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 sustainability[1]. 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 scale[3]. 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 world[1]. 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, Imangiri 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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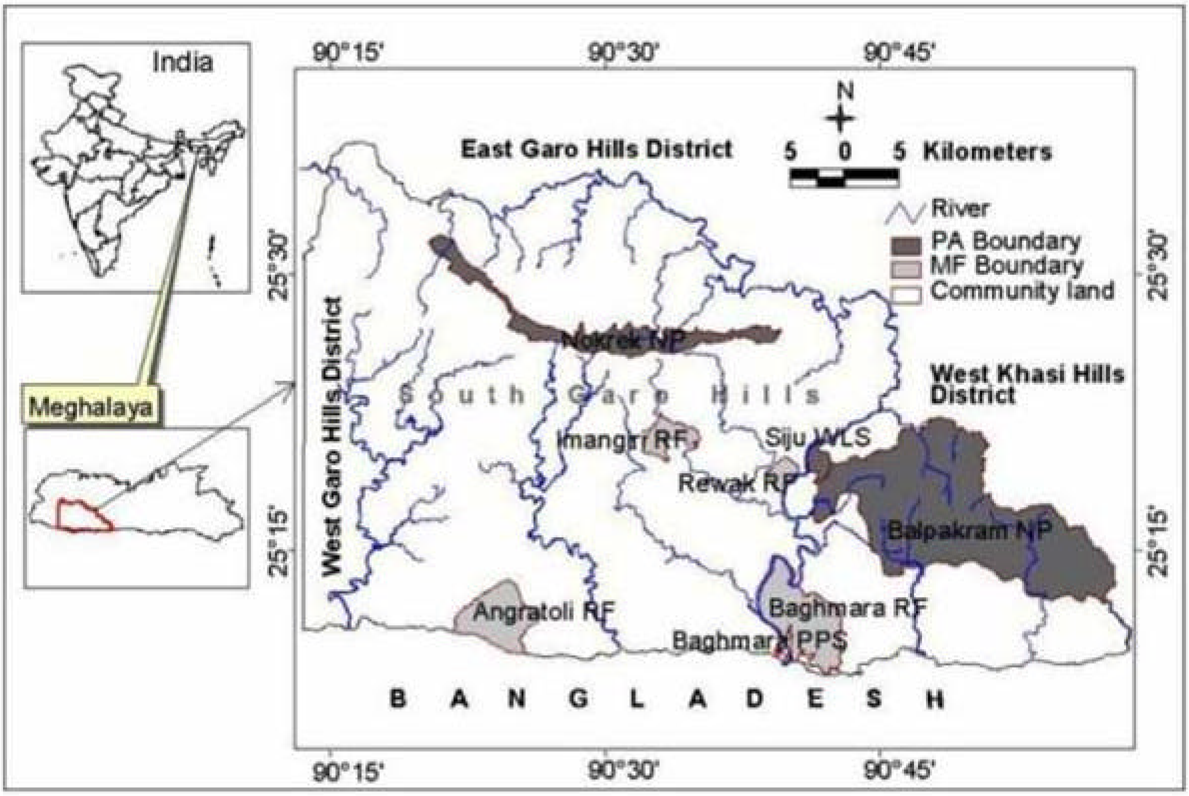

Figure 1. Study area of Garo Hills in western Meghalaya, Northeast India. PA, Protected area; MF, Managed forest also known as RF, reserved forest in Garo Hills; WLS, Wildlife sanctuary; PPS, Pitcher plant sanctuary.

tropical forest formations[8] 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 Horrills[11]. We located the belt-transects along existing footpaths 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), according to Raunkier's law of frequency, and we used the ratio of abundance to frequency as a measure of contagion of patterns tree distribution[3]. We computed tree density (number of trees/ha) and basal area (m^2/ha) for each vegetation type to compute SIV of each tree species, according to Misra[3], 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), Sørenson's (SI) and Czekanowski's (CI) indices. Jacard's and Sørenson'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 species[12].

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 stages[13]. We also compared these index measures using rarefaction by plotting the expected number of species or $E(Sn)$ against the number of trees to standardize the sample size for valid comparison[14]. 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%). *Artocararpus 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 *Macaranga indica*, *Moringa oleifera*, *Alstonia scholaris*, *Duabanga 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.

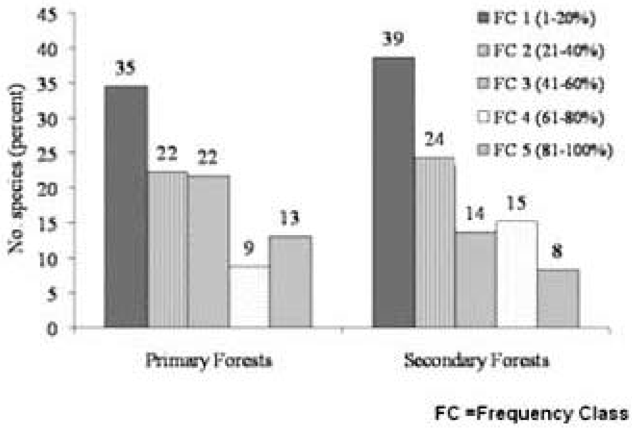

Figure 2. Raunkier's frequency classes of tree species in primary and secondary forests.

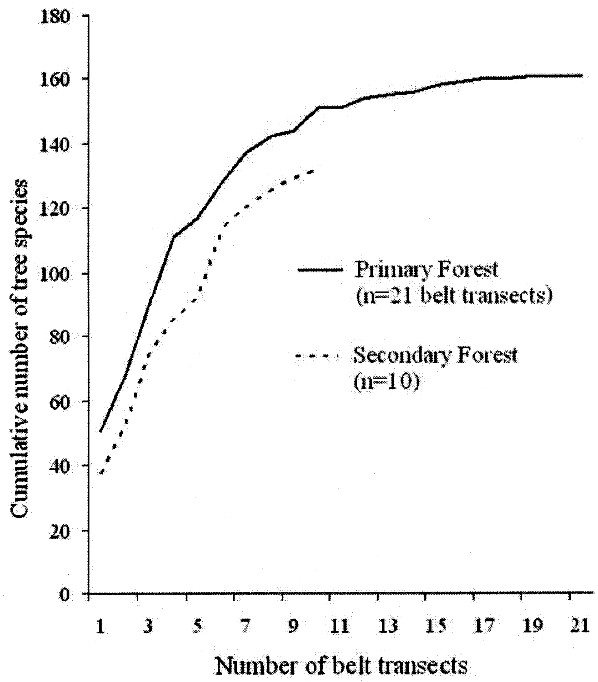

Figure 3. Cumulative number of tree species as a function of cumulative number of 1 ha belt-transects in primary and secondary forests.

Table 1. Phyotosociological characters and diversity patterns (mean values ± 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 ± 10	816 ± 187	63 ± 35	2.35 ± 0.53	3.32 ± 0.34	0.61 ± 0.10
1a. PF1	67 ± 9	684 ± 205	51 ± 27	2.65 ± 0.51	3.33 ± 0.40	0.57 ± 0.14
1b. PF2	61 ± 7	906 ± 124	50 ± 9	2.05 ± 0.32	3.23 ± 0.32	0.62 ± 0.07
1c. PF3	71 ± 16	878 ± 130	118 ± 33	2.43 ± 0.66	3.49 ± 0.25	0.66 ± 0.04
2. SF	53 ± 11	916 ± 151	43 ± 43	1.79 ± 0.38	2.94 ± 0.27	0.58 ± 0.10
2a. SF1	62 ± 12	821 ± 254	16 ± 3	2.19 ± 0.23	3.14 ± 0.17	0.55 ± 0.16
2b. SF2	47 ± 7	918 ± 25	51 ± 5	1.53 ± 0.23	2.8 ± 0.10	0.6 ± 0.06
2c. SF3	52 ± 9	1006 ± 91	93 ± 51	1.65 ± 0.34	3.05 ± 0.43	0.64 ± 0.08
3. Sal plantation	42 ± 13	887 ± 115	54 ± 17	1.82 ± 0.39	3.29 ± 0.43	0.69 ± 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

	F	*P*
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 5 *a*). 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 5 *b*). 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).

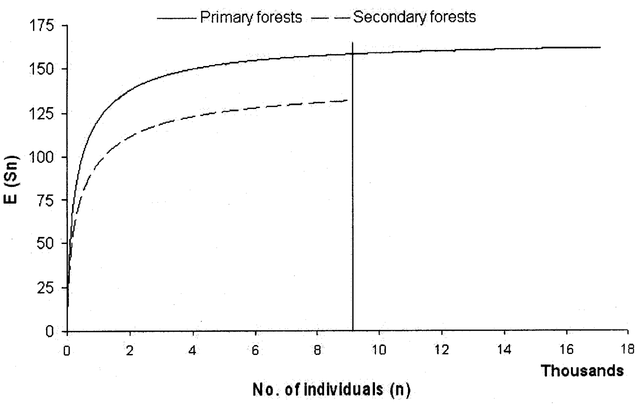

Figure 4. Rarefaction curves standardizing number of samples (1 ha belt transects) for comparing tree species richness in PF ($n = 21$ belt transects; top curve) and in SF ($n = 10$; bottom curve). $E(Sn)$, Expected number of tree species.

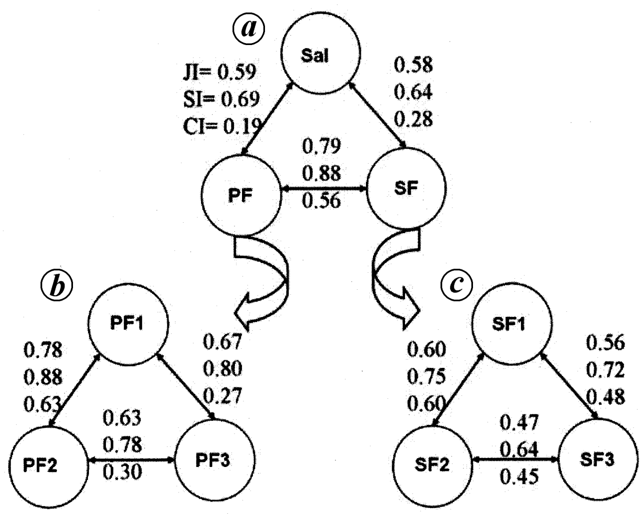

Figure 5. Jacard's (JI), Sørenson's (SI), and Czekanowski's (CI) indices of similarity measured among: (***a***) three broad forest vegetation types of primary forest (PF), secondary forest (SF), and sal plantations (Sal); (***b***) three formations of PF and (***c***) three successional stages of SF.

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 5 *c*).

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 State[2]. 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 *et al.*[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 *et al.*[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 *et al.*[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 *et al.*[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 *et al.*[25]
Equatorial insular forest	Eastern Carolline Island, Panama	50	>31.4	98–114	17	Itow[15]
Tropical rain forest	Jengka Reserve, Malaysia	11	91	104	23	Ho *et al.*[26]
Tropical rain forest	Gunung Silam, Malaysia	0.04	31.4	513–1596	23–46	Proctor *et al.*[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 *et al.*[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 forest[15] to 1720 trees/ha in Amazonian tropical rain forests[16] (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 m^2/ha, the upper value being far greater than the highest value of 107 m^2/ha in any of the tropical forests of the world[17] (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 India[18]. 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, respectively[19]. Tree species diversity values in tropical forests of Kalakad Reserved Forests in Western Ghats[20] were reported as 3.31 and 3.69, and in tropical forests of Barro Colorado Island in Panama[4] 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
Shorea robusta Gaertn.	6.02	12.95	104.90	123.87
Schima wallichii (DC) Korth.	10.45	26.30	11.57	48.32
Castanopsis purpurella (Miq.) Balak.	10.30	16.75	4.57	31.62
Syzygium cumini (Linn.) Skeels	7.82	8.12	8.24	24.18
Grewia microcos Linn.	7.32	10.32	4.21	21.86
Aporusa dioica (Roxb.) Muell.-Arg.	5.56	8.07	7.32	20.94
Glycosmis arborea (Roxb.) DC.	0.66	–	16.08	16.74
Dillenia pentagyna Roxb.	6.86	6.41	3.03	16.30
Sapium baccatum Roxb.	5.54	4.58	4.63	14.75
Eurya acuminata DC.	4.83	8.04	1.01	13.88
Macaranga denticulata Muell.-Arg.	2.10	10.74	0.84	13.69
Vitex peduncularis Wall. ex Sch.	3.05	5.13	5.38	13.57
Artocarpus chaplasha Roxb.	2.50	1.15	9.00	12.65
Canarium strictum Roxb.	6.11	2.21	4.12	12.44
Polyalthia simiarum (Hk. f. & Th.) Hk. f. & Th.	12.30	–	–	12.30
Diospyros variegata Kurz	6.09	5.18	0.66	11.93
Drimycarpus racemosus (Roxb.) Hk. f.	7.31	2.57	1.99	11.86
Ilex umbellulata (Wall.) Loes.	2.71	4.54	4.27	11.52
Stereospermum chelonoides (Linn. f.) DC.	3.22	4.57	3.49	11.28
Litsea monopelata (Roxb.) Pers.	3.15	3.46	4.62	11.24
Betula alnoides Buch.-Ham. ex D. Don	2.27	5.39	2.82	10.48
Cynometra polyandra Roxb.	6.53	1.53	1.60	9.65
Syzygium operculatum (Roxb.) Wall	5.35	4.28	–	9.63
Glochidion velutinum Wt.	2.66	2.46	4.29	9.41
Callicarpa arborea Roxb.	1.82	6.19	1.37	9.38
Persea villosa (Roxb.) Koster.	3.33	4.52	1.32	9.17
Lagerstroemia parviflora Roxb.	2.88	4.53	1.72	9.14
Terminalia bellirica (Gaertn.) Roxb.	2.42	4.24	2.37	9.02
Croton joufera Roxb.	2.67	3.67	2.60	8.94
Holarrhena antidysenterica (Roth) A. DC.	2.50	3.99	2.39	8.88
Castanopsis sp.	4.63	4.18	–	8.81
Aphanamixis polystachya (Wall.) Parker	6.45	1.54	0.70	8.70
Tectona grandis Linn. f.	4.29	–	4.28	8.56
Lannea coromandelica (Houtt.) Merr.	2.69	2.14	3.40	8.23
Mesua ferrea Linn.	3.88	1.14	2.94	7.95
Bauhinia purpurea Linn.	1.27	2.33	4.00	7.60
Walsura tubulata Hiern	6.42	0.53	0.65	7.60
Actinodaphne obovata (Nees) Bl.	2.49	2.68	1.47	6.64
Tetrameles nudiflora R. Br.	4.63	1.08	0.91	6.62
Careya arborea Roxb.	1.56	2.80	2.13	6.49
Ilex sp.	1.98	1.57	2.92	6.47
Garcinia cowa Roxb. ex DC.	3.12	2.16	0.67	5.96
Ficus gibbosa Bl.	2.16	1.52	2.23	5.92
Micromelem integerrimum (Roxb.) Wt. & Arn.	2.91	1.42	1.56	5.90
Kydia calycina Roxb.	2.46	1.20	2.23	5.88
Pterospermum lancifolium DC.	2.62	2.62	0.64	5.88
Calophyllum polyanthum Choisy	1.25	4.58	–	5.84
Polyalthia simiamum (Hk. f. & Th.) Hk. f. & Th.	–	2.87	2.70	5.57
Kayea floribunda Wall.	3.10	1.72	0.75	5.56
Salmalia malabarica (DC.) Schott. & Endlicker	1.09	2.27	2.18	5.54
Elaeocarpus aristatus Roxb.	2.71	1.98	0.69	5.38
Bursera serrata Colebr.	1.60	0.69	3.08	5.37
Albizia odoratissima (Linn. f.) Benth.	0.56	2.84	1.59	4.99
Michelia champaca Linn.	4.70	0.23	–	4.93
Mallotus philippinensis (Lam.) Muell.-Arg.	1.65	0.90	2.23	4.78
Glochidion sphaerogynum Kurz	1.38	3.37	–	4.75
Oreocnide integrifolia (Gaud.) Miq.	1.58	3.06	–	4.64
Elaeocarpus rugosus Roxb.	1.48	2.42	0.70	4.60
Boehmeria hamiltoniana Wedd.	0.65	3.45	–	4.10
Cinnamomum bejolghota (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
Albizia lebbek (Linn.) Benth.	0.91	1.45	1.73	4.09
Duabanga grandiflora (Roxb. ex DC.) Walp.	2.41	1.66	–	4.07
Trewia nudiflora Linn.	2.67	0.43	0.76	3.86
Actinodaphne augustifolia Nees	1.47	0.72	1.58	3.77
Emblica officinalis Gaertn.	0.77	1.59	1.35	3.71
Pterospermum acerifolium Willd.	1.58	1.44	0.62	3.64
Litsea sebifera Pers.	0.97	1.91	0.67	3.55
Vitex glabrata R. Br.	0.57	1.63	1.25	3.45
Artocarpus gomezianus Wall. ex Trecul	0.90	1.07	1.41	3.37
Maesa ramentacea Wall.	0.36	2.24	0.71	3.31
Albizia chinensis (Osb.) Merr.	1.45	1.18	0.63	3.25
Hibiscus macrophyllus Roxb. ex Hornem.	1.05	1.55	0.64	3.23
Ficus infectoria Roxb.	0.18	0.21	2.69	3.08
Gmelina arborea Roxb.	1.28	0.86	0.90	3.04
Randia griffithii Hk. f.	0.71	0.48	1.81	3.00
Celtis tetranda Roxb.	0.99	0.53	1.47	3.00
Toona ciliata Roem.	0.81	0.71	1.43	2.95
Bridelia retusa (Linn.) Spreng	1.18	1.03	0.69	2.90
Ailanthus integrifolia Lamk.	1.76	0.24	0.83	2.84
Sterculia villosa Roxb.	1.09	1.68	–	2.77
Viburnum colebrookianum Wall. ex DC.	0.98	1.75	–	2.73
Mangifera sylvatica Roxb.	1.76	0.92	–	2.68
Rhus acuminata DC.	1.30	0.67	0.66	2.63
Oroxylum indicum (Linn.) Vent.	1.09	0.84	0.70	2.63
Trema orientalis (Linn.) Bl.	1.06	0.94	0.62	2.62
Saurauia nepaulensis DC.	0.49	2.07	–	2.57
Acronychia pedunculata (Linn.) Miq.	1.81	0.68	–	2.49
Schefflera sp.	0.52	0.67	1.26	2.45
Parapentapanax subcordatum (G. Don) Hutch.	2.07	0.29	–	2.37
Vitex pinnata Linn.	1.11	0.39	0.76	2.26
Casearia glomerata Roxb.	1.63	0.61	–	2.24
Saraca asoca (Roxb.) de Wilde	1.57	0.63	–	2.19
Carallia brachiata (Lour.) Merr.	1.15	0.99	–	2.15
Alstonia scholaris (Linn.) R. Br.	0.60	0.69	0.81	2.11
Ligustrum robustum (Roxb.) Bl.	1.21	0.85	–	2.06
Flacourtia jangomas (Lour.) Raeusch.	0.97	1.00	–	1.97
Moringa oleifera Lamk.	1.19	0.67	–	1.86
Pterygota alata (Roxb.) R. Br.	0.64	1.15	–	1.79
Lagerstroemia speciosa (Linn.) Pers.	0.47	1.30	–	1.77
Garcinia tinctoria (DC.) W. F. Wight	0.70	1.03	–	1.74
Tamarindus indica Linn.	0.60	0.39	0.72	1.71
Grewia sp.	1.04	0.66	–	1.69
Ficus nervosa Heyne ex Roth	0.85	0.20	0.64	1.69
Syzygium balsameum (Wt.) Wall. ex AM. & SM. Cowan	0.99	0.69	–	1.68
Macaranga indica Wt.	0.46	1.21	–	1.67
Erythrina stricta Roxb.	0.55	1.11	–	1.66
Cinnamomum glaucescens (Nees) Meissn.	0.86	–	0.77	1.62
Artocarpus sp.	1.12	0.42	–	1.54
Xylosma longifolium Clos.	0.16	0.55	0.83	1.53
Aesculus assamica Griff.	1.08	0.43	–	1.51
Knema linifolia (Roxb.) Warb. Mon. Myrist.	0.98	0.48	–	1.45
Phoebe sp.	0.56	0.23	0.62	1.42
Adina cordifolia (Roxb.) Hk. f. ex Brandis	–	–	1.42	1.42
Ficus semicordata Buch.-Ham. ex Sm.	0.73	0.66	–	1.39
Chikrassia tabularis Anbr. Juss.	1.31	–	–	1.31
Mallotus roxburghianus Muell.-Arg.	0.43	0.84	–	1.28
Gynocardia odorata R. Br.	0.33	0.21	0.72	1.26
Garcinia lancifolia (G.Don) Roxb.	0.73	0.48	–	1.21
Walsura robusta Roxb.	1.19	–	–	1.19
Castanopsis indica A. DC.	0.71	0.46	–	1.18
Ulmus lanceifolia 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
Podocarpus neerifolia D. Don	0.10	1.03	–	1.13
Ilex embelioides Hk. f.	1.10	–	–	1.10
Ochna integerrima (Lour.) Merr.	0.21	0.27	0.62	1.10
Cinnamomum tamala Fr. Nees	0.18	0.91	–	1.08
Diospyros malabarica (Desr.) Kostel	1.06	–	–	1.06
Ostodes paniculata Bl.	0.48	0.54	–	1.01
Premna latifolia Roxb.	0.34	–	0.67	1.01
Polyalthia jenkinsii Benth. & Hk. f.	0.37	–	0.62	1.00
Terminalia citrina (Gaertn.) Flem.	0.72	0.26	–	0.98
Sterculia colorata Roxb.	0.43	0.53	–	0.96
Pithecellobium heterophyllum (Roxb.) Haridasan & Rao	0.48	0.45	–	0.93
Meliosma simplicifolia (Roxb.) Walp	0.26	–	0.65	0.91
Bischofia javanica Bl.	0.66	0.20	–	0.86
Heteropanax fragrans (D. Don) Seem	0.30	0.45	–	0.75
Alangium chinense (Lour.) Harms	0.08	0.65	–	0.73
Ficus sp.	0.73	–	–	0.73
Firmiana colorata (Roxb.) R. Br.	0.72	–	–	0.72
Sapium eugeniaefolium Ham. ex Hk. f.	0.65	–	–	0.65
Aquilaria malaccensis Lamk.	0.35	0.26	–	0.61
Mallotus tetracoccus (Roxb.) Kurz.	0.60	–	–	0.60
Ficus lamponga Miq.	0.08	0.49	–	0.57
Ficus hispida Linn. f.	0.29	0.23	–	0.52
Pithecellobium monadelphum (Roxb.) Koster.	0.48	–	–	0.48
Croton roxburghii Balak.	0.45	–	–	0.45
Rhus javanica Linn.	0.22	0.20	–	0.43
Ardisia sp.	0.38	–	–	0.38
Cassia fistula Linn.	0.17	0.21	–	0.38
Aporusa sp.	0.35	–	–	0.35
Neocinnamomum caudatum (Wall. ex Nees) Merr.	0.34	–	–	0.34
Ficus heterophylla Linn. f.	0.34	–	–	0.34
Anthocephalus chinensis (Lam.) A. Rich. ex Walp.	0.34	–	–	0.34
Lithocarpus elegans (Bl.) Hatus ex Soep.	0.31	–	–	0.31
Dalbergia stipulacea Roxb.	0.30	–	–	0.30
Dillenia indica Linn.	0.09	0.21	–	0.29
Bauhinia malabarica Roxb.	0.27	–	–	0.27
Dysoxylum alliarium (Ham.) Balak.	–	0.22	–	0.22
Anacardium occidentale Linn.	–	0.20	–	0.20
Bridelia monoica (Lour.) Mess	0.18	–	–	0.18
Garuga pinnata Roxb.	0.18	–	–	0.18
Syzygium sp. (1)	0.18	–	–	0.18
Derris robusta (Roxb. ex DC.) Benth.	0.18	–	–	0.18
Citrus medica Linn.	0.16	–	–	0.16
Lepisanthes rubiginosa (Roxb.) Leenh.	0.10	–	–	0.10
Bauhinia sp.	0.08	–	–	0.08
Syzygium 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	*Artocarpus gomezianus, Artocarpus* sp., *Oroxylum indicum, Macaranga indica, Moringa oleifera, Alstonia scholaris, Rhus acuminata, Duabanga grandiflora, Albizia chinensis* and *Ficus nervosa*	*Tectona grandis, Casearia glomerata, Boehmeria hamiltoniana, Ilex embelioides, Syzygium* sp., *Cinnamomum tamala, Castanopsis* sp., *Syzygium balsameum, Saurauia nepaulensis* and *Shorea robusta*
SF	*A. gomezianus, Garcinia tinctoria, Gmelina arborea, Pterygota alata, Mesua ferrea, Mallotus roxburghianus, O. indicum, Litsea sebifera, R. acuminata* and *Saraca asoca*	*Castanopsis* sp., *B. hamiltoniana, Viburnum colebrookianum, S. nepaulensis, S. robusta, Calophyllum polyanthum, Syzygium operculatum, Acronychia pedunculata, Lagerstroemia speciosa* and *Schima wallichii*
Sal plantations	*Persea villosa, Schefflera* sp., *Vitex glabrata, Drimycarpus racemosus, Betula alnoides, Ficus gibbosa, Toonaciliata, Albizia chinensis, Careya arborea* and *Emblica officinalis*	*S. robusta, Glycosmis arborea, Ficus infectoria, Actinodaphne augustifolia, Callicarpa arborea, Schima wallichii, Albizia odoratissima, Aporusa dioica, Salmalia malabarica* and *Eurya acuminata*

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

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

These species include (in increasing order of SIV) *Lepisanthes rubiginosa*, *Citrus medica*, *Derris robusta*, *Garuga pinnata*, *Bridelia monoica*, *Dysoxylum alliarium*, *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.

1. Kumar, A., Gupta, A. K., Marcot, B. G., Saxena, A., Singh, S. P. and Marak, T. T. C., Management of forests in India for biological diversity and forest productivity, a new perspective. Volume IV: Garo Hills Conservation Area (GCA). Wildlife Institute of India – USDA Forest Service collaborative project report, Wildlife Institute of India, Dehra Dun, 2002, p. 206.
2. Khan, M. L., Menon, S. and Bawa, K. S., Effectiveness of the protected area network in biodiversity conservation: a case study of Meghalaya state. *Biodiver. Conserv*., 1997, **6**, 853–868.
3. Misra, R., *Ecology Workbook*, Oxford & IBH Co, New Delhi, 1968, p. 244.
4. Knight, D. H., A phytosociological analysis of species rich tropical forest on Borro Colorado Island, Panama. *Ecol. Monogr.*, 1975, **45**, 259–284.
5. Visalakshi, N., Vegetation analysis of two Tropical Dry Evergreen Forests in Southern India. *Trop. Ecol.*, 1995, **36**, 117–127.
6. Ganesh, T., Ganesan, R., Devy, M. S., Davidar, P. and Bawa, K. S., Assessment of plant biodiversity at a mid-elevation evergreen forest of Kalakad–Mundanthurai Tiger Reserve. *Curr. Sci.*, 1996, **71**, 379–392.
7. Heaney, A. and Proctor, J., Preliminary studies on forest structure and floristics on Volcan Barva, Costa Rica. *J. Trop. Ecol.*, 1990, **6**, 307–320.
8. Kumar, Y. and Rao, R. R., Studies on Balpakram Wildlife Sanctuary in Meghalaya – 3: General account, forest types and fauna. *Indian J. For.*, 1985, **8**, 300–309.
9. Rodgers, W. A. and Panwar, H. S., Planning a protected area network in India. Report prepared for the Department of Environment, Forests and Wildlife, 1988, Vols 1 and 2, pp. 341, 267.
10. Holdridge, L. R., Grenke, W. C., Hathway, W. H., Liang, T. and Toshi Jr., J. A., *Forest Environment in Tropical Life Zones: A Pilot Study*, Pergamon Press, Oxford, 1971.
11. Sykes, J. M. and Horrills, A. D., Vegetation monitoring in Indian Tiger Reserves; A report to the WWF, 1977, p. 121.
12. Hmaier, A lecture note on similarity indices, 2002, available online at URL: http://www.geobotany.uaf.edu-teaching-biol475-lecture07_ho.pdf,.
13. Ludwig, J. A. and Reynolds, J. F., *Statistical Ecology: A Primer on Methods and Computing*, Wiley-Interscience Publication, New York, 1988, p. 337.
14. Hurlbert, S. H., The monoconcept of species diversity: a critique and alternative parameters. *Ecology*, 1971, **52**, 577–586.
15. Itow, S., Species diversity of equatorial insular forest on Ponape and Kosrae, Micronesia. *Ecol. Res*., 1986, **1**, 223–227.
16. Campbell, D. G., Stone, J. L. and Rosas A. Jr., A comparison of phytosociology and dynamics of three flood plains (Varzea) forests of known age, Rio Jurua, Western Brazilian Amazon. *Bot. J. Linn. Soc*., 1992, **108**, 213–237.
17. Parthasarathy, N., Studies on the vacular Flora, Structure and Nutrient Cycling in Kalakad Reserve Forest, Western Ghats, Tamil Nadu. Ph D thesis, University of Madras, 1986.
18. Sundarapandian, S. M. and Swamy, P. S., Forest ecosystem structure and composition along an altitudinal gradient in the Western Ghats, South India. *J. Trop. For. Sci.*, 2000, **12**, 104–123.
19. Singh, J. S., Singh, S. P., Saxena, A. K. and Ravat, Y. S., The forest vegetation of Silent Valley. Tropical. Rain Forests – The Leeds Symposium, 1984, pp. 25–52.
20. Parthasarathy, N., Kinhal, V. and Kumar, L. P., Plant species diversity and human impacts in the tropical wet evergreen forests of southern western ghats. Indo-French Workshop on Tropical Forest Ecosystems: Natural Functioning and Anthropogenic Impact, French Institute, Pondicherry, 1992.
21. Rai, S. N. and Procter, J., Ecological studies on four rain forests in Karnataka, India I. Environment, forest structure and vegetation. *J. Ecol*., 1986, **74**, 455–463.
22. Jha, C. S and Singh, J. S., Composition and dynamics of dry tropical Forest in relation to soil texture. *J. Veg. Sci*., 1990, **1**, 609–614.
23. Thorington, R. W., Tannenbaum, S., Tarak, A. and Rudran, R., Distribution of trees in Baro colorado Islands: A five hectare sample. In *The Ecology of a Tropical Forest – Seasonal Rhythms and*

Long-term Changes (eds Leigh Jr., E. G. Rand, A. S. and Windsor, D. M.), Smithsonian Institute Press, Washington DC, 1982.
24. Hubbell, S. P. and Foster, R. B., Diversity of canopy species in a neotropical forest and implications for conservation. In *Tropical Rain Forest: Ecology and Management* (eds Sutton, S. L., Whitmore, T. C. and Chadwick, A. C.), Blackwell, Oxford, 1983.
25. Campbell, D. G., Daly, D. C., Prance, G. T. and Maciel, U. N., Quantitative ecological inventory of Terra firma and the Varzea tropical forest on the Rio Xingu, Brazilian Amazon. *Brittanica*, 1986, **38**, 369–393.
26. Ho, C. C., Newbery, D. M. C. and Poore, M. E. D., Forest composition and inferred dynamics in Jengka forest reserve, Malaysia. *J. Trop. Ecol.*, 1987, **3**, 25–26.
27. Proctor, J., Lee, Y. F., Langley, A. M., Munro, W. R. C. and Nelson, T., Ecological studies on Gunung Silam, a small ultrabasic mountain Sabah, Malaysia. *J. Ecol.*, 1988, **74**, 455–463.
28. Swan Jr., F. R., Tree distribution patterns in the Bukittimah nature reserve, Singapore. *Gar. Bull.* (*Singapore*), 1988, **41**, 59–81.
29. Jaffré, T. and Veillon, J. M., Etude floristique et structurale de deux forêts denses humides sur roches ultrabasiques en Nouvelle-Calédonie. *Bull. Natl. Hist. Nat*., *Paris*, 1990, **12**, 243–273.
30. Mosango, M., Contribution ‘A l’étude botanic biogéo 1’ ecosystem Forêt en région equatorial (Ile Kongolo,Zaire). *Belg. J. Bot.*, 1991, **124**, 167–194.

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