exceeded 35 m (Figure 4). The density and basal area of standing coarse woody debris in the low disturbed forest type were 4.4 N/ha and 0.14 m²/ha, respectively. This was equal to 0.76% of the density of 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.

Diversity
There was a highly significant negative correlation between the disturbance index and the Shannon–Wiener diversity index for all plant groups. In contrast, the disturbance index had a significant positive correlation with the dominance index. Linear regression indicated that, with an increase of disturbances, evenness decreased significantly for saplings and large seedlings (Table 4). The least significant difference (LSD) indicated no significant difference for the diversity index of mature trees between the medium and highly disturbed forest types. ANOVA and LSD showed that the dominance index varied significantly among all forest sites and forest types (Table 5). The evenness of mature trees, 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).

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 chapadasha, Mallotus philippensis, Terminalia bellirica, Milusia roxburghiana, Dillenia pentagyna, Lannea coromandelica, Ficus benghalensis, Bursera serrata, Smilax macrophylla and Calamus tenuis. The diameter distributions of the sampled trees in all individual plots in all forest types followed a reverse J-shaped distribution. Diameter at breast height (DBH) and tree density were inversely related. With few exceptions, DBH of the medium and highly disturbed forest types ranged from 10 to 30 cm. Giant trees (DBH > 100 cm) were found (5 trees/ha) only in the low disturbed forest type (Figure 3). The tree height distributions showed a tendency towards normal distribution.

Note: *Including introduced tree species, L = low disturbed, M = medium disturbed and H = high disturbed.
Table 3. Density (N/ha), basal area (m²/ha) and importance value index (IVI) of the listed 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 | 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 Wild.*           | Mangium     | –        | –        | 0.6 ± 4.3 | – | – | 0.01 ± 0.10 | – | – | 5.00 |
| Acacia montiflora Griseb.*      | Akashmoni   | –        | –        | 37.2 ± 93.3 | – | – | 0.49 ± 1.26 | – | – | 49.55 |
| Adina cordifolia (Roxb.)        | Haldu       | 4.4 ± 15.6 | –        | –   | 0.19 ± 0.88 | – | – | 2.77 | – | – |
|                                |             |          |          |      |          |          |   |          |    |    |
| Albtia chinensis (Osbeck) Merr. | Cheshara    | 1.1 ± 8.4 | –        | –   | 0.03 ± 0.27 | – | – | 0.54 | – | – |
| Albtia 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 | – | – |
| Annona retusa (Roxb.)           | 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 variegate 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 pentagona Roxb.        | Ajuli       | 17.8 ± 24.9 | –        | –   | 1.12 ± 2.86 | – | – | 12.10 | – | – |
| Diospyros corinifolia Roxb.     | Tamal       | 0.6 ± 4.3  | –        | –   | 0.04 ± 0.29 | – | – | 0.44 | – | – |
| Dipterscarpus 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.                | 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.*     | Gaman       | –        | –        | 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 kotschyi Vahl.           | Khilaladomar | 2.2 ± 8.4 | –        | –   | 0.04 ± 0.17 | – | – | 1.49 | – | – |
| Grewia microcosm L.             | Datoi       | 11.1 ± 29.2 | –        | –   | 0.21 ± 0.71 | – | – | 5.29 | – | – |
| Holarrhena pubescens            | Kurchi      | 1.1 ± 6.0  | –        | –   | 0.02 ± 0.13 | – | – | 0.75 | – | – |
| (Buch.-Ham.) Wall. Ex G. Don    |             |          |          |      |          |          |   |          |    |    |
| Hymenodictyon exsulcsum         | Bhutum      | 6.1 ± 14.4 | –        | –   | 0.32 ± 0.85 | – | – | 4.16 | – | – |

(Continued)
| Botanical Name | Local Name       | L (Mean ± SD) | M (Mean ± SD) | H (Mean ± SD) | Density (Mean ± SD) | Basal area (Mean ± SD) | IVI |
|---------------|------------------|---------------|---------------|---------------|---------------------|------------------------|-----|
| Lagerstroemia  | Shida            | 3.3 ± 10.1    | –             | –             | 0.29 ± 1.06         | –                      | 2.84| – |
| parviflora (L.) Roxb. |         |               |               |               |                     |                        |     |   |
| Lannea coromandelica | Jiga         | 15.6 ± 20.8   | –             | –             | 1.09 ± 2.40         | –                      | 11.59| – |
| (Houtt.) Merr. |                  |               |               |               |                     |                        |     |   |
| Litsea glutinosa (Lour.) | Kukurchita | 0.6 ± 4.3     | –             | –             | 0.01 ± 0.05         | –                      | 0.36 | – |
| C.B. Rob. |                  |               |               |               |                     |                        |     |   |
| Litsea monopetala (Roxb.) Pers. | Kharajora | 2.2 ± 8.4     | –             | –             | 0.12 ± 0.63         | –                      | 1.70 | – |
| Madhuca longifolia (L.) | Mohaya       | 1.7 ± 7.3     | –             | –             | 0.04 ± 0.18         | –                      | 1.13 | – |
| Mach. |                  |               |               |               |                     |                        |     |   |
| Mallotus philippensis | Shindhuri | 35.6 ± 42.5   | 2.8 ± 12.7    | –             | 0.71 ± 1.07         | 0.03 ± 0.14            | 16.26| 9.08|
| (Lamk.) Muell.-Arg. |            |               |               |               |                     |                        |     |   |
| Melia azedarach L.* | Bokain      | –             | –             | 37.8 ± 99.4   | –                   | –                      | – | 47.81|
| Milliusa rotundifolia (Wall. Ex Griff.) | Gandhigajari | 7.8 ± 14.2 | –             | –             | 0.45 ± 1.07         | –                      | 6.01 | – |
| (Wall.) f.&Thoms. |                  |               |               |               |                     |                        |     |   |
| Oroxylum indicum (L.) Vent. | Kanadinda | 2.2 ± 8.4     | –             | –             | 0.03 ± 0.13         | –                      | 1.46 | – |
| Polyalthia longifolia | Debana       | 0.6 ± 4.3     | –             | –             | 0.07 ± 0.57         | –                      | 0.54 | – |
| (Sonn.) Thwaites |                  |               |               |               |                     |                        |     |   |
| Schleichera oleosa (Lour.) | Joina | 7.2 ± 13.8    | –             | –             | 0.32 ± 0.79         | –                      | 5.54 | – |
| (L.) Oken |                  |               |               |               |                     |                        |     |   |
| Semecarpus anacardium L.f. | Behula | 13.9 ± 21.5   | –             | –             | 0.53 ± 1.14         | –                      | 8.82 | – |
| Schorba 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 |
| Sterculia villosa Roxb. | Udhal        | 1.7 ± 9.6     | –             | –             | 0.02 ± 0.14         | –                      | 0.86 | – |
| Stereospermum suaveolens | Bonsonala  | 1.1 ± 6.0     | –             | –             | 0.02 ± 0.12         | –                      | 0.74 | – |
| (Roxb.) DC. |                  |               |               |               |                     |                        |     |   |
| Sterculia asper Lour | Sheora       | 2.8 ± 9.3     | –             | –             | 0.06 ± 0.26         | –                      | 1.88 | – |
| Terminalia arjuna | Arjun        | –             | –             | 5.0 ± 20.2    | –                   | 0.05 ± 0.23            | – | 9.99|
| (Roxb. ex DC) Wight & Am.* |         |               |               |               |                     |                        |     |   |
| 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            | 15.79 | 6.43 | 13.48 |
| Toona ciliate M.J. Roem. | Rongi      | 0.6 ± 4.3     | –             | –             | 0.05 ± 0.35         | –                      | 0.47 | – |
| Vitex agnus-castus 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 | – |
131 species (28 trees, 10 shrubs, 6 climbers and 87 herbs) in forests of India and Nepal. Webb and Sah (2003) listed 159 (26 climbers and 23 herbs) as comparable to other studies in Sal Ghats of India. In the present study, all herbs having less than 24 ha in the Eastern Terai of India. Shankar (2001) examined 87 species (≥10 cm dbh) on 2 ha 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 elevation (250–400 m altitude), moist deciduous forest in the Western Ghats of India. In the present study, all herbs having less than 1% forest floor cover (<3 m² cover of the forest floor) were not considered during data investigations due to the sampling design (to reduce the time of data collection and probability of

### Table 4. Linear relationship between disturbance index and diversity indices.

| Relationship between | MT | Sapling | LS | SS | Shrub | Climber | Herb |
|----------------------|----|---------|----|----|-------|---------|------|
| Disturbance index (y) and Species richness (x) | -0.86*** | -0.55*** | -0.81*** | -0.67*** | -0.90*** | -0.87*** | -0.80*** |
| Disturbance index (y) and Diversity index (x) | -0.87*** | -0.74*** | -0.75*** | -0.68*** | -0.85*** | -0.87*** | -0.73*** |
| Disturbance index (y) and Dominance index (x) | 0.86*** | 0.79*** | 0.78*** | 0.68*** | 0.83*** | 0.85*** | 0.65*** |
| Disturbance index (y) and Evenness (x) | -0.12ns | -0.89*** | -0.33** | -0.14** | -0.03ns | -0.16ns | 0.16ns |

Note: ***p = 0.000, **p < 0.01, ns (not significant), MT (Mature tree), LS (Large seedling), SS (Small seedling).

### Table 5. Average (arithmetic mean ± SE) values of diversity indices and parameters of stand characteristics of three forest types (low–medium–high disturbance).

| Parameters | Plant group | Low | Medium | High | ANOVA |
|------------|-------------|-----|--------|------|-------|
| Density (N/ha) | Mature tree | 526 ± 19a | 136 ± 26b | 192 ± 17b | 98.6 ± 0.000 |
| | Sapling | 177 ± 17 | 1359 ± 51 | 0 | 596.4 ± 0.000 |
| | Large seedling | 1908 ± 114 | 337 ± 35 | 219.4 ± 0.000 |
| | Small seedling | 3197 ± 225 | 2029 ± 194 | 84.4 ± 0.000 |
| | Shrub | 4481 ± 269 | 2571 ± 117 | 175.0 ± 0.000 |
| | Climber | 247 ± 14 | 78 ± 5 | 208.6 ± 0.000 |
| BA (m²/ha) | Mature tree | 36.6 ± 3.40a | 1.8 ± 0.40b | 3.4 ± 0.40b | 96.9 ± 0.000 |
| | Sapling | 1.52 ± 0.06a | 0.05 ± 0.03b | 0.06 ± 0.02b | 450.6 ± 0.000 |
| | Large seedling | 0.89 ± 0.07 | 0.38 ± 0.03 | 26.5 ± 0.000 |
| | Small seedling | 1.10 ± 0.04 | 0.48 ± 0.06 | 26.2 ± 0.000 |
| | Shrub | 1.16 ± 0.08 | 0.78 ± 0.08 | 38.16 ± 0.000 |
| | Climber | 1.35 ± 0.04 | 0.55 ± 0.07 | 57.43 ± 0.000 |
| | Herb | 1.43 ± 0.04 | 0.58 ± 0.06 | 81.9 ± 0.000 |
| | Mature tree | 1.10 ± 0.04 | 0.87 ± 0.03 | 57.6 ± 0.000 |
| | Sapling | 0.97 ± 0.01b | 0.96 ± 0.02b | 454.0 ± 0.000 |
| | Large seedling | 0.83 ± 0.01 | 162.9 ± 0.000 |
| | Small seedling | 0.44 ± 0.02 | 69 ± 0.04 | 20.2 ± 0.000 |
| | Shrub | 0.53 ± 0.03 | 0.54 ± 0.04 | 45.7 ± 0.000 |
| | Climber | 0.39 ± 0.03 | 1.00 ± 0.00 | 46.5 ± 0.000 |
| | Herb | 0.50 ± 0.02b | 0.52 ± 0.02b | 42.8 ± 0.000 |
| | Mature tree | 0.82 ± 0.02 | 0.32 ± 0.02 | 301.5 ± 0.000 |
| | Sapling | 0.82 ± 0.02 | 0.92 ± 0.02 | 6.7 ± 0.002 |
| | Large seedling | 0.99 ± 0.02 | 0.98 ± 0.01 | 9.9 ± 0.424 |
| | Small seedling | 0.83 ± 0.02 | 0.76 ± 0.05 | 1.5 ± 0.222 |
| | Shrub | 0.94 ± 0.01 | 0.96 ± 0.01 | 1.3 ± 0.281 |
| | Climber | 0.65 ± 0.01b | 0.65 ± 0.01b | 20.7 ± 0.000 |
| | Herb | 0.79 ± 0.02a | 0.57 ± 0.01b | 3.6 ± 0.033 |
| | Sapling | 0.57 ± 0.01b | 0.76 ± 0.10ab | 3.6 ± 0.033 |
| | Large seedling | 0.32 ± 0.02 | 301.5 ± 0.000 |
| | Small seedling | 0.92 ± 0.02 | 6.7 ± 0.002 |
| | Shrub | 0.98 ± 0.01 | 9.9 ± 0.424 |
| | Climber | 0.76 ± 0.05 | 1.5 ± 0.222 |
| | Herb | 0.96 ± 0.01 | 1.3 ± 0.281 |
| | Mature tree | 1.00 ± 0.00 | 20.7 ± 0.000 |
| | Sapling | 0.65 ± 0.01a | 1.00 ± 0.00 | 3955.8 ± 0.000 |

Note: Means within columns followed by the same letter or letters (a–c) are not significantly different (p < 0.05), by LSD; BA = Basal area

### Discussion

It is often observed that increased fragmentation of natural habitats by human disturbances leads to reduced species richness, and that many variables cause species loss along that gradient (McKinney 2002). The species richness on the total area of the plots of 5.4 ha (134 plant species: 70 tree, 15 shrub, 26 climber and 23 herb) was comparable to other studies in 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 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 in the Eastern Terai of India. Shankar (2001) examined 87 species (≥10 cm dbh) on 2 ha 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 elevation (250–400 m altitude), moist deciduous forest in the Western Ghats of India. In the present study, all herbs having less than 1% forest floor cover (<3 m² cover of the forest floor) were not considered during data investigations 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 herb 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), Shankar (2001), and Webb and Sah (2003). The mean basal area (36.6 m²/ha) of the low disturbed forest type 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 32 m²/ha (Dawkins 1959). It is important to mention that 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 sample plots with minimum tree cover were considered for data investigation; open areas were ignored. On the other hand, the presence of a few giant trees of Ficus benjamina and Artocarpus chapa-lasha 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 m²/ha), was similar to results of studies in the low disturbed and natural Sal forests (11.8 m²/ha) of the central Terai of Nepal (Webb and Sah 2003).

S. robusta dominated all categories of disturbance. In the highly disturbed forest type, Sal was dominant over the

Table 6. List of all shrub and climber species encountered and their density (mean ± SD) in low, medium and highly disturbed forest types.

| Botanical name | Local name | Low | Medium | High |
|----------------|------------|-----|--------|------|
| Shrub          |            |     |        |      |
| Ageratum sp.   | Fulkhari   | 31.7 ± 132.1 | – | – |
| Antidesma acidum Retz. | Chutkigota | 15.0 ± 86.0 | – | – |
| Barleria lapulina Lindl. | Bishkhatali | 498.3 ± 624.7 | 20.0 ± 89.8 | – |
| Bauhinia malabarica Roxb. | Chokoi | 100.0 ± 177.5 | – | – |
| Cassia sophera L. | Kalleshu | 43.3 ± 177.5 | – | – |
| Clerodendrum serratum (L.) Moon | Bhte | 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. | Bonverendra | 55.0 ± 181.7 | – | – |
| Mimosa brachybladis 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.) | Tagor | 233.3 ± 424.1 | – | – |
| R. Br. Ex Roem. & Schult. | – | – | – | – |
| Vitís negundo L. | Nishinda | 15.0 ± 68.5 | – | – |
| Ziziphus rugosa Lamk. | Anaigota | 200.0 ± 234.3 | 163.3 ± 214.7 | – |
| Climer          |            |     |        |      |
| Asparagus racemosus Willd. | Shotomuli | 6.1 ± 20.8 | – | – |
| Bauhinia vahili Wight et Arn. | Bidipata | 6.1 ± 20.8 | – | – |
| Caesalpinia nodulifera F. | Nata karanji | 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. | Kemyakanthali | 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 hispidoiden Dennst. | Bishalu | 3.3 ± 20.1 | – | – |
| Dioscorea pentaphylla L. | Jhumali | 5.6 ± 13.9 | – | – |
| Dioscorea tomentosa Koen. Ex Spreng. | Shuorialu | 4.4 ± 13.0 | – | – |
| Ficus scandens Roxb. | Dumburila | 23.3 ± 38.5 | – | – |
| Ichnocarpus frutescens (L.) R. Br. | Kalidudhi | 2.2 ± 12.1 | – | – |
| Melothria maderaspatana (L.) Cogn. | Patialalau | 7.2 ± 15.1 | 1.1 ± 6.0 | – |
| Mikania cordata (Burm. f.) B.L. Rob. | Germanatalu | 3.3 ± 14.7 | 5.6 ± 13.9 | – |
| Mikania micrantha (L.) Kunth. | Assamalata | 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 | – |
| Spaltholbus parviflorus (Roxb. ex DC.) Kuntze | Goalialata | 6.1 ± 14.4 | – | – |
| Thunbergia grandiflora Roxb. | Nilata | 1.7 ± 7.3 | – | – |
| Tragia invoiculatula L. | Bishuti | 0.6 ± 4.3 | – | – |
| Trichosanthes bracteata (Lam.) Voigt | Makal | 12.2 ± 20.3 | 6.7 ± 13.4 | – |
| Vitís quadrangularis (L.) Wall. ex Wight | Harjora | 6.1 ± 14.4 | 1.1 ± 6.0 | – |
sole natural associate, without considering introduced species. The medium disturbed forest type was highly dominated by *S. robusta* and can be considered 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 derived from the restricted access of humans in comparison to the other two forest types (compare Hassan 2004).

The proportion of small seedlings, large seedlings and saplings in the low disturbed forest type indicated that natural regeneration took place adequately, despite existing competition with shrubs, climbers and herbs, as well as tree canopy closure. Gaps in the canopy created by thinning operations promoted good regeneration 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 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 small seedlings of 30 different tree species, compared to five mature tree species, indicated a high potential for natural regeneration. Although these sites had been bare for many years, seed dispersion from neighbouring mature trees in low or undisturbed forest types was sufficient to allow highly diverse regeneration. However, the absence of organic matter due to frequent sweeping of forest litter, grazing and cutting of seedlings might have decreased the density of large seedlings (Troup 1986).

The cover of herbs in the low disturbed forest type was comparatively lower than in the medium disturbed sites due to low insolation on the forest floor caused by the closed canopy (compare Nath et al. 2005). Webb and Sah (2003) reported the abundance of shrubs and climbers increased with a decrease of regeneration density and by gap creation. However, in the present study, the density of shrubs and climbers was higher in the low disturbed forest type than in the medium disturbed site. It appears 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 are not congruent for growing ground flora such as herbs, shrubs and climbers, or for regeneration, in the highly disturbed forest type. Heavy soil disturbances from tillage operations, cultivation of agricultural crops between forest plantations and introduction of fast-growing tree species have degraded the habitat for natural regeneration in the highly disturbed forest type (compare Rahman et al. 2007).

There was less coarse woody debris (CWD) in the low disturbed forest type than in other tropical forests of India (Nath et al. 2005; Chandrashekar and Shibchan 2006). To date, there is no reference level of CWD for sub-continental tropical forests, and even CWD status in tropical forests of the world has gone largely unreported (Grove 2001). Due to the scarcity of fuelwood, local people cut trees immediately after their death. CWD has become an important indicator in determining the degree of naturalness of a forest ecosystem (Kowarik 1995; Grabher et al. 1998). 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 aboveground biomass (Nilsson et al. 2002) or about 40% of the volume of

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**Figure 3.** Diameter distribution of mature trees in the three forest types.

**Figure 4.** Height distribution of mature trees in the three forest types.
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 (Büttler et al. 2004). Along with the lack of CWD, human disturbance has caused the disappearance, or red-listing, of most of the birds, mammals, reptiles, and amphibians of this region (Kabir and Ahmed 2005; Alam et al. 2008).

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 (McKinney 2002). Various studies have documented how succession increases species diversity in ruderal and managed communities (e.g. Crowe 1979). It has been stated that 30–40 years are required for tropical forests to return to the diversity level before the last clear cut (Webb and Fa’amau 1999; Webb and Sah 2003). It can therefore be predicted that the medium disturbed site could return to the diversity level of the low disturbed site within the next 20 years – if destruction of regeneration and 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 successful seed dispersion. Consequently, 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, 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 coppicing from root suckers providing 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. common species more abundant and uncommon species absent) and possibly reducing richness. In this study, the regeneration potential 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 among the richest ecosystems of Bangladesh in terms of forest diversity. However, the level of diversity is generally unknown to the scientific community, politicians and local people and is, therefore, not well documented. The forests face severe threats from disturbance by people 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 forests 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, providing an insight to the state of species richness at different disturbance intensities. Moreover, the findings 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 Sal forest ecosystems will also help the country implement international legal instruments, such as the Convention on Biological Diversity.

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