

Tree species diversity and distribution patterns in tropical forests of Garo Hills

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We analysed phytosociological characteristics and diversity patterns of tropical forest tree species in Garo Hills, western Meghalaya, Northeast India. The main vegetation of the region included primary forests (PFs), secondary forests (SFs), and sal (*Shorea robusta*) plantations, with 162, 132, and 87 tree species respectively. The Shannon–Wiener diversity index of trees in PF was 4.27 ($n = 21$ one-ha belt-transects), which is comparable to the world's richest tropical forests. Statistical results revealed that primary forests were more tree-rich and diverse than secondary forests or sal plantations. Results of the study will help forest managers in conservation planning of the tropical forest ecosystem of Northeast India.

Keywords: Distribution pattern, Garo Hills, tree species diversity, tropical forests, rarefaction.

TROPICAL forests often are referred to as one of the most species-diverse terrestrial ecosystems. Their immense biodiversity generates a variety of natural resources which help sustain the livelihood of local communities^{1–3}. However, many tropical forests are under great anthropogenic pressure and require management intervention to maintain the overall biodiversity, productivity and sustainability¹. Understanding species diversity and distribution patterns is important for helping managers evaluate the complexity and resources of these forests. Trees form the major structural and functional basis of tropical forest ecosystems and can serve as robust indicators of changes and stressors at the landscape scale³. The present study focused on analysing distribution and abundance pattern of tree species over a landscape covering 2459 sq. km area in the tropical hills of Northeast India.

The old native forests of the Garo Hills in western Meghalaya—one of the seven northeast Indian States—support one of the most diverse and luxuriant tropical vegetation conditions in the world¹. The native primary forests (PFs), secondary forests (SFs), and sal (*Shorea robusta*) plantations comprise the main forest vegetation types, the first two of which are subjected to anthropogenic

pressure, particularly shifting cultivation (locally known as *jhum*)¹. Nevertheless, pristine PFs of Garo Hills still occur as remnant patches in remote localities mainly in the interior hills. SF growth originates from many years of practising *jhum*, resulting in patches of various forest ages dispersed across the area. Many recent studies^{4–7} have described vegetation characteristics and diversity of the tropical forests of India and other parts of the world. Meghalaya, however, has remained, largely unstudied, except for our work and another landscape level assessment^{1,2,8}. Here, we present empirical data on diversity of tree species in the tropical forests of Garo Hills.

Study area

The study area covers 2459 sq. km in the South Garo Hills district (1850 sq. km) and part of the East and West Garo Hills districts (609 sq. km) in Meghalaya (Figure 1). The study area belongs to biogeographic zone 9B (northeastern India)⁹ and occurs between 90°07'–91°E long. and 25°02' and 25°32'N lat.¹. Elevation ranges from 100 to 1500 m amsl. Forests of the study area occur in three main land-use classes: (i) protected areas (PAs), which include Nokrek National Park and Biosphere Reserve, Balpakram National Park, Siju Wildlife Sanctuary and Baghmara Pitcher Plant Sanctuary; (ii) managed forests (MFs) which include four reserved forests (RFs), namely Angratoli RF, Baghmara RF, Imanigiri RF and Rewak RF; and (iii) privately-owned Garo community land (see Figure 1 for location). The government manages only 15% (362 sq. km) of the total land in PAs and RFs. The remaining land belongs to the local Garo communities, who use it widely for *jhumming* and as sources of non-timber forest resources.

Although PF is mainly confined to PAs, a few intact patches of PF still exist in the interior hills within community land. SF is confined mainly to community land and some newly acquired portions of PAs. RFs of the region, where sal plantations are found, have been managed through forestry working plans since the initiation of formal forest management during the late 19th century. An intensive study in Balpakram National Park, one of the most important PAs of Meghalaya, had identified eight

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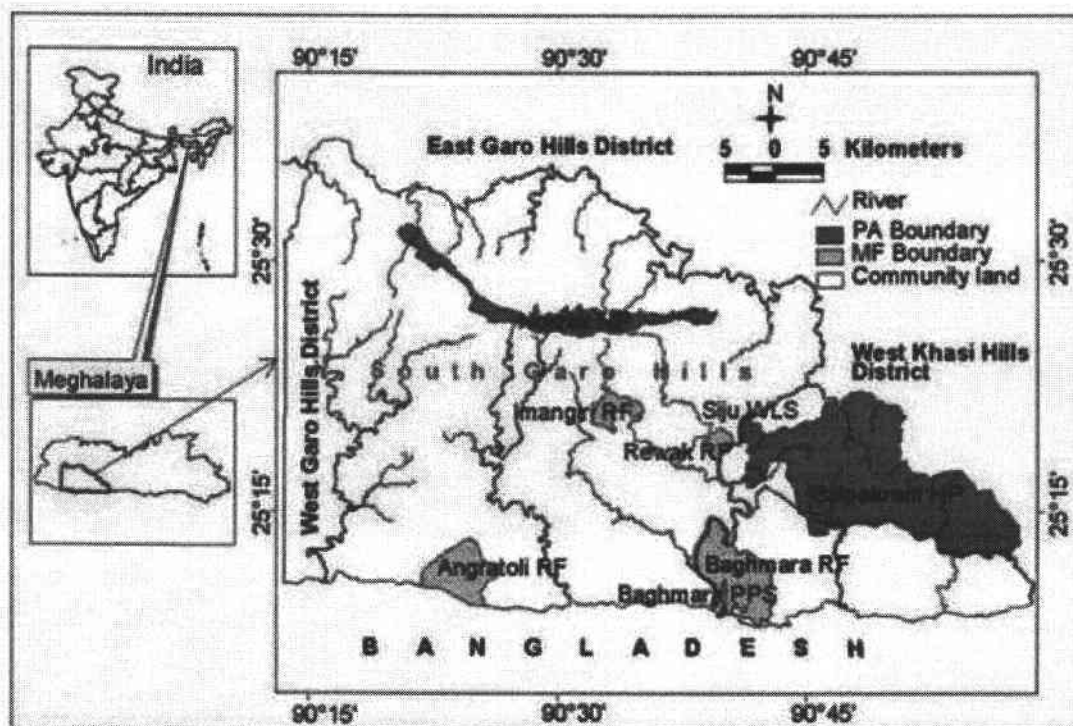


Figure 1. Study area of Garo Hills in western Meghalaya, Northeast India. PA, Protected area; MF, Managed forest also known as RF, reserved forest in Garo Hills; WLS, Wildlife sanctuary; PPS, Pitcher plant sanctuary.

tropical forest formations⁸ based on the classification scheme suggested by Holdridge *et al.*¹⁰. The reported formations included tropical moist evergreen forests, tropical semi-evergreen forests, tropical moist deciduous forests, secondary formations, shola type forests, riverine forests, grassland and tree-savannas and bamboo forests. Our present study identified forest types as PF, SF and sal plantation, which included these above-mentioned forest formations.

Methods

We used stratified random sampling to collect tree data within 1 ha belt-transects (1000 m × 10 m), which could be used as an alternate of 1 ha square plots in rugged and undulating hilly terrain, as suggested by Sykes and Horrills¹¹. We located the belt-transects along existing foot-paths and elephant travel lanes, which often were the only means of effectively entering the forest interiors. We established 35 belt-transects of which 21, 10, and 4 were in PF, SF, and sal plantation respectively, to record the local names and circumference (girth) of all trees ≥ 30 cm girth at breast height (gbh). If a tree trunk was buttressed near breast height, the girth was measured just above the buttress, and if a tree was branched at or below breast height,

it was counted as two (or more) trees and each measured just above the branch point.

We stratified PF into three forest formations based on elevation: PF1 ($n = 8$ belt-transects) at <400 m elevation, PF2 ($n = 9$) at 400–800 m elevation, and PF3 ($n = 4$) at >800 m elevation. We stratified SF into three successional stages based on age (years since stand-replacing disturbance, principally *jhum*): SF1 as 15 years or younger ($n = 3$), SF2 as 15–30 years ($n = 4$), and SF3 as >30 years ($n = 3$). We plotted cumulative number of tree species as a function of cumulative number of belt-transects for all PFs and SFs to evaluate the adequacy of sample size of belt transects in PF and SF for estimating tree species richness in 1 ha areas (but not in sal plantations owing to their relative sparseness in the study area).

We assessed the following phytosociological characteristics of the tree communities: per cent frequency (per cent of all belt-transects in which a tree species was present), density (ratio of total number of trees and total number of belt-transects laid out), abundance (ratio of total number of trees and total number of belt-transects of occurrence), basal area (m^2/ha) and species importance value (SIV)³. In PFs and SFs (but not in sal plantations because of low sample size), we grouped each tree species into one of five frequency classes (FC): 1–20% (FC1), 21–40% (FC2), 41–60% (FC3), 61–80% (FC4) and 81–100% (FC5), ac-

cording to Raunkier's law of frequency, and we used the ratio of abundance to frequency as a measure of contagion of patterns tree distribution³. We computed tree density (number of trees/ha) and basal area (m²/ha) for each vegetation type to compute SIV of each tree species, according to Misra³, who used the term 'importance value index' or IVI for same.

We computed similarity measures of tree species among the three forest vegetation types (PF, SF, sal), three PF formations, and three SF successional stages using Jacard's (JI), Sørensen's (SI) and Czekanowski's (CI) indices. Jacard's and Sørensen's indices were based on the presence or absence of species shared between samples, and species unique to each sample respectively. CI is similar to JI or SI, except that it also considers abundance of the species¹².

We used the statistical software STATECOL to compute tree species richness (Menhinick index), species diversity (Shannon–Wiener diversity index) and species evenness (modified Hill's ratio) based on the number of trees of each species in the forest vegetation types, PF formations, and SF successional stages¹³. We also compared these index measures using rarefaction by plotting the expected number of species or $E(S_n)$ against the number of trees to standardize the sample size for valid comparison¹⁴. We tested for significance of differences in the number of observed species, tree density, basal area, Menhinick richness, Shannon–Wiener diversity, and modified Hill's evenness using analysis of variance (ANOVA) and unpaired *t*-tests. Also, we used likelihood chi-square analysis to test for differences in tree species frequency classes between PFs and SFs.

Results and discussion

Composition and structure of forest vegetation types

We counted a total of 29,884 trees belonging 165 tree species (153 identified to species level) among 54 families from all 35 belt-transects in PF, SF, and Sal forests. *Castanopsis purpurella* and *Syzigium cumini* were the most frequent species (observed in 33 of 35 belt-transects), and *Adina cardifolia*, *Dysoxylum alliarium* and *Lepisanthes rubiginosa* were the least frequent tree species, each occurring in only one belt-transect. *S. robusta*, *Schima wallichii*, *C. purpurella*, *Polyalthia simiarum*, *S. cumini* and *Grewia microcos* dominated the PFs. SIVs of tree species in the forest vegetation types are listed in Appendix 1.

Analysis of Raunkier's frequency classes revealed that most of the tree species had low frequency (Figure 2) as would be expected in typical species-abundance distributions in tropical forests. The PFs and SFs were not significantly different in frequency class distributions (likelihood ratio chi-square = 13.32, *df* = 12, *P* = 0.35), although SFs had a slightly higher proportion of species (63%) in low frequency classes (FC1 and FC2) than PF (57%). *Arto-*

carpus gomezianus, *Oroxylum indicum*, and *Rhus accuminata* had the most regular distribution (low abundance and high frequency) among both PFs and SFs forests. Other species with regular distributions included *Maca-ranga indica*, *Moringa oleifera*, *Alstonia scholaris*, *Dua-banga grandiflora*, *Albizia chinensis* and *Ficus nervosa* in PF, and *Garcinia tinctoria*, *Gmelina arborea*, *Pterygota alata*, *Mesua ferrea*, *Mallotus roxburghianus*, *Litsea sebifera* and *Saraca asoca* in SF. *S. robusta*, *Boehmerea hamiltoniana*, and *Saurauia nepaulensis* had the most clumped distribution (high abundance and low frequency) in both PF and SF. Appendix 2 gives the distribution pattern or contagiousness of species in SF and sal plantations.

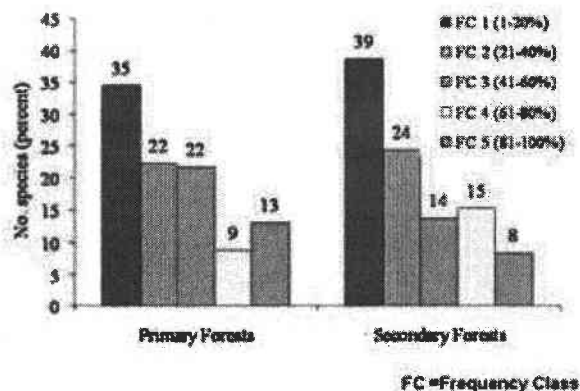


Figure 2. Raunkier's frequency classes of tree species in primary and secondary forests.

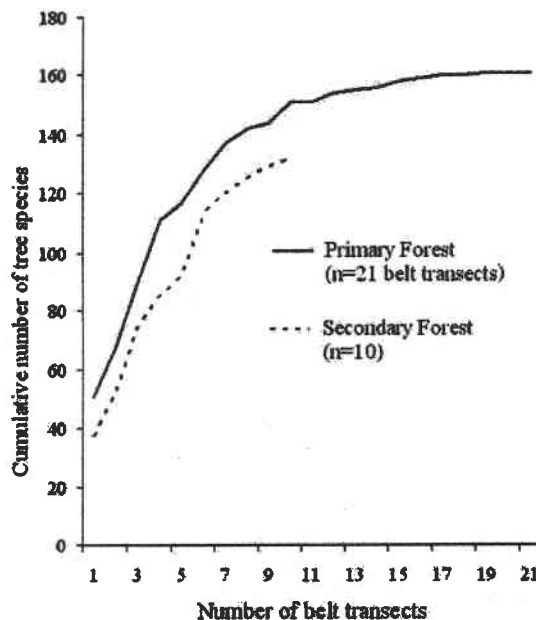


Figure 3. Cumulative number of tree species as a function of cumulative number of 1 ha belt-transects in primary and secondary forests.

Table 1. Phytosociological characters and diversity patterns (mean values $\pm$ standard deviation) in various forest vegetation types, primary forest formations and successional stages of secondary forests

Vegetation type/ forest formation	No. of observed species	Tree density (trees/ha)	Basal area (m ² /ha)	Menhinick index	Shannon index	Modified Hill's ratio
1. PF	65 $\pm$ 10	816 $\pm$ 187	63 $\pm$ 35	2.35 $\pm$ 0.53	3.32 $\pm$ 0.34	0.61 $\pm$ 0.10
1a. PF1	67 $\pm$ 9	684 $\pm$ 205	51 $\pm$ 27	2.65 $\pm$ 0.51	3.33 $\pm$ 0.40	0.57 $\pm$ 0.14
1b. PF2	61 $\pm$ 7	906 $\pm$ 124	50 $\pm$ 9	2.05 $\pm$ 0.32	3.23 $\pm$ 0.32	0.62 $\pm$ 0.07
1c. PF3	71 $\pm$ 16	878 $\pm$ 130	118 $\pm$ 33	2.43 $\pm$ 0.66	3.49 $\pm$ 0.25	0.66 $\pm$ 0.04
2. SF	53 $\pm$ 11	916 $\pm$ 151	43 $\pm$ 43	1.79 $\pm$ 0.38	2.94 $\pm$ 0.27	0.58 $\pm$ 0.10
2a. SF1	62 $\pm$ 12	821 $\pm$ 254	16 $\pm$ 3	2.19 $\pm$ 0.23	3.14 $\pm$ 0.17	0.55 $\pm$ 0.16
2b. SF2	47 $\pm$ 7	918 $\pm$ 25	51 $\pm$ 5	1.53 $\pm$ 0.23	2.8 $\pm$ 0.10	0.6 $\pm$ 0.06
2c. SF3	52 $\pm$ 9	1006 $\pm$ 91	93 $\pm$ 51	1.65 $\pm$ 0.34	3.05 $\pm$ 0.43	0.64 $\pm$ 0.08
3. Sal plantation	42 $\pm$ 13	887 $\pm$ 115	54 $\pm$ 17	1.82 $\pm$ 0.39	3.29 $\pm$ 0.43	0.69 $\pm$ 0.10

Forest vegetation types: 1, Primary forest (PF); 2, Secondary forest (SF); 3, Sal plantation.

Primary forest formations: 1a, PF1; 1b, PF2; 1c, PF3.

Secondary forest successional stages: 2a, SF1; 2b, SF2; 2c, SF3 (see text for description).

Sample sizes of 1 ha belt-transects were 9, 8, 4 in PF1, PF2, PF3; 3, 4, 3 in SF1, SF2, SF3; and 4 in sal plantation, respectively.

Table 2. Statistical comparison of tree parameters among three forest vegetation types, three primary forest formations, and three secondary forest successional stages. All tests used analysis of variance and $df = 2$

	<i>F</i>	<i>P</i>
Forest vegetation type		
No. observed species	10.463	<0.0005***
Tree density	1.230	0.306
Basal area	1.120	0.339
Menhinick richness index	9.574	0.001***
Shannon–Wiener diversity index	23.956	<0.0005***
Modified Hill's evenness index	9.898	<0.0005***
Primary forest formation		
No. observed species	1.458	0.259
Tree density	4.344	0.029**
Basal area	14.635	<0.0005***
Menhinick richness index	3.425	0.055*
Shannon–Wiener diversity index	0.775	0.475
Modified Hill's evenness index	1.035	0.376
Secondary forest successional stage		
No. observed species	2.634	0.140
Tree density	1.170	0.364
Basal area	7.089	0.021**
Menhinick richness index	5.877	0.032**
Shannon–Wiener diversity index	1.665	0.256
Modified Hill's evenness index	0.579	0.585

* $P < 0.10$; ** $P < 0.05$; *** $P < 0.01$.

See Table 1 for description of forest vegetation type, primary forest formation and secondary forest successional stages.

PF, SF, and sal plantations had 162, 132 and 87 tree species belonging to 54, 53 and 37 tree families respectively. Plots of cumulative number of tree species by number of belt-transects (Figure 3) and rarefaction analysis (Figure 4) revealed that for a given sample effort, PF consistently had significantly more tree species than SF. The number of observed tree species ($F = 10.463$, $df = 2$ and $P < 0.0005$) and Menhinick's species richness ($F = 9.574$, $df = 2$ and $P = 0.001$) both differed significantly among the three

forest vegetation types (Tables 1 and 2), being greatest in PFs. In terms of the presence and abundance of tree species, PF was most similar to SF, and sal plantations were least similar to both PF and SF (Figure 5a). Neither mean tree density nor basal area differed significantly among the three forest vegetation types (Tables 1 and 2). However, Shannon–Wiener diversity ($F = 23.956$, $df = 2$ and $P < 0.0005$) and Hill evenness ($F = 9.898$, $df = 2$ and $P < 0.0005$) both varied significantly among forest vegetation types (Table 2), being lowest in sal plantations (Table 1). Furthermore, results of the unpaired t -test also suggested that the Shannon–Wiener diversity was significantly greater in PF than SF ($t = 2.99$, $df = 22$, $P = 0.007$; Table 2).

Primary forest formations and secondary forest successional stages

Tree species composition of PF formations and SF successional stages is presented in Appendix 3. PFs are confined to the interior hills of Nokrek Biosphere Reserve and Balpakram National Park around deep gorges of Simsang and Mahadeo rivers, and in the surroundings of thinly populated habitation at higher elevations. Patches of PF1 formation are less humid than the other PF formations, and are being subjected to more disturbances; hence at several places near habitations on the southern boundary of study area and along river valleys, PF1 contains some deciduous elements. However, the PF2 formation constitutes vast tracts of dense forest cover, the major portion of which occurs in the limestone areas of Balpakram. A few patches of the PF2 formation also were observed in the southern side of Nokrek National Park. The PF3 formation occurs near Nokrek and Tura peak areas and in the high reaches of Chutmang (or Kailash) hills near Balpakram. PF3 formations were characterized by humid conditions and relatively lower atmospheric temperature.

The number of observed species ($F = 1.458$, $df = 2$ and $P = 0.259$) did not vary significantly across the three PF formations (Tables 1 and 2), although Menhinick richness index ($F = 3.425$, $df = 2$ and $P = 0.055$) was marginally lower in PF2 than in PF1 or PF3 (Tables 1 and 2). The rarefaction analysis suggested that PF1 was on average the most tree-diverse followed by PF3 and PF2 (Figure 6). The three PF formations were fairly similar in terms of the presence of tree species, and when considering abundance, PF1 and PF2 were far more similar to each other than either was to PF3 (Figure 5b). Tree density ($F = 4.344$, $df = 2$ and $P = 0.029$) was significantly lowest in PF1, and basal area was significantly greatest in PF3 (Tables 1 and 2). Tree species diversity ($F = 0.775$, $df = 2$ and $P = 0.475$) and evenness ($F = 1.035$, $df = 2$ and $P = 0.376$) did not differ significantly among the three PF formations (Tables 1 and 2).

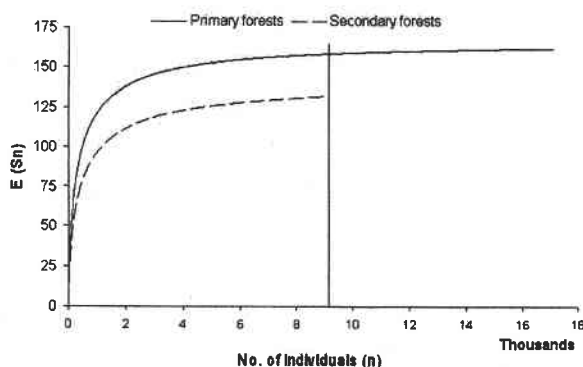


Figure 4. Rarefaction curves standardizing number of samples (1 ha belt transects) for comparing tree species richness in PF ($n = 21$ belt transects; top curve) and in SF ($n = 10$; bottom curve). $E(Sn)$, Expected number of tree species.

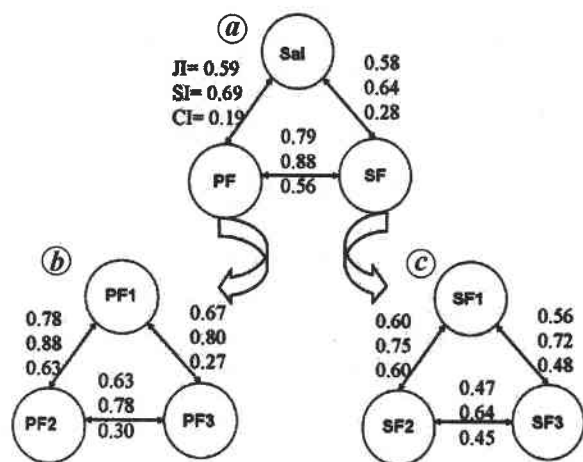


Figure 5. Jaccard's (JI), Sørensen's (SI), and Czekanowski's (CI) indices of similarity measured among: (a) three broad forest vegetation types of primary forest (PF), secondary forest (SF), and sal plantations (Sal); (b) three formations of PF and (c) three successional stages of SF.

The number of observed species did not vary significantly across the three SF successional stages (Tables 1 and 2), although Menhinick richness index ($F = 5.877$, $df = 2$ and $P = 0.032$) was significantly higher in SF1 than in SF2 or SF3 (Tables 1 and 2). Rarefaction analysis suggested that SF2 was consistently less species rich than SF1 or SF3 (Figure 7). The three successional stages of SF were fairly similar in terms of the presence of tree species, and when considering abundance, SF1 and SF2 were more similar to each other than either was to SF3 (Figure 5c).

Tree density did not differ significantly among the three SF successional stages, although basal area ($F = 7.089$, $df = 2$ and $P = 0.021$) did, being far greater in SF3 than in SF1 and SF2 (Tables 1 and 2). Tree species diversity and evenness did not differ significantly among the three SF formations nor did Shannon-Wiener diversity and Hill's evenness (Tables 1 and 2). The reason for this observed pattern is because of larger average (gbh) trees rather than a greater dominance of fast-growing species, which would be expected to dominate SF1 and not SF2. Pioneer tree species in SF1 are, nearly by definition, faster growing.

Both of these forest growth forms, i.e. PF and SF had shown closer affinity with each other compared to that of sal plantations, which had been represented by a unique set of tree species. The three PF formations of PF1, PF2 and PF3 were fairly similar when evaluated using presence and absence of tree species, and had greater similarity on the basis of abundance of tree species. The three SF successional stages were quite similar to each other and showed greater similarity. Tree density and basal areas were higher in PF, but did not significantly differ from SF and sal plantations. However, PF formations revealed significantly lowest tree density in PF1 and significantly highest basal area in PF3. Among the three SF successional stages, tree density did not differ significantly, although basal area did, being far greater in SF3 than in SF1 and SF2.

Forest tree species diversity in the global and regional context

A database of reported plant species of Meghalaya includes 830 tree species, of which 305 and 58 species are from low (0–750 m) and mid (750–1500 m) elevations respectively, in Garo, Khasi and Jaintia Hills throughout the State². The present study area is confined to these elevation ranges in the Garo Hills only. Systematic surveys in the present study revealed a comparable 165 tree species (> 30 cm gbh) for a relatively small portion of Meghalaya.

Ranges of tree density among the three forest vegetation types from the present study (417–1111 trees/ha of trees > 30 cm gbh) are within those of estimates from

Table 3. Vegetation characteristics of forest communities in the tropics of India and other countries

Forest type	Location	Plot size (ha)	Tree girth studied (cm)	Tree density (no./ha)	Tree basal area (m ² /ha)	Source
India						
Evergreen forest	Silent Valley, Kerala	—	≥ 31.5	620–709	29–103	Singh <i>et al.</i> ¹⁹
Tropical forest: Scrub jungle to wet evergreen forest	Kalakad RF, Western Ghats	0.2	> 20	320–1260	18–107	Parthasarathy ¹⁷
Tropical wet evergreen forest	Kalakad RF, Western Ghats	1.0	> 30	574–915	55–94	Parthasarathy <i>et al.</i> ²⁰
Evergreen forest	Karnataka	0.44	—	466–1386	33–48	Rai and Procter ²⁰
Dry tropical forest	Vindhyan region	—	> 30	294–559	7–23	Jha and Singh ²²
Dry evergreen forest	Marakkanam RF, Coromandel coast	0.3	≥ 20	280	11	Visalakshi ⁵
Dry evergreen forest	Puthupet Sacred Grove, Coromandel coast	0.2	≥ 20	1130	36	Visalakshi ⁵
Tropical wet evergreen forest	Kakachi, Kalakad–Mundanthurai Tiger Reserve, Western Ghats	0.50	> 30	315–418	54–84 (reported as 27–42/0.5 ha)	Ganesh <i>et al.</i> ⁶
Tropical wet evergreen forest, 250–1150 m elevation	Kodayar, Western Ghats	0.5	> 30	352–1173	28–81	Sundarapandian and Swamy ¹⁸
PF	South Garo Hills and adjoining Nokrek area, Garo Hills	1.0	> 30	417–1023	29–162	Present study
SF	South Garo Hills and adjoining Nokrek area, Garo Hills	1.0	> 30	620–1111	12–151	Present study
Sal plantations	South Garo Hills and adjoining Nokrek area, Garo Hills	1.0	> 30	724–980	39–74	Present study
Other tropical forests						
Tropical rain forest	Barro Colorado Island, Panama	5	60.0	171	—	Thorington <i>et al.</i> ²³
Tropical rain forest	Barro Colorado Island, Panama	50	> 62.8	152	—	Hubbell and Foster ²⁴
Tropical rain forest	Amazonia	3	31.4	1420	28–68	Campbell <i>et al.</i> ²⁵
Equatorial insular forest	Eastern Caroline Island, Panama	50	> 31.4	98–114	17	Itow ¹⁵
Tropical rain forest	Jengka Reserve, Malaysia	11	91	104	23	Ho <i>et al.</i> ²⁶
Tropical rain forest	Gunung Silam, Malaysia	0.04	31.4	513–1596	23–46	Proctor <i>et al.</i> ²⁷
Tropical moist forest	Singapore	0.4	> 6.3	604	—	Swan Jr. ²⁸
Tropical rain forest	Valcan Barva, Costa Rica	6	> 31.4	391–617	—	Heaney and Proctor ⁷
Slope forest	New Caledonia	2.8	> 31.4	1533	49	Jaffré and Veillon ²⁹
Alluvium forest	New Caledonia	2.6	31.4	1183	47	Jaffré and Veillon ²⁹
Equatorial forest	Kongo Island, Zaire	—	—	440–553	10–45	Mosango ³⁰
Tropical rain forest	Amazonia	3	> 31.4	1720	78	Campbell <i>et al.</i> ¹⁶

—, Not reported.

other studies of tropical evergreen forest within India (294–1173 trees/ha; Table 3). In general, tree density varies with forest community type, forest age class, tree species and size class, site history, site condition, and other factors. Studies in tropical forests outside India also reveal a wide range of densities of trees > 30 cm gbh, ranging from 98 trees/ha in Panamanian equatorial insular forest¹⁵ to 1720 trees/ha in Amazonian tropical rain forests¹⁶ (Table 3). Tree density in our study area compares well with that reported from other tropical forests. Basal area recorded in this study ranged from 12 to 162 m²/ha, the upper value being far greater than the highest value of 107 m²/ha in any of the tropical forests of the world¹⁷ (Table 3). The high annual precipitation rate and equable tropical climate of our study area may have contributed to high tree growth rates and high tree basal area.

Shannon–Wiener values for tree species diversity in the present study were 4.27, 3.78 and 2.47 for PF, SF and sal plantations respectively, which are quite high compared to 2.20–2.65 for the tropical forests of Kodayar in the Western Ghats of southern India¹⁸. More comparable values were reported from Silent Valley, Kerala, with diversity index values of 4.15, 4.08 and 3.52 in riparian, mesic upland and less-mesic upland communities, respectively¹⁹. Tree species diversity values in tropical forests of Kalakad Reserved Forests in Western Ghats²⁰ were reported as 3.31 and 3.69, and in tropical forests of Barro Colorado Island in Panama⁴ as 4.8. It would be inappropriate to draw quantitative comparisons among these studies, however, because of significant differences in sample size, plot size and dimensions, choice of standard gbh by researchers, environmental conditions, and other site factors men-

Appendix 1. Species importance value of trees in different forest vegetation types (blank indicates the absence of species in the particular vegetation type)

Species	PF (n = 21 belt-transects)	SF (n = 10)	Sal (n = 4)	Grand total
<i>Shorea robusta</i> Gaertn.	6.02	12.95	104.90	123.87
<i>Schima wallichii</i> (DC.) Korth.	10.45	26.30	11.57	48.32
<i>Castanopsis purpurella</i> (Miq.) Balak.	10.30	16.75	4.57	31.62
<i>Syzygium cumini</i> (Linn.) Skeels	7.82	8.12	8.24	24.18
<i>Grewia microcos</i> Linn.	7.32	10.32	4.21	21.86
<i>Aporosa dioica</i> (Roxb.) Muell.-Arg.	5.56	8.07	7.32	20.94
<i>Glycosmis arborea</i> (Roxb.) DC.	0.66	—	16.08	16.74
<i>Dillenia pentagyna</i> Roxb.	6.86	6.41	3.03	16.30
<i>Sapium baccatum</i> Roxb.	5.54	4.58	4.63	14.75
<i>Eurya acuminata</i> DC.	4.83	8.04	1.01	13.88
<i>Macaranga denticulata</i> Muell.-Arg.	2.10	10.74	0.84	13.69
<i>Vitex peduncularis</i> Wall. ex Sch.	3.05	5.13	5.38	13.57
<i>Artocarpus chaplasha</i> Roxb.	2.50	1.15	9.00	12.65
<i>Canarium strictum</i> Roxb.	6.11	2.21	4.12	12.44
<i>Polyalthia simiarum</i> (Hk. f. & Th.) Hk. f. & Th.	12.30	—	—	12.30
<i>Diospyros variegata</i> Kurz	6.09	5.18	0.66	11.93
<i>Drimycarpus racemosus</i> (Roxb.) Hk. f.	7.31	2.57	1.99	11.86
<i>Ilex umbellulata</i> (Wall.) Loes.	2.71	4.54	4.27	11.52
<i>Stereospermum chelonoides</i> (Linn. f.) DC.	3.22	4.57	3.49	11.28
<i>Litsea monopelata</i> (Roxb.) Pers.	3.15	3.46	4.62	11.24
<i>Betula alnoides</i> Buch.-Ham. ex D. Don	2.27	5.39	2.82	10.48
<i>Cynometra polyandra</i> Roxb.	6.53	1.53	1.60	9.65
<i>Syzygium operculatum</i> (Roxb.) Wall	5.35	4.28	—	9.63
<i>Glochidion velutinum</i> Wt.	2.66	2.46	4.29	9.41
<i>Callicarpa arborea</i> Roxb.	1.82	6.19	1.37	9.38
<i>Persea villosa</i> (Roxb.) Koster.	3.33	4.52	1.32	9.17
<i>Lagerstroemia parviflora</i> Roxb.	2.88	4.53	1.72	9.14
<i>Terminalia bellirica</i> (Gaertn.) Roxb.	2.42	4.24	2.37	9.02
<i>Croton joufera</i> Roxb.	2.67	3.67	2.60	8.94
<i>Holarrhena antidysenterica</i> (Roth) A. DC.	2.50	3.99	2.39	8.88
<i>Castanopsis</i> sp.	4.63	4.18	—	8.81
<i>Aphanamixis polystachya</i> (Wall.) Parker	6.45	1.54	0.70	8.70
<i>Tectona grandis</i> Linn. f.	4.29	—	4.28	8.56
<i>Lannea coromandelica</i> (Houtt.) Merr.	2.69	2.14	3.40	8.23
<i>Mesua ferrea</i> Linn.	3.88	1.14	2.94	7.95
<i>Bauhinia purpurea</i> Linn.	1.27	2.33	4.00	7.60
<i>Walsura tubulata</i> Hiern	6.42	0.53	0.65	7.60
<i>Actinodaphne obovata</i> (Nees) Bl.	2.49	2.68	1.47	6.64
<i>Tetrameles nudiflora</i> R. Br.	4.63	1.08	0.91	6.62
<i>Careya arborea</i> Roxb.	1.56	2.80	2.13	6.49
<i>Ilex</i> sp.	1.98	1.57	2.92	6.47
<i>Garcinia cowa</i> Roxb. ex DC.	3.12	2.16	0.67	5.96
<i>Ficus gibbosa</i> Bl.	2.16	1.52	2.23	5.92
<i>Micromelum integerrimum</i> (Roxb.) Wt. & Arn.	2.91	1.42	1.56	5.90
<i>Kydia calycina</i> Roxb.	2.46	1.20	2.23	5.88
<i>Pterospermum lancifolium</i> DC.	2.62	2.62	0.64	5.88
<i>Calophyllum polyanthum</i> Choisy	1.25	4.58	—	5.84
<i>Polyalthia simiamum</i> (Hk. f. & Th.) Hk. f. & Th.	—	2.87	2.70	5.57
<i>Kaya floribunda</i> Wall.	3.10	1.72	0.75	5.56
<i>Salmalia malabarica</i> (DC.) Schott. & Endlicher	1.09	2.27	2.18	5.54
<i>Elaeocarpus aristatus</i> Roxb.	2.71	1.98	0.69	5.38
<i>Bursera serrata</i> Colebr.	1.60	0.69	3.08	5.37
<i>Albizia odoratissima</i> (Linn. f.) Benth.	0.56	2.84	1.59	4.99
<i>Michelia champaca</i> Linn.	4.70	0.23	—	4.93
<i>Mallotus philippinensis</i> (Lam.) Muell.-Arg.	1.65	0.90	2.23	4.78
<i>Glochidion sphaerogynum</i> Kurz	1.38	3.37	—	4.75
<i>Oreocnide integrifolia</i> (Gaud.) Miq.	1.58	3.06	—	4.64
<i>Elaeocarpus rugosus</i> Roxb.	1.48	2.42	0.70	4.60
<i>Boehmeria hamiltoniana</i> Wedd.	0.65	3.45	—	4.10
<i>Cinnamomum bejolghota</i> (Buch.-Ham.) Sweet.	2.27	1.12	0.70	4.10

Contd...

Appendix 1. (contd....)

Species	PF (n = 21 belt-transects)	SF (n = 10)	Sal (n = 4)	Grand total
<i>Albizia lebbek</i> (Linn.) Benth.	0.91	1.45	1.73	4.09
<i>Duabanga grandiflora</i> (Roxb. ex DC.) Walp.	2.41	1.66	—	4.07
<i>Trewia nudiflora</i> Linn.	2.67	0.43	0.76	3.86
<i>Actinodaphne augustifolia</i> Nees	1.47	0.72	1.58	3.77
<i>Emblica officinalis</i> Gaertn.	0.77	1.59	1.35	3.71
<i>Pterospermum acerifolium</i> Willd.	1.58	1.44	0.62	3.64
<i>Litsea sebifera</i> Pers.	0.97	1.91	0.67	3.55
<i>Vitex glabrata</i> R. Br.	0.57	1.63	1.25	3.45
<i>Artocarpus gomezianus</i> Wall. ex Trecul	0.90	1.07	1.41	3.37
<i>Maesa ramentacea</i> Wall.	0.36	2.24	0.71	3.31
<i>Albizia chinensis</i> (Osb.) Merr.	1.45	1.18	0.63	3.25
<i>Hibiscus macrophyllus</i> Roxb. ex Hornem.	1.05	1.55	0.64	3.23
<i>Ficus infectoria</i> Roxb.	0.18	0.21	2.69	3.08
<i>Gmelina arborea</i> Roxb.	1.28	0.86	0.90	3.04
<i>Randia griffithii</i> Hk. f.	0.71	0.48	1.81	3.00
<i>Celtis tetrandia</i> Roxb.	0.99	0.53	1.47	3.00
<i>Toona ciliata</i> Roem.	0.81	0.71	1.43	2.95
<i>Bridelia retusa</i> (Linn.) Spreng	1.18	1.03	0.69	2.90
<i>Ailanthus integrifolia</i> Lamk.	1.76	0.24	0.83	2.84
<i>Sterculia villosa</i> Roxb.	1.09	1.68	—	2.77
<i>Viburnum colebrookianum</i> Wall. ex DC.	0.98	1.75	—	2.73
<i>Mangifera sylvatica</i> Roxb.	1.76	0.92	—	2.68
<i>Rhus acuminata</i> DC.	1.30	0.67	0.66	2.63
<i>Oroxylum indicum</i> (Linn.) Vent.	1.09	0.84	0.70	2.63
<i>Trema orientalis</i> (Linn.) Bl.	1.06	0.94	0.62	2.62
<i>Saurauia nepaulensis</i> DC.	0.49	2.07	—	2.57
<i>Acronychia pedunculata</i> (Linn.) Miq.	1.81	0.68	—	2.49
<i>Schefflera</i> sp.	0.52	0.67	1.26	2.45
<i>Parapentapanax subcordatum</i> (G. Don) Hutch.	2.07	0.29	—	2.37
<i>Vitex pinnata</i> Linn.	1.11	0.39	0.76	2.26
<i>Casearia glomerata</i> Roxb.	1.63	0.61	—	2.24
<i>Saraca asoca</i> (Roxb.) de Wilde	1.57	0.63	—	2.19
<i>Carallia brachiata</i> (Lour.) Merr.	1.15	0.99	—	2.15
<i>Alstonia scholaris</i> (Linn.) R. Br.	0.60	0.69	0.81	2.11
<i>Ligustrum robustum</i> (Roxb.) Bl.	1.21	0.85	—	2.06
<i>Flacourtia jangomas</i> (Lour.) Raeusch.	0.97	1.00	—	1.97
<i>Moringa oleifera</i> Lamk.	1.19	0.67	—	1.86
<i>Pterygota alata</i> (Roxb.) R. Br.	0.64	1.15	—	1.79
<i>Lagerstroemia speciosa</i> (Linn.) Pers.	0.47	1.30	—	1.77
<i>Garcinia tinctoria</i> (DC.) W. F. Wight	0.70	1.03	—	1.74
<i>Tamarindus indica</i> Linn.	0.60	0.39	0.72	1.71
<i>Grewia</i> sp.	1.04	0.66	—	1.69
<i>Ficus nervosa</i> Heyne ex Roth	0.85	0.20	0.64	1.69
<i>Syzygium balsameum</i> (Wt.) Wall. ex AM. & SM. Cowan	0.99	0.69	—	1.68
<i>Macaranga indica</i> Wt.	0.46	1.21	—	1.67
<i>Erythrina stricta</i> Roxb.	0.55	1.11	—	1.66
<i>Cinnamomum glaucescens</i> (Nees) Meissn.	0.86	—	0.77	1.62
<i>Artocarpus</i> sp.	1.12	0.42	—	1.54
<i>Xylosma longifolium</i> Clos.	0.16	0.55	0.83	1.53
<i>Aesculus assamica</i> Griff.	1.08	0.43	—	1.51
<i>Knema linifolia</i> (Roxb.) Warb. Mon. Myrist.	0.98	0.48	—	1.45
<i>Phoebe</i> sp.	0.56	0.23	0.62	1.42
<i>Adina cordifolia</i> (Roxb.) Hk. f. ex Brandis	—	—	1.42	1.42
<i>Ficus semicordata</i> Buch.-Ham. ex Sm.	0.73	0.66	—	1.39
<i>Chikrassia tabularis</i> Anbr. Juss.	1.31	—	—	1.31
<i>Mallotus roxburghianus</i> Muell.-Arg.	0.43	0.84	—	1.28
<i>Gynocardia odorata</i> R. Br.	0.33	0.21	0.72	1.26
<i>Garcinia lancifolia</i> (G. Don) Roxb.	0.73	0.48	—	1.21
<i>Walsura robusta</i> Roxb.	1.19	—	—	1.19
<i>Castanopsis indica</i> A. DC.	0.71	0.46	—	1.18
<i>Ulmus lanceifolia</i> Roxb.	0.51	0.65	—	1.16

Contd....

Appendix 1. (contd....)

Species	PF (n = 21 belt-transects)	SF (n = 10)	Sal (n = 4)	Grand total
<i>Podocarpus neerifolia</i> D. Don	0.10	1.03	—	1.13
<i>Ilex embelioides</i> Hk. f.	1.10	—	—	1.10
<i>Ochna integerrima</i> (Lour.) Merr.	0.21	0.27	0.62	1.10
<i>Cinnamomum tamala</i> Fr. Nees	0.18	0.91	—	1.08
<i>Diospyros malabarica</i> (Desr.) Kostel	1.06	—	—	1.06
<i>Ostodes paniculata</i> Bl.	0.48	0.54	—	1.01
<i>Premna latifolia</i> Roxb.	0.34	—	0.67	1.01
<i>Polyalthia jenkinsii</i> Benth. & Hk. f.	0.37	—	0.62	1.00
<i>Terminalia citrina</i> (Gaertn.) Flem.	0.72	0.26	—	0.98
<i>Sterculia colorata</i> Roxb.	0.43	0.53	—	0.96
<i>Pithecellobium heterophyllum</i> (Roxb.) Haridasan & Rao	0.48	0.45	—	0.93
<i>Meliosma simplicifolia</i> (Roxb.) Walp	0.26	—	0.65	0.91
<i>Bischofia javanica</i> Bl.	0.66	0.20	—	0.86
<i>Heteropanax fragrans</i> (D. Don) Seem	0.30	0.45	—	0.75
<i>Alangium chinense</i> (Lour.) Harms	0.08	0.65	—	0.73
<i>Ficus</i> sp.	0.73	—	—	0.73
<i>Firmiana colorata</i> (Roxb.) R. Br.	0.72	—	—	0.72
<i>Sapium eugeniaefolium</i> Ham. ex Hk. f.	0.65	—	—	0.65
<i>Aquilaria malaccensis</i> Lamk.	0.35	0.26	—	0.61
<i>Mallotus tetracoccus</i> (Roxb.) Kurz.	0.60	—	—	0.60
<i>Ficus lampunga</i> Miq.	0.08	0.49	—	0.57
<i>Ficus hispida</i> Linn. f.	0.29	0.23	—	0.52
<i>Pithecellobium monadelphum</i> (Roxb.) Koster.	0.48	—	—	0.48
<i>Croton roxburghii</i> Balak.	0.45	—	—	0.45
<i>Rhus javanica</i> Linn.	0.22	0.20	—	0.43
<i>Ardisia</i> sp.	0.38	—	—	0.38
<i>Cassia fistula</i> Linn.	0.17	0.21	—	0.38
<i>Aporosa</i> sp.	0.35	—	—	0.35
<i>Neocinnamomum caudatum</i> (Wall. ex Nees) Merr.	0.34	—	—	0.34
<i>Ficus heterophylla</i> Linn. f.	0.34	—	—	0.34
<i>Anthocephalus chinensis</i> (Lam.) A. Rich. ex Walp.	0.34	—	—	0.34
<i>Lithocarpus elegans</i> (Bl.) Hatus ex Soep.	0.31	—	—	0.31
<i>Dalbergia stipulacea</i> Roxb.	0.30	—	—	0.30
<i>Dillenia indica</i> Linn.	0.09	0.21	—	0.29
<i>Bauhinia malabarica</i> Roxb.	0.27	—	—	0.27
<i>Dysoxylum alliariatum</i> (Ham.) Balak.	—	0.22	—	0.22
<i>Anacardium occidentale</i> Linn.	—	0.20	—	0.20
<i>Bridelia monoica</i> (Lour.) Mess	0.18	—	—	0.18
<i>Garuga pinnata</i> Roxb.	0.18	—	—	0.18
<i>Syzygium</i> sp. (1)	0.18	—	—	0.18
<i>Derris robusta</i> (Roxb. ex DC.) Benth.	0.18	—	—	0.18
<i>Citrus medica</i> Linn.	0.16	—	—	0.16
<i>Lepisanthes rubiginosa</i> (Roxb.) Leenh.	0.10	—	—	0.10
<i>Bauhinia</i> sp.	0.08	—	—	0.08
<i>Syzygium</i> sp. (2)	0.08	—	—	0.08

tioned above. Still, it is useful to rank-order tropical forests by tree species richness, density, basal area and diversity. In so doing, tropical forests from the present study rank as some of the most diverse and dense in the world.

Using 1 ha belt-transects as sampling unit, species-effort curves from the current study (Figure 3) suggest adequate sampling in PF but not SF, because the SF curve does not asymptote. However, the number of tree species in PF was consistently greater than in SF at all sample sizes. Our rarefaction analysis also suggested that PFs are always more tree-diverse (Figure 4). For example, a random sample of 5000 trees would expect to draw from about

150 species in PF but only 120 species in SF (Figure 4). We could not find similar rarefaction analyses in other tropical forests of India and the world by which to draw comparisons.

Management implications for forest biodiversity conservation

The rarer tree species with poor representation in our samples need proper attention from plant biologists to determine their conservation status and key functions.

Appendix 2. Species distribution pattern in different forest vegetation types

Forest vegetation types	Regular (low abundance and high frequency)	Clumped (high abundance and low frequency)
PF	<i>Artocarpus gomezianus</i> , <i>Artocarpus</i> sp., <i>Oroxylum indicum</i> , <i>Macaranga indica</i> , <i>Moringa oleifera</i> , <i>Alstonia scholaris</i> , <i>Rhus acuminata</i> , <i>Duabanga grandiflora</i> , <i>Albizia chinensis</i> and <i>Ficus nervosa</i>	<i>Tectona grandis</i> , <i>Casearia glomerata</i> , <i>Boehmeria hamiltoniana</i> , <i>Ilex embelioides</i> , <i>Syzygium</i> sp., <i>Cinnamomum tamala</i> , <i>Castanopsis</i> sp., <i>Syzygium balsameum</i> , <i>Saurauia nepaulensis</i> and <i>Shorea robusta</i>
SF	<i>A. gomezianus</i> , <i>Garcinia tinctoria</i> , <i>Gmelina arborea</i> , <i>Pterygota alata</i> , <i>Mesua ferrea</i> , <i>Mallotus roxburghianus</i> , <i>O. indicum</i> , <i>Litsea sebifera</i> , <i>R. acuminata</i> and <i>Saraca asoca</i>	<i>Castanopsis</i> sp., <i>B. hamiltoniana</i> , <i>Viburnum colebrookianum</i> , <i>S. nepaulensis</i> , <i>S. robusta</i> , <i>Calophyllum polyanthum</i> , <i>Syzygium operculatum</i> , <i>Acronychia pedunculata</i> , <i>Lagerstroemia speciosa</i> and <i>Schima wallichii</i>
Sal plantations	<i>Persea villosa</i> , <i>Schefflera</i> sp., <i>Vitex glabrata</i> , <i>Drimycarpus racemosus</i> , <i>Betula alnoides</i> , <i>Ficus gibbosa</i> , <i>Toonaciliata</i> , <i>Albizia chinensis</i> , <i>Careya arborea</i> and <i>Emblica officinalis</i>	<i>S. robusta</i> , <i>Glycosmis arborea</i> , <i>Ficus infectoria</i> , <i>Actinodaphne augustifolia</i> , <i>Callicarpa arborea</i> , <i>Schima wallichii</i> , <i>Albizia odoratissima</i> , <i>Aporusa dioica</i> , <i>Salmalia malabarica</i> and <i>Eurya acuminata</i>

Appendix 3. Species composition in three PF formations and three SF successional stages

PF1: <i>Tectona grandis</i> , <i>Castanopsis purpurella</i> , <i>Canarium strictum</i> , <i>Polyalthia simiarum</i> , <i>Drimycarpus racemosus</i> , <i>Grewia microcos</i> , <i>Dillenia pentagyna</i> , <i>Tetrameles nudiflora</i> , <i>Schima wallichii</i> and <i>Shorea robusta</i>	SF1: <i>S. wallichii</i> , <i>Macaranga denticulata</i> , <i>C. purpurella</i> , <i>S. cumini</i> , <i>Albizia odoratissima</i> , <i>Stereospermum chelonoides</i> , <i>E. acuminata</i> , <i>Persea villosa</i> , <i>Aporusa dioica</i> and <i>Callicarpa arborea</i>
PF2: <i>P. simiarum</i> , <i>Walsura tubulata</i> , <i>S. wallichii</i> , <i>Syzygium cumini</i> , <i>Cynometra polyandra</i> , <i>G. microcos</i> , <i>S. robusta</i> , <i>D. racemosus</i> , <i>C. purpurella</i> and <i>Sapium baccatum</i>	SF2: <i>Grewia microcos</i> , <i>Schima wallichii</i> , <i>Aporusa dioica</i> , <i>Macaranga denticulata</i> , <i>Castanopsis purpurella</i> , <i>S. cumini</i> , <i>Terminalia bellirica</i> , <i>S. robusta</i> , <i>Holarrhena antidysenterica</i> and <i>C. arborea</i>
PF3: <i>Aphanamixis polystachya</i> , <i>Syzygium operculatum</i> , <i>Castanopsis</i> sp., <i>S. wallichii</i> , <i>Diospyros variegata</i> , <i>C. purpurella</i> , <i>Parapentapanax subcordatum</i> , <i>Garcinia cowa</i> , <i>Eurya acuminata</i> and <i>Dillenia pentagyna</i>	SF3: <i>S. wallichii</i> , <i>C. purpurella</i> , <i>S. robusta</i> , <i>E. acuminata</i> , <i>D. variegata</i> , <i>D. pentagyna</i> , <i>Betula alnoides</i> , <i>S. operculatum</i> , <i>Calophyllum polyanthum</i> and <i>Castanopsis</i> sp.

These species include (in increasing order of SIV) *Le-pisanthes rubiginosa*, *Citrus medica*, *Derris robusta*, *Garuga pinnata*, *Bridelia monoica*, *Dysoxylum alliariun*, *Bauhinia malabarica*, *Dillenia indica*, *Dalbergia stipulacea*, *Lithocarpus elegans*, *Anthocephalus chinensis*, *Ficus heterophylla*, *Neocinnamomum caudatum*, *Rhus javanica*, *Croton roxburghii* and *Pithecellobium monadelphum*. Mapping concentration areas of these species and further studies on their key ecological and cultural functions would help identify locations for conservation actions and determine which wildlife species may depend on them in South Garo Hills.

Forest managers can use such information on rare and common tree species alike to help manage wildlife habitat as well as provide cultural resource values of these trees. The quantitative characters related with density, dominance and diversity of these trees could well act as indicators of changes and susceptibility to anthropogenic stressors among various vegetation categories and their formations, which could be further interpreted as distinct wildlife habitats.

The frequency distribution of tree species suggested that most of them had low frequency as would be expected

in typical species-abundance distributions. PF and SF did not significantly differ in tree species frequency class distributions, although SF had a higher proportion of species in the lowest frequency class, which indicated that SFs were more heterogeneous compared to PF or sal plantations. The knowledge on distribution patterns of several tree species would be of prime importance in deciding the management options for specific host populations of native wildlife, which otherwise may face the danger of local extinction due to frequent removal of old forest conditions in the Garo Hills.

The number of observed tree species and species richness, diversity and evenness all varied significantly among the three forest vegetation types, whereas only the Menhinick index of species richness varied significantly among PF formations and SF successional stages. Rarefaction analysis suggested that PF had greater tree species richness than SF. Among the three PF formations, PF1 was the most tree-diverse, and among the three SF successional stages, SF3 was the most tree-diverse. SF1 and SF3 were more tree diverse than SF2, which suggested a higher colonization or renewal rate of pioneer tree species in the

early successional stages and an increase again in later stages as conditions allow for more mature forest conditions. Although we found that SF is less tree-diverse than PF, trees of SF nonetheless provide valuable services to wildlife as well as to human beings.

Our findings could help rationalize the need for an ecologically sound fallow period between *jhum* cutting cycles, viz. extending *jhum* cycles from their current periods of 2–5 years to a longer period of 10–20+ years. This would help ensure renewal of at least some tree species, wildlife habitat elements, and valuable cultural forest resources associated with SF3 and some PF. Further, silviculture of PF tree species coupled with analysis of various forest formations of PF, successional stages of SF and response by individual tree species, would provide information useful in recovering PF following clearing and developing a scientific foundation for forest management and biodiversity conservation. It would recommend a better form of regulated *jhum* to ensure that at least some patches and elements of PF could be restored and retained throughout the region to reduce the impact of forest fragmentation which frequent *jhumming* is posing over the landscape.

Conclusion

The forest vegetation types in the Garo Hills investigated during the present study include PF, SF, and sal plantations, in which PF had the highest tree species richness. PF formations varied mostly by tree density and basal area being significantly greater in higher elevations. SF successional stages varied mostly by early stages having higher tree species richness and later stages having greater basal area.

Overall, stand density, basal area and diversity of tropical forests of western Meghalaya equal or exceed those of the densest tropical rainforests anywhere in the world. The tree community structure described in this communication depends on distributional and abundance patterns of individual tree species. Further studies on silviculture of rare trees and those closely associated with the PF vegetation type, and with the various PF formations and SF successional stages, would provide information useful to help recover PF following clearing (*jhum*), and would provide a scientific foundation for better regulation of *jhum* to ensure that at least some patches and elements of PF are restored and retained throughout the region. We recommend also that extending the *jhum* cycle to 10–20+ years also can help restore some PF conditions.

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