A case of high tree diversity in a sal (*Shorea robusta*)-dominated lowland forest of Eastern Himalaya: Floristic composition, regeneration and conservation

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A seasonally dry, sal (*Shorea robusta*)-dominated forest in the Eastern Himalayan lowlands of the Mahananda Sanctuary, Darjeeling had a far greater species richness (87 species in ≥ 10 cm and 69 species in ≥ 30 cm girth class) and diversity than other sal forests in India. Euphorbiaceae, with 8 species, was the most speciose family followed by Lauraceae, Meliaceae and Leguminosae. Dispersion of species was either clumped or random, and only two species were uniform. Rare species (≤ 1 stem ha^{-1}) constituted 36% of the flora and were randomly distributed. Tree species dominated the flora with 87.3% share. Mixed dominance of species groups prevailed in the forest, i.e. large, medium and small trees and shrubs shared stand density in nearly equal proportions, but climbers were less abundant. Among five most abundant species, none was a large tree. However, four of the five species accumulating maximum basal area were large trees. All the girth classes showed a multi-species dominance, with 21 species in mature (≥ 180 cm girth), 40 in elder (≥ 90 to < 180 cm), 55 in young (≥ 30 to < 90 cm), and 68 in juvenile class (≥ 10 to < 30 cm). Six species were available only in seedling layer (≥ 30 cm height to < 10 cm girth). Thus of all 93 species, 20.4% showed good regeneration, 10.8% fair, 30.1% poor and 17.2% lacked regeneration. The remaining 21.5% species seem to be reappearing. While high-grade timber species were poorly regenerating, shrubs and climbers were regenerating well. Despite legal protection, this diverse sal forest continually experiences anthropogenic interference by the inhabitants on fringes. Rare species that contribute maximum to the tree diversity are at high risk of local extinction.

TROPICAL deciduous forests occur under varied climatic conditions, but essentially with alternate wet and dry periods. The structure and composition of deciduous forests change with the length of wet period, amount of rainfall, latitude, longitude and altitude. Phytosociological patterns in Indian deciduous forests are not well-known. Darjeeling district in Eastern Himalaya, encompasses a variety of forests that have been used for centuries and managed for decades[1–4]. In Darjeeling 'terai' (Himalayan lowland), the forests are tropical, deciduous and seasonally dry, despite > 3000 mm of annual rainfall. Champion and Seth[3] classified these forests under very moist sal (*Shorea robusta* Gaertn.)-bearing forest ($_3C/C_1$) to moist mixed deciduous forest without sal ($_3C/C_3$). Information on deciduous forests in India as well as abroad is available mostly from the sites experiencing < 2000 mm rainfall.

Deciduous forests are not considered species-rich[5], but have a diversity of life forms[6]. Still these forests assume unusual significance for conservation since they are the most used and threatened ecosystems[7], especially in India. For instance, early foresters focused on only a few valuable timber species[1]. Importance of all other species in maintaining ecosystem structure and function was neglected. The natural forest was narrated as 'irregular mixed forest' and thus converted into a regular, normal and even-aged forest of valuable species, in order to improve the quality and quantity of future yields[8]. Consequently, 'taungya' conversions with teak and cinchona occurred on a large scale. However, 'taungya' dramatically alters landscape, interrupts recovering ecosystem structure and causes considerable loss of species[4]. Currently, sal forests are mostly restricted to the protected area network, since vast tracts of forested land in 'terai' have been cleared for agriculture, human settlements and developmental activities. The anthropogenic pressure continues to degrade the natural patches in spite of stringent forest laws, rigorous management policy and best efforts of the Forest Department towards conservation.

Sal forest in Darjeeling 'terai' is markedly different from its counterparts in Central Himalaya and the tropical deciduous forests widely spread in India. The proportion of sal is lesser in this forest compared to other sal forests. The deciduous phase is short and vertical stratification is remarkable. The aim of this paper is to delineate phytosociological attributes of a sal forest in Darjeeling 'terai' and compare them with other counterparts. Three specific

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hypotheses are examined: (a) species diversity is high compared to other deciduous forests in the country; (b) randomly dispersed rare species enhance species diversity; and (3) regeneration of the constituent species is adequate.

Study area

Mahananda Wildlife Sanctuary in Darjeeling district, West Bengal expands between 26°46′ to 26°56′E lat. and 88°20′ to 88°32′N long. covering an area of about 158 km² (Figure 1) The altitude ranges from 100 to 1700 m amsl, harbouring a mosaic of vegetation types. This study pertains to a seasonally dry, sal-dominated forest at the junction of Jogijhora and Upper Champasari blocks. The canopy is fairly close, with nearly 80% crown cover. Sal can attain up to 40 m height, and the other emergent species up to 35 m. The forest represents a pre-climax state maintained by surface burning, which sal and associate species can withstand.

Average annual rainfall in recent years has been 3344 mm (average from 1990 to 1994) that has not changed considerably from 3484 mm in the past (average from 1956 to 1965). Approximately 93% of annual precipitation occurs during the wet period (May to October), distributed over 102 rainy days and the balance (7%) during the dry period (November to April), distributed over 17 rainy days. Relative humidity is high (70–100%) all year round.

The geology of the sanctuary is extremely complex. There are four distinct orders of rock formations: (1) recent to sub-recent and Pleistocene, (2) Miocene (Siwaliks), (3) Permian (Damuda series of Lower Gondwana), and (4) Archaeans (Daling series and Darjeeling Gneiss). The Siwalik rock formations comprising of micaceous and arkosic sandstone, bluish and greyish siltstones, conglomerates and pebble beds are prevalent around study plots. The soils over these rocks are sandy and poorly developed. The soil is coarse and pale yellow in sand rock areas to fine and red in sandstone areas. These soils support gregarious growth of sal.

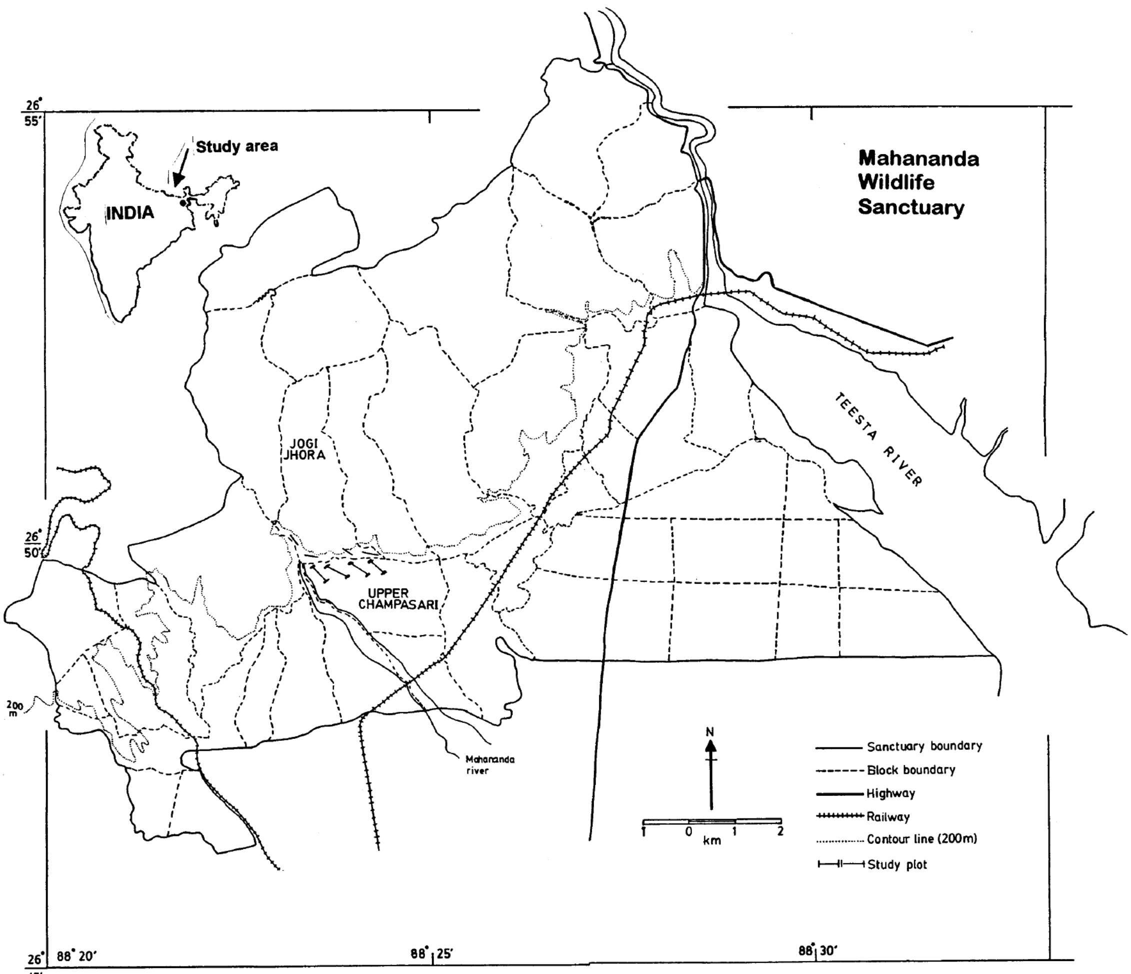

Figure 1. Geographical location of transects at the junction of Upper Champasari and Jogijhora blocks in Mahananda Wildlife Sanctuary in Darjeeling district.

Methodology

The woody vegetation was sampled in 1994–1995 at three levels, namely adult, sapling and seedling. Adults exhibited ≥ 30 cm girth (gbh) over bark at breast height (1.3 m). Saplings included all individuals ≥ 10 cm to < 30 cm girth. The seedling class composed of the individuals with ≥ 30 cm height, but < 10 cm girth. Four 10-m wide and 500-m long transects were laid along the slope, with each transect covering an area of 0.5 ha, and the total sampling area being 2 ha (Figure 1). A transect encompassed five 100-m long contiguous sub-plots, with each sub-plot covering an area of 1000 m^2.

Both adults and saplings (i.e. all individuals ≥ 10 cm girth) were sampled in the entire 2 ha area. For each individual, the girth was measured at 1.3 m height from the ground level and the height was measured to the nearest metre, using a clinometer. The physical condition of every individual was noted under live and dead categories. The live categories involved all the individuals that were healthy, lopped, partly broken at the top or were partly dry. The dead category included all the individuals that were standing dead, completely dry, logged, and fallen (green or dry) by wind-breaks or elephants. The seedlings were sampled by laying a 2 m × 2 m quadrat in the centre of each sub-plot. Thus, twenty quadrats accounted for 80 m^2.

The species sampled in the three layers of vegetation were classified into the following five growth forms, namely large tree, medium tree, small tree, shrub and woody climber. All the emergent species were grouped under large trees. Medium trees included species that are found in subcanopy. The species that are shade-loving, prevalent in understorey and do not cross 15 m height were labelled as small trees. The species that are characterized by short stature, armed and irregular multiple stems and spiny structures (thorns and prickles) were classified as shrubs. Several climber species are common in this forest. However, we enumerated only those woody climbers that attained a girth of at least 10 cm. For the girth measurement of climbers, breast height was not recorded.

Frequency, density, basal area and importance value index (IVI) were determined for each species following Mueller-Dombois and Ellenberg[9]. Shannon's diversity index was calculated following Magurran[10], and evenness index following Pielou[11]. The dispersion of species was studied by variance-to-mean ratio at the scale of 1000 m^2 plots[12]. A ratio of 1.0 indicates a random dispersion, < 1 a uniform dispersion and > 1 an increasingly clumped dispersion. A value close to 1, but not significantly different from it, was considered as near random. The population structure was studied by tallying species, individuals and basal area in four girth (gbh) classes, namely juvenile (≥ 10 to < 30 cm), young (≥ 30 to < 90 cm), elder (≥ 90 to < 180 cm) and mature (≥ 180 cm).

The state of regeneration of sampled species was assessed based on one-time phytosociological data[13] in the following categories: (a) 'good', if seedling > sapling > adult; (b) 'fair', if seedling > sapling ≤ adult; (c) 'poor', if a species survives in only sapling stage, but not as seedlings (though saplings may be less, more or equal to adults); (d) 'none', if a species is absent both in sapling and seedling stages, but present as adults; and (e) 'new', if a species has no adults, but only saplings and/or seedlings.

Results

Of 1015 individuals inventoried in four transects of 0.5 ha each, 95.4% were live and 4.6% were dead (Table 1). About 3.5% of live individuals were damaged at the top, either due to windfall or lopping. Among the dead individuals, 44.7% were standing dead, 32.3% had fallen on the ground following death, and elephants and/or firewood collectors had felled 17%. The coefficient of variation among transects was about 16.6% for total individuals. For all further analyses, only live individuals will be considered.

Table 1. Transect-wise distribution of individuals ≥ 10 cm girth in live and dead categories

Category	Transect 1	Transect 2	Transect 3	Transect 4	Mean ± SD
Live					
Normal	285	240	203	206	233.5 ± 38.2
Top damaged	12	12	6	4	8.5 ± 4.1
Dead					
Standing dead	6	9	2	4	5.3 ± 3.0
Dead fallen	0	5	4	9	4.5 ± 3.7
Green fallen	4	2	2	0	2.0 ± 1.6
Total live	297	252	209	210	242.0 ± 41.8
Total dead	10	16	8	13	11.8 ± 3.5
Total live + dead	307	268	217	223	253.8 ± 42.2

Each transect was 500 m long and 10 m wide, covering an area of 0.5 ha.

Family dominance

Of 968 individuals, 959 were identified to species level. The 9 unidentified individuals belonged to 4 species that could be identified by local names only. The identified individuals belonged to 42 families and 9 unidentified individuals were classified under 'family undetermined' (Table 2). Taxonomic diversity at family level was high; as much as 25 families were represented by one species only. Among others, 8 families had two species, 4 families three species, 3 families four species, 2 families seven species and 1 family eight species. Euphorbiaceae (8 species) and Lauraceae and Meliaceae (7 species each) were the most dominant families in terms of species richness, jointly accounting for 25.2% of the total species. These families were also dominant in terms of the number of individuals (44.6%), basal area (26.5%) and importance value (36.6%). Of 22 species in the three dominant families, 20 were trees (8 large, 8 medium and 4 small) and 2 shrubs. Leguminosae as a pool of Caesalpinoideae, Mimosoideae and Papilionatae was also one of the most speciose families, with 7 species but with only 3% individuals. Vitaceae by the virtue of *Leea* sp. dominated understorey, with 15.6% of the total individuals (Table 2). A large part of the basal area (43%) was accounted by the following six families: Dipterocarpaceae, Dilleniaceae, Theaceae, Combretaceae, Sterculiaceae and Datiscaceae, but by the virtue of a single dominant species in each family.

Table 2. Distribution of species and individuals (≥ 10 cm girth) in different families according to their habit

Plant family	Large tree	Medium tree	Small tree	Shrub	Climber	Total
Alangiaceae	–	–	–	8	–	8
Anacardiaceae	1	3	–	–	–	4^2
Anonaceae	–	5	–	–	–	5
Apocynaceae	3	–	22^2	–	–	25^3
Bignoniaceae	13	–	6	–	–	19^2
Boraginaceae	–	2	–	–	–	2
Burseraceae	4	–	–	–	–	4
Caesalpinoideae	–	2^2	–	–	–	2^2
Capparidaceae	–	–	4	–	–	4
Combretaceae	25^3	–	–	–	27	52^4
Datiscaceae	7	–	–	–	–	7
Dilleniaceae	22	–	–	–	–	22
Dipterocarpaceae	15	–	–	–	–	15
Elaeocarpaceae	5	–	–	–	–	5
Euphorbiaceae	14^2	18	143^4	5	–	180^8
Fagaceae	8	1	–	–	–	9^2
Flacourtiaceae	–	3	–	–	–	3
Ilicaceae	–	1	–	–	–	1
Juglandaceae	5	–	–	–	–	5
Lauraceae	19^3	65^3	–	49	–	133^7
Lecythidaceae	–	8	–	–	–	8
Lythraceae	13^2	–	–	–	–	13^2
Magnoliaceae	6	7^2	–	–	–	13^3
Malvaceae	–	1	–	–	–	1
Meliaceae	22^3	97^4	–	–	–	119^7
Mimosoideae	–	–	–	–	1	1
Moraceae	5^2	–	1	–	–	6^3
Myristicaceae	2	–	–	–	–	2
Myrtaceae	5	–	1	–	–	6^2
Papilionatae	–	1	–	–	25^3	26^4
Rubiaceae	–	–	–	15	–	15
Rutaceae	4	–	–	–	–	4
Sabiaceae	–	2	–	–	–	2
Simarubaceae	12	–	–	–	–	12
Staphylaceae	–	3	–	–	–	3
Sterculiaceae	9	–	–	–	–	9
Symplocaceae	–	–	8	–	–	8
Theaceae	16	–	1	–	–	17^2
Tiliaceae	–	–	3	–	–	3
Ulmaceae	1	–	–	–	–	1
Verbenaceae	–	33^3	–	–	–	33^3
Vitaceae	–	–	–	151	1	152^2
Families undetermined	2	5^2	2	–	–	9^4
Total species	34	28	14	5	6	87
Total individuals	238	257	191	228	54	968

Superscript indicates the number of species, if more than one.

Species richness and diversity

The individual sample plots of 1000 m² had as few as 15 and as many as 35 species, with a mean of 21.45 ± 4.42. The total species richness was 87 (Table 3). Of this, 87.3% was trees (39% large, 32.2% medium and 16.1% small), 5.8% shrubs and 6.9% climbers. The Shannon's diversity index was 3.59 and evenness or homogeneity index was 0.80.

Density, basal area and importance value index

The stand density was 484 ha^{-1} and basal area was 26.3 m² ha^{-1} for individuals with ≥ 10 cm girth (Table 4). Growth forms, namely large, medium and small tress and shrubs, shared the density in equal proportions, but climbers were less abundant. Within each growth form, one or two species were dominant and rest of the species were rare (Table 3). However, several species within the large-tree group shared the abundance. The five most abundant species were *Leea* sp., *Mallotus philippinensis*, *Amoora rohituka*, *Litsea* sp. and *Cryptocarya floribunda*, together accounting for 43% of total stand density (Table 3). None of the species was large trees. The density of all large tree species was ≤ 11 ha^{-1}. However, large tree species accumulated most basal area and important among them are *S. robusta*, *Dillenia pentagyna*, *Schima wallichii*, *Terminalia belerica*, *Tetrameles nudiflora* and *Sterculia villosa*, together constituting 56% of the total. Twenty species (4 large, 8 medium, 4 small trees, and 4 climbers) were represented by only one individual and 11 species (5 large, 4 medium and 2 small trees) by two individuals (Table 3). All 31 species were designated as rare (≤ 1 individual ha^{-1}) and accounted for 4.1% of total individuals and 4.2% of total basal area. The individuals with ≥ 30 cm girth accounted for 69 species, 248 ha^{-1} density and 25.52 m² ha^{-1} basal area. Only seven species had an importance value ≥ 10 and *A. rohituka* topped with 26.2. Twenty-eight species had an importance value < 1 and the rest of the 52 species between 1 and 10.

Dispersion

Almost 48.3% species exhibited a clump dispersion (Table 4). Twenty species were randomly dispersed and 23 species near-randomly dispersed (Table 3). Only *T. nudiflora* and *Vitex heterophylla* had uniform dispersion. All the rare species were randomly or near-randomly distributed. The clumping of species increased with abundance. For example, the five most abundant species showed a ratio > 2, indicating high clumping. As an exception to this, three low abundance species (*Morinda citrifolia*, *Lagerstroemia parviflora* and *Terminalia tomentosa*) also showed high clumping (Table 3).

Population structure

The distribution of species and individuals in four size classes showed a nearly linear decline from juvenile through mature class (Figure 2 *a* and *b*). The distribution of basal area showed a progressive increase from juvenile through mature girth class, signifying that the small number of mature individuals accounted for a greater percentage of basal area (Figure 2 *c*). There were 21 mature, 40 elder, 55 young and 68 juvenile species, and in each class 3–4 species were dominant in terms of individuals and basal area, giving rise to a mixed dominance pattern. For instance, *S. robusta*, *S. wallichii*, *S. villosa* in mature, *D. pentagyna*, *T. belerica* and *A. rohituka* in elder, *M. philippinensis* and *C. floribunda* in young, and *Leea* sp. and *Litsea* sp. in juvenile classes were the dominant species.

Regeneration

Besides 87 species of ≥ 10 cm girth, six new species were regenerating in seedling layer (Table 3), viz. a large tree (*Chukrasia tabularis*), a medium tree (*Litsea polyantha*), a small tree (*Acronychia laurifolia*), two shrubs (*Coffea bengalensis* and Kafal), and a climber (*Millettia pachycarpa*). Of all 93 species, 20.4% showed good regeneration, 10.8% fair, 30.1% poor, and 17.2% lacked regeneration (Table 5). The remaining 21.5% seems to be either reappearing or immigrating. Climbers were either regenerating well or were making new appearance in sapling or seedling stages. Only six large tree species showed good-to-fair regeneration. Between medium and small tree species, only abundant species exhibited good-to-fair regeneration, and less abundant species were either poorly regenerating or failing. The low-grade timber species such as *M. philippinensis* and *A. wallichii* were regenerating well (Figure 2 *d* and *e*) besides a dominant shrub, *Leea* sp. (Figure 2 *f*). The high-grade timber species such as *S. robusta*, *S. wallichii* and *T. tomentosa* were poorly regenerating (Figure 2 *g* to *i*). Sal had good population of seedlings, but these were not maturing in enough numbers to juveniles and young stages.

Discussion

Being evergreen is a characteristic feature of this sal forest. Although foliage becomes markedly thin at the onset of summer, simultaneous leaf flushing never renders these forests naked. The floristic composition evinces the presence of many evergreen species, chiefly Lauraceae, Fagaceae and Magnolicaceae. The leafless period of sal is only 1–2 weeks. Most evergreen species confine to lower

Table 3. Floristic composition of individuals ≥ 10 cm girth in five species groups

Species	Local name	Family	Occurrence	Density (ha^{-1})	Basal area (cm² ha^{-1})	IVI	Variance to mean ratio	Seedling density (ha^{-1})
Large trees								
Shorea robusta Gaertn.	Sal	Dipterocarpaceae	9	7.5	33016	16.2	1.67^{C}	750^{F}
Dillenia pentagyna Roxb.	Tantri	Dilleniaceae	10	11.0	18897	11.8	1.71^{C}	0^{P}
Schima wallichii Choisy.	Chilaune	Theaceae	9	8.0	17242	10.3	1.53^{C}	0^{P}
Terminalia belerica Roxb.	Barra	Combretaceae	10	7.0	15779	9.8	1.37^{C}	0^{P}
Sterculia villosa Roxb.	Odal	Sterculiaceae	7	4.5	13191	7.6	1.28^{C}	0^{P}
Tetrameles nudiflora R.Br.	Moina	Datiscaceae	4	3.5	15079	7.4	1.89^{C}	0^{N}
Stereospermum tetragonum DC.	Parari	Bignoniaceae	9	6.5	8737	6.8	1.18^{C}	125^{F}
Amoora wallichii King	Lali	Meliaceae	10	9.5	5579	6.4	2.27^{C}	125^{G}
Zanthoxylum budrunga Wall.	Timur	Rutaceae	3	2.0	8392	4.3	1.37^{C}	125^{F}
Ailanthus grandis Prain.	Gokul	Simarubaceae	6	6.0	4278	4.3	2.18^{C}	0^{P}
Trewia nudiflora L.	Pitali	Euphorbiaceae	9	4.5	2875	4.1	0.58^{U}	0^{P}
Actinodaphne obovata Blume	Runche	Lauraceae	8	6.0	2021	3.9	1.30^{C}	0^{P}
Lagerstroemia parviflora Roxb.	Sidha	Lythraceae	5	5.5	2574	3.3	4.49^{C}	625^{G}
Castanopsis tribuloides A. DC.	Katus	Fagaceae	7	4.0	1883	3.2	0.89^{N}	0^{P}
Ficus benjamina L.	Swamy	Moraceae	4	2.0	4606	3.1	0.84^{N}	0^{P}
Terminalia tomentosa Roth.	Pakasaj	Combretaceae	3	4.5	2088	2.4	5.49^{C}	0^{P}
Alstonia scholaris R. Br.	Chatiun	Apocynaceae	2	1.5	4351	2.4	1.60^{C}	0^{P}
Phoebe attenuata Nees.	Angare	Lauraceae	3	1.5	2726	2.0	0.89^{N}	0^{N}
Michelia champaca L.	Champ	Magnoliaceae	4	3.0	1164	2.0	1.79^{C}	0^{P}
Knema linifolia Warb.	Ramgua	Myristicaceae	2	1.0	3374	2.0	0.95^{N}	0^{N}
Eugenia jambolana DC.	Jamuna	Myrtaceae	5	2.5	702	1.9	0.79^{N}	125^{F}
Engelhardtia spicata Blume	Mauwa	Juglandaceae	4	2.5	906	1.8	1.21^{C}	0^{P}
Bridelia retusa Spreng.	Gayo	Euphorbiaceae	3	2.5	1397	1.7	1.63^{C}	0^{P}
Garuga pinnata Roxb.	Dabdabe	Burseraceae	2	2.0	1820	1.6	2.42^{C}	0^{P}
Elaeocarpus varuna Ham.	Bhadrase	Elaeocarpaceae	3	2.5	274	1.3	1.63^{C}	0^{P}
Litsea khasyana Meissn.	Dude lampate	Lauraceae	3	2.0	598	1.3	1.37^{C}	0^{P}
Terminalia chebula Retz.	Harra	Combretaceae	2	1.0	1576	1.3	0.95^{N}	0^{N}
Dysoxylum hamiltonii Hiern.	Katletuni	Meliaceae	1	0.5	1754	1.0	1.00^{R}	0^{N}
Unidentified	Kimkimasi		2	1.0	184	0.7	0.95^{N}	0^{P}
Cedrela toona Roxb.	Tuni	Meliaceae	2	1.0	28	0.7	0.95^{N}	0^{I}
Lagerstroemia flosreginae Retz.	Jarul	Lythraceae	1	1.0	61	0.5	2.00^{C}	0^{I}
Odina wodier Roxb.	Jeol	Anacardiaceae	1	0.5	374	0.5	1.00^{R}	0^{N}
Ulmus lancifolia Roxb.	Pipli	Ulmaceae	1	0.5	398	0.5	1.00^{R}	0^{N}
Artocarpus chaplasha Roxb.	Lator	Moraceae	1	0.5	100	0.4	1.00^{R}	0^{N}
Medium trees								
Amoora rohituka W. & A.	Lahsune	Meliaceae	20	39.5	35238	26.2	2.01^{C}	500^{F}
Cryptocarya floribunda Nees.	Patmero	Lauraceae	15	23.5	7724	11.3	2.57^{C}	1250^{F}
Premna mucronata Roxb.	Ginari	Verbenaceae	10	10.5	3226	5.7	2.65^{C}	375^{G}
Aporosa dioica Muell.	Asare	Euphorbiaceae	10	9.0	435	4.4	1.74^{C}	0^{P}
Vitex heterophylla Roxb.	Panchpate	Verbenaceae	8	4.0	3993	4.2	0.63^{U}	0^{P}
Machilus gamblei King.	Kawla	Lauraceae	8	8.0	774	3.8	1.79^{C}	250^{G}
Careya arborea Roxb.	Kumbhi	Lecythidaceae	5	4.0	1449	2.5	2.21^{C}	0^{P}
Walsura tabulata Hiern.	Phalame	Meliaceae	6	3.5	605	2.4	0.98^{N}	125^{G}
Heynea trijuga Roxb.	Ankhatarua	Meliaceae	5	5.0	616	2.4	1.79^{C}	500^{G}
Polyalthia simiarum Benth.	Khuttikath	Anonaceae	5	2.5	1033	2.1	0.79^{C}	125^{F}
Magnolia plerocarpa Roxb.	Patpate	Magnoliaceae	5	3.0	91	1.8	1.09^{N}	0^{I}
Semecarpus anacardium L.	Kalo bhalayo	Anacardiaceae	3	1.5	1426	1.6	0.89^{N}	0^{P}
Turpinia pomifera DC.	Thali	Staphyleaceae	3	1.5	1633	1.6	0.89^{N}	0^{P}
Unidentified	Ampe		3	1.5	1186	1.5	0.89^{N}	375^{F}
Callicarpa arborea Roxb.	Guenlo	Verbenaceae	3	2.0	466	1.3	1.37^{C}	0^{P}
Casearia graveolens Dalz.	Barkaule	Flacourtiaceae	3	1.5	279	1.1	0.89^{N}	250^{F}
Unidentified	Diospy		2	1.0	509	0.9	0.95^{N}	0^{N}
Erythrina stricta Roxb.	Phaledo	Papilionatae	1	0.5	1591	0.9	1.00^{R}	0^{N}
Cordia myxa L.	Bohori	Boraginaceae	2	1.0	52	0.7	0.95^{N}	125^{G}
Meliosma simplicifolia Walp.	Dalchewri	Sabiaceae	2	1.0	36	0.7	0.95^{N}	0^{I}
Machilus villosa Hk.f.	Vaisi kawla	Lauraceae	1	1.0	36	0.5	2.00^{C}	0^{I}
Cassia fistula L.	Sonalu	Caesalpinoideae	1	0.5	88	0.4	1.00^{R}	0^{N}
Kydia calycina Roxb.	Kubinde	Malvaceae	1	0.5	92	0.4	1.00^{R}	0^{N}
Quercus spicata Smith.	Arkawla	Fagaceae	1	0.5	16	0.3	1.00^{R}	0^{I}
Talauma hodgsonii Hk.f.	Bhalukath	Magnoliaceae	1	0.5	9	0.3	1.00^{R}	0^{I}
Ilex godajam Colebr.	Hathisure	Ilicaceae	1	0.5	16	0.3	1.00^{R}	0^{I}
Chisocheton paniculatus Riern.	Ramsuntala	Meliaceae	1	0.5	9	0.3	1.00^{R}	0^{I}
Bauhinia purpurea L.	Tanki	Caesalpinoideae	1	0.5	18	0.3	1.00^{R}	0^{I}

Contd . . .

(**Table 3.** *Contd.*)

Species	Local name	Family	Occurrence	Density (ha^{-1})	Basal area (cm^2 ha^{-1})	IVI	Variance to mean ratio	Seedling density (ha^{-1})
Small trees								
Mallotus philippinensis Muell.	Sindure	Euphorbiaceae	16	44.5	4460	14.6	4.58^{C}	125^{G}
Glochidion sp.	Lathikath	Euphorbiaceae	14	17.5	876	7.2	1.86^{C}	0^{P}
Wrightia tomentosa Roem.	Khirra	Apocynaceae	9	10.0	2290	5.0	3.16^{C}	250^{F}
Baccaurea sapida Muell.	Kusum	Euphorbiaceae	10	9.0	690	4.5	2.09^{C}	375^{G}
Symplocos caudata Wall.	Kharani	Symplocaceae	7	4.0	2947	3.6	0.89^{N}	0^{N}
Crataeva unilocularis Ham.	Chiple	Capparidaceae	4	2.0	433	1.5	0.84^{N}	125^{G}
Oroxylum indicum Vent.	Totola	Bignoniaceae	2	3.0	400	1.2	4.24^{C}	0^{P}
Grewia vestita Wall.	Sialphusre	Tiliaceae	3	1.5	71	1.0	0.89^{N}	0^{I}
Holarrhena antidysentrica Wall.	Kurchi	Apocynaceae	2	1.0	176	0.7	0.95^{N}	0^{P}
Unidentified	Bajradanty		1	1.0	72	0.5	2.00^{C}	0^{N}
Eurya acuminata DC.	Jhingini	Theaceae	1	0.5	81	0.4	1.00^{R}	0^{N}
Streblus asper Lour.	Sheora	Moraceae	1	0.5	255	0.4	1.00^{R}	0^{N}
Eugenia balsamea Wight.	Ambake	Myrtaceae	1	0.5	25	0.3	1.00^{R}	0^{I}
Phyllanthus emblica L.	Amla	Euphorbiaceae	1	0.5	16	0.3	1.00^{R}	0^{I}
Shrubs								
Leea sp.	Galeni	Vitaceae	19	75.5	5268	22.0	3.23^{C}	875^{G}
Litsea sp.	Kalikath	Lauraceae	15	24.5	1336	9.1	2.38^{C}	375^{G}
Morinda citrifolia L.	Hardikath	Rubiaceae	4	7.5	188	2.6	5.32^{C}	500^{G}
Alangium begoniaefolium Baill.	Galsune	Alangiaceae	4	4.0	151	1.8	1.95^{C}	0^{P}
Antidesma diandrum Roth.	Archal	Euphorbiaceae	5	2.5	70	1.7	0.79^{N}	125^{G}
Climbers								
Millettia auriculata Baker	Gaujo	Papilionatae	14	11.5	818	6.0	1.15^{N}	750^{G}
Combretum decandrum Roxb.	Seti lahara	Combretaceae	10	13.5	1492	5.7	1.35^{C}	1125^{G}
Acacia pinnata Willd.	Arari lahara	Mimosoideae	1	0.5	25	0.3	1.00^{R}	125^{G}
Mucuna monosperma DC.	Baldangra	Papilionatae	1	0.5	9	0.3	1.00^{R}	0^{I}
Cissus elongata Roxb.	Charchare	Vitaceae	1	0.5	9	0.3	1.00^{R}	0^{I}
Dalbergia stipulacea Roxb.	Siris lahara	Papilionatae	1	0.5	16	0.3	1.00^{R}	0^{I}
Species in seedling class only								
Chukrasia tabularis A. Juss.	Chikrasi	Meliaceae						125^{I}
Litsea polyantha Juss.	Kutmero	Lauraceae						125^{I}
Acronychia laurifolia Blume	Puanle	Rutaceae						125^{I}
Coffea bengalensis Roxb.	Baishakhi	Rubiaceae						19000^{I}
Unidentified shrub	Kafal							875^{I}
Millettia pachycarpa Benth.	Karkus lahara	Papilionatae						125^{I}

Spellings and authorities of the species have been adapted from Brandis[33] and Cowan and Cowan[1]. Superscripts for variance to mean ratio denote uniform (U), random (R), near-random (N) and clumped (C) dispersion. Superscripts for seedling density denote good (G), fair (F), poor (P) and no (N) regeneration and immigration (I). See text for details. Six species that appear in seedling class only are shown at the end of the table.

stratum, thus keeping the forest floor moist and cool. This contradicts dry deciduous forests in the Western Ghats[13–15], where lengthy leaf-drop period renders the canopy almost naked and forest floor gets dry and hot during summer. In Central Himalayan lowlands, long lasting dry period (6–7 months), and relatively lower rainfall (< 2000 mm) and humidity (60–65%) alter floristics. *M. philippinensis*, *Anogeissus latifolia* and *Pinus roxburghii* turn major associates of sal, with the presence of a bamboo (*Dendrocalamus strictus*) in undergrowth[3,16]. In north-east India, *Shorea assamica* is a principal associate of sal[17].

This sal forest appears unusually rich in species number. With 87 species in 2 ha, it tops the list of its counterparts in India (Table 6). The richness is greater than that of sal forests in Central Himalaya[16] and central India[18,19] and deciduous forests of the Western Ghats[13–15,20–22]. These comparisons convey limited meaning since the sample area is variable across studies. Shannon's diversity of 3.59 at the present site is greater than 1.58–3.53, recorded for old sal plantations in Gorakhpur[23,24]. Global assessments of species richness in 0.1 ha plots showed an average of 64.9 species in Neotropical forests[5], which is far greater than an average of 21.5 for the present site. It is believed that although species richness is similar, stand diversity is lower in Indian tropical forests than Neotropical forests.

The Neotropical deciduous forests are remarkably consistent in their taxonomic composition, with Leguminosae the most speciose family followed by Bignoniaceae[5]. This trend seems somewhat different for Indian deciduous forests wherein the Leguminosae is a prominent family[13–15], but Euphorbiaceae stands first. Furthermore, the next most prominent family is not Bignoniaceae. Instead, Lauraceae and Meliaceae prevail at the present

Table 4. Density, basal area and species in three dispersion categories based on the inventory of individuals with ≥ 10 cm girth in a sal forest. (See text for explanation)

	Density		Basal area		Dispersion (number of species)		
Species group	ha^{-1}	%	$m^2 ha^{-1}$	%	Uniform	Random	Clumped
Large trees	119.0	24.6	17.8	67.7	1	12	21
Medium trees	128.5	26.5	6.3	23.8	1	17	10
Small trees	95.5	19.7	1.3	4.9	0	8	6
Shrubs	114.0	23.6	0.7	2.7	0	1	4
Climbers	27.0	5.6	0.2	0.9	0	5	1
Total	484.0	100	26.3	100	2	43	42

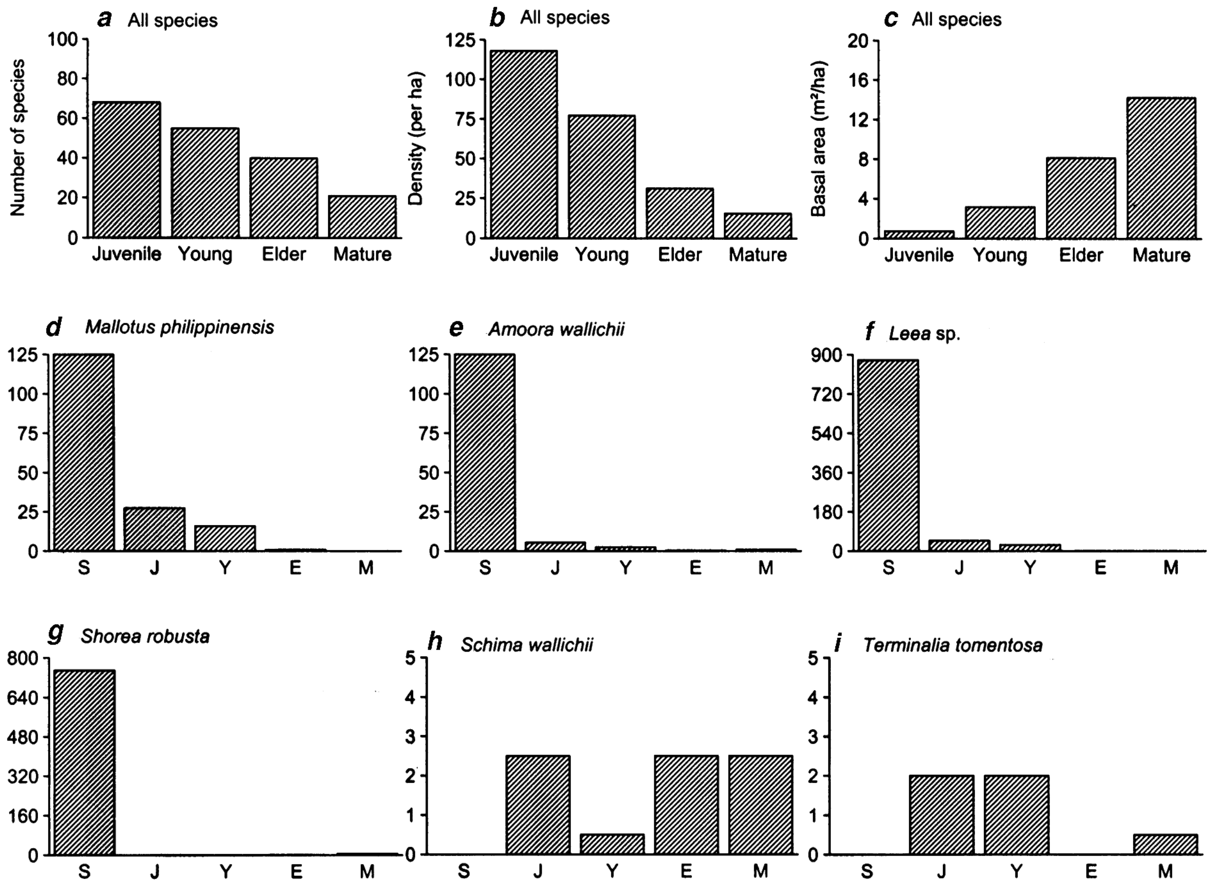

Figure 2. Population structure of all species based on the number of species (*a*), density (*b*), and basal area (*c*). Girth class is ≥ 10 to < 30 cm for juvenile (J), ≥ 30 to < 90 cm for young (Y), ≥ 90 to < 180 cm for elder (E), and ≥ 180 cm for mature (M) classes. ***d–f*** show 'good' regeneration of three species, and ***g–i*** show 'poor' regeneration of three species. S depicts seedling class. The *y*-axis for ***d–i*** shows density per ha.

site, and Combretaceae, Rubiaceae, Euphorbiaceae and Moraceae elsewhere in India[13–15].

The flora of sal forest is characterized by overwhelming dominance of the tree species (76 species). Of all individuals, 70.8% belonged to trees. In Central Himalaya, there were only 11–13 tree species in Siwalik sal forest, 5 in an oldgrowth sal forest and 8 in a sal coppice forest[16]. In 24 stands of Gorakhpur sal plantations, only 29 tree species were found and most of them were in the habit of shrub[23]. Ganesh *et al.*[25] recorded 56.6% tree species at Kakachi. The dominance of tree species in the flora of the present sal forest declined to 66.7% after inclusion of 27 herbaceous species, which is still very high. In fact, the number of herbaceous species in the forest floor may be high in the early stage of succession following a gap formation and may decline as the succession proceeds[26]. Woody shrubs that yield useful timber for household and agricultural implements dominate the undergrowth. All climber species are gregarious and woody and there were a few epiphytes. This is in sharp contrast with Central Himalaya, where sal undergrowth is herbaceous and grasses predominate[17].

Tropical species with low density tend to have relatively uniform dispersion and those with high density have clumped dispersion[27]. The sal forest followed this pattern with 48% species exhibiting clumped dispersion, 49% species random or near-random dispersion, and two species uniform dispersion. The rare species showed random or near-random dispersion. Sukumar *et al.*[13] also found clumped dispersion of all species at Mudumalai on 0.04 and 0.25 ha scales, with clumping increasing with the abundance of species. On the contrary, Murali *et al.*[14] at BR Hills, found clumped dispersion of all species, except six most abundant species that had uniform or random dispersion.

Mixed dominance of species is an important feature of this sal forest. Large, medium and small trees, and shrubs shared a stem density of 484 ha^{-1}. Only climbers were less abundant. In each growth form, except large trees, density was concentrated to one or two species, and the rest of the species was rare. Interestingly, large trees that exhibit maximum species richness are not dominant in terms of density. This is contrary to other Indian deciduous forests, where the large tree species dominate in numbers. The mixed dominance is also evident from the maximum IVI attained by sal which is only 16.2 in Darjeeling compared to > 120 in Central Himalaya (see Table 6). Mixed dominance of species prevailed since different species dominated in different girth classes, in spite of a progressive decline in the number of species from juvenile through mature class.

Table 5. Regeneration of species in five growth forms in Mahananda Sanctuary. (See text for explanation)

	Regeneration (number of species)				
Species group	Good	Fair	Poor	None	New
Large trees	2	4	18	8	3
Medium trees	5	5	6	4	9
Small trees	3	1	3	4	4
Shrubs	6	0	1	0	0
Climbers	3	0	0	0	4
Total	19	10	28	16	20

Table 6. Comparison of vegetation characteristics of the present study site with sal-dominated and other deciduous forests in India

Forest type and location	Plot size (ha)	Size class (cm)	Species richness	Stand density (ha^{-1})	Basal area (m^2 ha^{-1})	Source
Sal forests in Eastern Himalaya						
Mahananda Sanctuary, Darjeeling	2	≥ 10 gbh	87	484	26.3	Present study
Sal forests in Central Himalaya						
Phanduwala	0.2	≥ 10 gbh	13	1510	37.8	Pande[34]
Lachhiwala	0.2	≥ 10 gbh	21	1920	22.3	-do-
Balandiwala	0.2	≥ 10 gbh	17	1150	24.2	-do-
Jhajhra	0.2	≥ 10 gbh	18	1460	23.8	-do-
Timili	0.2	≥ 10 gbh	11	1332	23.4	-do-
Siwaliks	0.74	≥ 10 gbh	62	254–376	?	Rawat and Bhainsora[35]
Doon Valley	0.74	≥ 10 gbh	56	640	?	-do-
Outer Himalaya	0.74	≥ 10 gbh	54	644	?	-do-
Corbett National Park	2.9	≥ 31.5 gbh	3–20	180–860	14.5–71.8	Singh *et al.*[36]
Sal forest, Gorakhpur	?	≥ 30 gbh	10	814	56.2	Shukla and Pandey[24]
Sal plantation, Gorakhpur	2.4	≥ 30 gbh	29	451	43.9	Pandey and Shukla[23]
Sal forests in Central India						
Dry tropical, Vindhyan Hills	?	≥ 30 gbh	?	294–559	7–23	Jha and Singh[18]
Deciduous, Karanjia, Mandla	0.75	≥ 30 gbh	12–14	324–476	27–55.3	Prasad and Pandey[19]
Deciduous forests in the Western Ghats						
Dry deciduous, Mudumalai	50	≥ 1 dbh	72	518	24.7	Sukumar *et al.*[20]
Dry deciduous, BR Hills	10	≥ 1 dbh	69	905	26.8	Murali *et al.*[14]
Deciduous scrub, BR Hills	4	≥ 1 dbh	69	2685	7.9	Uma Shankar *et al.*[15]
Moist deciduous, Western Ghats	0.5	≥ 10 dbh	77	352	33.7	Sundarapandian and Swamy[21]
Moist deciduous, Western Ghats	10.32	≥ 10 dbh	27	276	?	Ghate *et al.*[22]
Range for dry tropical forests	?	?	35–90	?	17–40	Murphy and Lugo[30]

dbh, diameter at breast height; gbh, girth at breast height; (?), value is not available in the source.

In fact, the high value of evenness index reflects that much of the value of diversity is attributable to evenness of abundances, or that most species are relatively rare. The sal forest contained 36% rare species. Primack and Hall[28] found 35, 44 and 50% rare species in Malaysian forests. In BR Hills, 52% species in a dry deciduous[14] and 50% species in a thorn scrub[15] were rare. The populations of rare species are probably maintained by the high rates of recruitment and mortality (high turnover) than the populations of common species[29].

A basal area of 26.3 m^2 ha^{-1} falls within the range compiled for the dry tropical forests by Murphy and Lugo[30], and stands very close to the deciduous forests of BR Hills and Mudumalai (Table 6). An increase in basal area from juvenile through mature class and from lower to upper stratum establishes that large tree species that are not dominant in terms of density, monopolize basal area with 68% share. Only six species could constitute 56% of the total basal area. This is unlike BR Hills, where the two dominant species with 41% share of density accumulated only 43% basal area in a deciduous forest[14], and three dominant species with 49% share of density accumulated only 40% basal area in a scrub forest[15].

The regeneration in this sal forest is satisfactory at the community level, as evinced by the population structure of all species. There were 31,250 seedlings and 236 saplings for 248 adults ha^{-1}. Only 20.4% species showed good regeneration. Another 21.5% species is either reappearing or immigrating since they occur in sapling or seedling phase, but have no adults. The remaining species show paucity of regeneration. While shrubs and climbers were regenerating well, tree species were lagging behind. High-grade timber species exhibited poor regeneration. The dominant medium and small tree species could achieve satisfactory regeneration. These conclusions are subjective to a certain extent, since the relative number of adults and juveniles does not seem to be a consistent trait across species. While some species could succeed with a relatively small stock of juveniles, others depend on a large stocking of juveniles to compensate for mortality[31]. Nonetheless, inadequate regeneration of the constituent species is a general phenomenon in Indian forests because of grazing, fire, timber and fuelwood cutting and cultivation[3,4,14].

Conservation implications and conclusions

Sal forests in Darjeeling 'terai' have been experiencing anthropogenic pressure for centuries. The most serious threat has been the change in landuse. Extensive forest tracts have been cleared for human settlements, road network and industrial units. Besides, sizeable-forested land has been diverted to agriculture, tea cultivation and 'taungya' plantations[4]. Currently, sal forests are available in fragmented state and are confined to the protected area network. The remnant patches are not safe despite legal protection. Certain degree of anthropogenic pressure exists in the form of illicit timber and fuelwood cutting, collection of non-timber products[32], grazing, fire and hunting. Since extraction is not legally permitted, quantitative estimation of the extraction is not possible. However, the phytosociological analysis clearly reveals that this sal forest is an extremely important ecosystem by the virtue of high richness and diversity of tree species with mixed dominance and satisfactory regeneration, a trio of characters unique to a deciduous forest community. Most of the hardwood species may not be available for extraction in the future, unless specifically augmented for regeneration. Yet, controlled quantities of fuelwood can be extracted from shrubs. Rare species need special attention since they are the major contributors to the species diversity and they should selectively be marked and protected. The sal forests are maintained in the pre-climax state by the anthropogenic pressure[23] which, if increased, may retrogress the succession into a degraded community, and, if decreased, may substitute sal by other species.

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