Tree stand structure and floristic composition of tropical forests in Garo hills, Meghalaya, North-East India

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Abstract: Fifty-one sampling plots were enumerated in 5.1 ha area in different forest categories and elevations ranging from 100 to 1250 m, for monitoring tree stand structure and floristic composition in tropical forests of Garo hills of Meghalaya, north-east India. Enumeration of all tree stands ≥ 10 cm GBH (girth at breast height) equivalent to 3.18 cm DBH (diameter at breast height) yielded a total of 2843 individuals ranging from 2 to 223 individuals per plot (0.1 ha) belonging to 132 species, 118 genera and 63 families. Euphorbiaceae was the dominant family in the forest with 12 species, 11 genera and family important value index (FIV) of 42.7. Tree stand density, species richness, diversity index and basal area were found to be highest in evergreen forest and least in mixed moist deciduous forest. We carried out spatial analysis of spread of species richness, basal area, tree density, and tree biodiversity. We found higher basal area, tree density and biodiversity in protected areas of the region. This demonstrates the conservation value of protected areas in the region. Schima wallichii (280 individuals), Macaranga denticulata (275 individuals) and Michelia oblonga (238 individuals) were some of predominant species having species important values (SIV) 26.48, 17.36, 14.41, respectively, representing all together 28% of the total tree stand density. The total basal area from all the sampling plots was 254.62 m² out of which, the highest contribution of 64.80 m² ha⁻¹ (50%) was by evergreen forest and lowest, 22.43 m² ha⁻¹ (17%) was contributed by deciduous forest. At the species level, Schima wallichii has contributed 13% of the total basal area. The smaller 10–20 cm diameter class showed maximum tree density implying regenerating forest and highest basal area (9.80 m² ha⁻¹) for overall study site. However, in evergreen forest 40–50 cm diameter class exhibited highest basal area of 64.80 m² ha⁻¹ and greater diversity (4.06) leading to higher stability of the community. It was found that elevation is directly proportional to tree density, species richness and basal area. This study provides useful baseline data to conserve the native flora of forests in Garo hills.

Key words: Forest category, Garo hills, phytosociology, species diversity, structural composition.

Introduction

Tropical forests constitute for an important component in the biological and genetic diversity of the World (Hubbell & Foster 1983). These forests cover 7% of the earth’s land surface and contain more than half of the world’s species (May & Stumpf 2000) therefore, often referred as one of the most species-diverse terrestrial ecosystems. In these ecosystems, the biological diversity generates a variety of natural resources (Khan et al. 1997; Kumar et al. 2002; Mishra 1968) which helps to

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fulfill the basic needs of community to sustain their livelihood. Floristic inventory is a prerequisite for fundamental research in community ecology, specifically, to understand species distribution pattern and model their pattern of diversity. In recent years, vegetation characteristics of tropical forests have been determined by quantitative floristic inventories (Ayyappan & Parthasarathy 1999; Condit 1996; Johnston & Gillman 1995; Parthasarathy 1999, 2001; Pascal & Pelissier 1996; Phillips et al. 2003a, b). The tropics has experienced a total of 15.8 million hectares (39.0 million acres) of tree cover loss in 2017 worldwide due to anthropogenic pressure (Weisse & Goldman 2018) and therefore causing a decline in species of that ecosystem (Ferraz et al. 2004; Parmesan & Yohe 2003; Pounds et al. 1999; Root et al. 2003; Thomas et al. 2003). It can be predicted that in the next few decades large number of these species are likely to become extinct which might lead to a loss of large proportion of genetic diversity (Novacek & Cleland 2001; Wilson 1992, 2000).

In the last four decades, several studies have been carried out on vegetation characteristics of forests in Meghalaya. The studies such as Kumar et al. (2006) focused on tree species diversity and distribution pattern in primary forests, secondary forests and sal (Shorea robusta) plantations of Garo hills in tropical forests. Singh & Ramakrishnan (1982) concentrated on vege-tation, biomass and its nutrients in central zone of the sub-tropical humid forests. Rao et al. (1990) studied composition and tree population structure in sub-tropical broad-leaved forests of Shillong. Quantification of species diversity on a regional scale is quite challenging because of difficulties in measuring species individuals and their scatteredness (Koellner et al. 2004). However, quantitative floristic sampling also provides a necessary tool for planning long term ecological monitoring and research (Phillips et al. 2003a, b) and floristic inventories and stand structures normally described by sampling plots (Dallmeier & Comiskey 1998). The tree stand structure and floristic composition is associated with latitude (Currie & Paquin 1987) and elevation (Mergenic et al. 2004; Stevens 1992). They act as simple indicator to interpret the biological diversity (Peet 1974; Whittaker 1977). So far almost no studies were present on tree stand structure and floristic composition in different forest type groups found in Meghalaya. The state of Meghalaya has eight different forest type as per Champion and Seth’s classification system (1968) belonging to five forest type groups namely, Tropical wet evergreen, Tropical semi evergreen, Tropical moist deciduous, Subtropical broad leaved hill forest and Sub Tropical pine forests. In the present study, the first three forest type groups of native forests of Garo hills are included. Garo hills are one of the most diverse and rich tropical vegetation systems in the world (Kumar et al. 2002). Therefore, this study is significant as it aims to generate baseline data for this rich forest system in India, which will be useful for conservation and management of the native flora of tropical forests in India. With this objective, we carried out the following studies: (1) inventory of the plant species and richness of the forests in Garo hills, (2) understanding tree stand structure and floristic composition in different forest type groups and in different elevations in the region, and 3) spatial distribution of tree stand structure and diversity in the region.

Material and methods

Study area

Meghalaya is situated in north eastern region of India lies between 24°58’ N to 26°07’ latitudes and 89°48’ E to 92°51’ E longitudes with an altitude ranging from 100–1965 m above sea level (m asl). The state covers an area of 22,429 km$^2$ and most of its land covered by hills scattered with ravine and small valleys endowed with dense forest and rivers. Out of the total forest area of 15,657 km$^2$ in the state only 1027.20 km$^2$ is under the control of State Forest department which constitutes 6.56% of the total forest area of the State. Remaining forests are managed by the respective Autonomous District Councils of Garo hills, Khasi hills and Jaintia hills as per provisions of Sixth Schedule of the Constitution of India.

The Garo hills district was earlier divided into three districts as West, East and South Garo hills and covers the area of 2459 km$^2$ in Meghalaya (currently Garo hills is divided in five districts). The study area covers West (3.4 ha), East (1.5 ha) and part of the South (0.2 ha) Garo hills districts. The study area belongs to bio-geographic zone 9B (North Eastern India) (Rodgers & Panwar 1988) and occurs between 90°07’ and 91° E longitude and between 25°02’ and 25°32’ N latitude. Elevation ranges from 100 to 1500 m above mean sea level with a variety of vegetation like wet evergreen, semi-evergreen and moist deciduous forests.

Twelve villages Amingokgre, Balladingre, Dura-kalakagre, Chibongre, Kalakagre, Ronchugre,
Kalakagre-VRF, Daringre, Dadenggre, Sasatgre, Silsotchigre, Upper-daringre from West Garo hills, four villages Chivatigre, Daribokgre, Mandalgre, Rongsakgre from East Garo hills and two villages Sankni and Nokrek National park from South Garo hills were selected for study.

**Methods**

A total of 51 sampling plots of size 0.1 ha (50 × 20 m) from 18 villages, were laid in all the three districts using cotton ropes and by fixing wooden pegs at the four corners. The field work was conducted from April 2012 to June 2012. All living woody plants ≥10 cm girth (circumference) at the breast height (GBH) (GBH = 1.32 cm) were identified and oil chalk marked on the trunk of the tree where GBH measurements were made and enumerated sequentially. Tree individuals with multiple stems at level lower than breast height, girth was taken separately (Sukumar et al. 1992). Common species were identified with botanical nomenclature and specimens of other species collected (with flower and fruits wherever possible) were identified by referring flora of Meghalaya (Haridasan & Raghvendra 1985) and local experts. To evaluate the vegetation dynamics in this region, the data was collected and analysed for characteristics of vegetation with reference to floristic composition and structural attributes explored. The diversity measurement predicts the scatteredness of the species present and enumeration of the tree population density represents number of individuals of a species per unit area. The dominant measurements indicate species with largest presence in an area. The frequency describes how widely a species is distributed. But, density may over-emphasize the importance of a small species with large number of individuals per unit area. Similarly, frequency measurements overemphasize the importance of the largely distributed species and overestimate the sparsely distributed species. To avoid this, important value index (IVI) is a reasonable measure to assess the overall significance of floristic composition and structure.

**Data analysis**

Phytosociological studies were carried out in three distinguished forest type, *i.e.* evergreen forests, semi-evergreen forests and mixed-moist deciduous forest in high and moderate elevations (Table 1).

Density, abundance, frequency, basal area (m²) and their relative measures for each species have been calculated. According to Krishnamurthy et al. (2010), species were grouped into five categories: a) Predominant species: Species with ≥200 individuals, b) Dominant species: Species with 100 to 199 individuals, c) Common species: Species with 25 to 99 individuals, d) Rare species: Species with 3 to 24 individuals, and e) Very rare species: Species with <3 individuals. A single summary statistic or important value index was calculated by summing the relative values for species (Species Importance Value - SIV) and for families (Family Importance Value - FIV) as suggested by Genesh et al. (1996), Shannon Weiner and Simpson diversity indices were calculated as described by Magurran (1998). The index of the dominance of the community was calculated by the Simpson's index (Simpson 1949).

Finally, a natural neighbour interpolation technique was used for spatial interpolation. For spatial interpolation additional data from 10 more village locations, sampled in 2014 in Garo hills is used in addition to 18 villages that were sampled in 2012. This interpolation performs well with scattered and irregularly spaced data, as is the case in this study. Figure 1 shows the location of the sampling sites in the study area.

**Results**

**Tree stand structure**

A total of 2843 individual trees were recorded from 51 sampling plots among evergreen, semi-evergreen and mixed deciduous forest categories along altitudinal gradient.

Eight tree species *Schima wallichii* (280 individuals), *Macaranga denticulata* (275 individuals), *Michelia oblonga* (238 individuals), *Calicarpa arborea* (192 individuals), *Saurauja roxbhurgii* (152 individuals), *Grewia microcos* (137 individuals), *Holarhena antidecenterica* (100 individuals), *Eugenia claviflora* (84 individuals) all together comprises more than 50% (51.2%) of total individuals. A sum of 86.4% tree individuals were included in three tree size classes 10–20 (39%), 0–10 (35%) and 20–30 (12.5%). However, 96% individuals in evergreen forest and 97% individuals in semi-evergreen forest were distributed up to 50–60 cm diameter size class.

Elevation is directly proportional to tree population density, species richness, diversity index and basal area was observed in evergreen
Table 1. Tree density, species richness, number of family, diversity indices and basal area in different forest types of Garo hills.

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Evergreen</th>
<th>Semi-evergreen</th>
<th>Mixed forest</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampled area (ha)</td>
<td>2.20</td>
<td>2.40</td>
<td>0.50</td>
<td>5.10</td>
</tr>
<tr>
<td>Number of trees in sampled area</td>
<td>1199.00</td>
<td>1476.00</td>
<td>168.00</td>
<td>2843.00</td>
</tr>
<tr>
<td>Tree density (Number ha⁻¹)</td>
<td>545.00</td>
<td>615.00</td>
<td>336.00</td>
<td>557.00</td>
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<tr>
<td>Species richness</td>
<td>118.00</td>
<td>81.00</td>
<td>31.00</td>
<td>132.00</td>
</tr>
<tr>
<td>Number of genera</td>
<td>107.00</td>
<td>73.00</td>
<td>31.00</td>
<td>118.00</td>
</tr>
<tr>
<td>Number of families</td>
<td>59.00</td>
<td>45.00</td>
<td>21.00</td>
<td>63.00</td>
</tr>
<tr>
<td>Shannon Wiener diversity index</td>
<td>4.06</td>
<td>3.02</td>
<td>2.79</td>
<td>3.77</td>
</tr>
<tr>
<td>Simpson’s diversity index (1-D)</td>
<td>0.97</td>
<td>0.91</td>
<td>0.90</td>
<td>0.95</td>
</tr>
<tr>
<td>Simpson’s index of dominance</td>
<td>0.03</td>
<td>0.09</td>
<td>0.10</td>
<td>0.04</td>
</tr>
<tr>
<td>Evenness</td>
<td>0.49</td>
<td>0.25</td>
<td>0.52</td>
<td>0.33</td>
</tr>
<tr>
<td>Basal area in sampling plots (m²)</td>
<td>142.57</td>
<td>100.83</td>
<td>11.22</td>
<td>254.62</td>
</tr>
<tr>
<td>Basal area (m² ha⁻¹)</td>
<td>64.80</td>
<td>42.01</td>
<td>22.43</td>
<td>49.92</td>
</tr>
</tbody>
</table>

Fig. 1. Location map of study area along with sampling plots (White dots).

and semi-evergreen forest while in moist deciduous forest it was inversely proportional to all these except basal area (Table S1). In overall study area, increase in elevation with increase in stand density, species richness and basal area was found whilst diversity index was decreased with increase in elevation.

**Basal area**

Basal area of the 5.1 ha of sampled area was 254.63 m². Sample plot wise the basal area varied from 0.23 m² to 40.2 m² with mean±SD (standard deviation) value is 5.0±8.82. Highest basal area was observed in evergreen forest as 142.6 m² (56.0%) while least in mixed moist deciduous forest as 11.2 m² (4.4%). *Schima wallichi* had largest basal area (32.84 m²) accounting 12.9% followed by other five species, *Eugenia claviflora*, *Macaranga denticulata*, *Castanopsis purpurella*, *Syzygium polyanthum* and *Michelia oblonga* all together
comprising 40.6% of the total basal area in sampling plots (Table S2). The spatial distribution of basal area is shown in figure 2.

**Floristic structure: species richness and density**

A total of 132 species (out of which 6 species were unidentified) belonging to 118 genera and 63 families were identified from sampling plots covering area of 5.1 ha. Species richness showed wide variation from single species per plot in non-forest category to 35 species per plot in high dense evergreen forest. A total of 118 species from evergreen forest, 81 species from semi-evergreen forest and 31 species from mixed moist deciduous forest were recorded from the sampling plots (Table 1). The spatial distribution of species richness is shown in figure 3.

The tree density of 132 species, enumerated in the study area showed wide variation ranging from single individual to 280 individuals. The spatial distribution of tree density is shown in figure 4.

Based on their density, species were grouped into 5 categories (Table S3). Three species, Schima wallichii (280 individuals), Macaranga denticulata (275 individuals), Michelia oblonga (238 individuals) belonged to predominant species category, representing 2.3% of total species and 27.9% of total density. Four species Callicarpa arorrea, Saurauga roxburghii, Grewia microcos, Holarhena antidycenterica were recorded in dominant species category, accounting for 3.0% species richness and 20.4% of stand density. Rare species category contributes 59.1% of species richness (78 species) and 24.1% of tree density (684 individuals) and finally 31 species, 42 individuals were recorded in very rare species category accounting 23.5% and 1.5%, respectively. Four unidentified species in rare species category and two unidentified species in very rare species category were included.

Species index value (SIV) showed clear distribution of reverse ‘J’ shape (Fig. 5) with prolonged tail.

Among the top 10 species Schima wallichii is the most dominant species in the forest with SIV 26.48 (Table S2). The co-dominant species are
Fig. 3. Spatial distribution of Species Richness in Garo Hills.

Fig. 4. Spatial distribution of Tree Density in Garo Hills.
Fig. 5. Species importance values (SIV) for study plot in Garo hills.

Macaranga denticulata, Eugenia claviflora, Michelia oblonga, Callicarpa arborea, Castanopsis purpurella, Saurauja roxburghii, Grewia microcos, Gliochidian velutinum, Syzygium polyanthum with SIV as 17.36, 15.79, 14.41, 13.45, 10.77, 9.07, 8.67, 8.43 and 6.59, respectively, accounting 44% values all together. Species such as, Carallia brachiata, Engelhardtia polystachya and six unknown had lowest SIV with 0.17 each. The species area curve exhibited an increase in species until it reached an asymptote at 3.7 ha (Fig. 6).

Shannon-Wiener and Simpson’s diversity indices were 3.77 and 0.95, respectively, in whole study area (Table 1). These indices were observed highest (4.05 and 0.97) in evergreen forest and lowest (2.79 and 0.90) in mixed moist deciduous forest. Consequently, least value of dominance (0.027) in evergreen forest and highest value (0.097) of dominance in deciduous forest were found. The spatial distribution of Shannon Wiener and Simpson’s diversity indices is shown in figure 7.

While the floristic structure of the study site exhibited perfect reverse ‘J’ shaped curve (Fig. 8) in tree stand density, the basal area curve exhibited three humps or peaks in 10–20 cm, 40–50 cm and 80–90 cm diameter classes (Fig. 9). The diameter class 10–20 cm was the richest in number of species (106, 80.3%), stand density (1112, 39.1%) and basal area (50 m², 19.6%). The least number of species were found in 100–110 cm and 110–160 cm diameter class having two species in each class with 2 and 3 individuals, respectively. Similarly, in diameter class 40–50 and 80–90 cm the basal area of 35.8 (14.06%) and 11.4 m² (4.5%) were observed. The tree stand-density in evergreen forest and in mixed moist forest initially observed an increasing trend until 10–20 cm diameter class and further showed a sudden drop in the next class 20–30 and then gradually observed a decrease in stand density. But in the semi-evergreen forest tree density was highest in the smallest DBH class of 0–10 cm and then showed a rapid declined until 30–40 cm DBH class and with gradual decrease thereafter (Fig. 8).

In basal area all the three forest categories showed varieties of distribution in each diameter class (Fig. 9).

Evergreen forest exhibited two peaks one at 40–50 cm DBH class with basal area 25.46 m² and 90–100 cm DBH class with 10.71 m². In semi-evergreen forest, basal area was highest (33.77 m²) in 10–20 cm diameter class and sudden drop until 30–40 cm DBH class, thereafter gradual decrease. There was no significant basal area change among the diameter classes in mixed deciduous forest. However, in diameter class 50–60 cm, the highest basal area of 2.36 m² was recorded.

Family composition

Sixty-three families were present in the study area (six not identified) where Euphorbiaceae was the most dominant with 11 genera and 12 species followed by Fabaceae, Rubiaceae, Verbenaceae with 10, 8, 5 genera and 10, 9, 5 species, respectively (Table S4). Based on the tree density survey, family Euphorbiaceae showed dominance (485 individuals). This was however followed by family Theaceae (284 individuals), Magnoliaceae (240 individuals), Vebenaceae (218 individuals), Actiniaceae (151 individuals). Table S3 provides the entire list of species richness and tree abundance of the vegetation in study sites of Garo hills. Hence, FIV was derived to understand the sequence of dominant family. Based on FIV, Euphorbiaceae (42.67) scored highest rank among the families.
followed by Theaceae (24.45), Magnoliaceae (15.92), Vebeaeceae (14.97) Fabaceae (14.10). Table S3 provides the complete list of FIV of the vegetation in study sites of Garo hills.

Shifting cultivation

Shifting cultivation (also known as jhum cultivation locally) is being practiced by tribal community of Garo hills. Apart from the forest vegetation study, ten fresh plots (shifting cultivation during 2012) of size 0.1 ha (50 × 20 m) were laid to understand the impact of shifting cultivation on forest structure and composition. It is revealed that out of 784 tree stands in total from all sampling plots, 749 (95%) tree stumps (cut stem) were recorded at a level of 1 to 1.5 m height.
(Table 2). An estimated basal area loss from the study plot was 5.64 m² ha⁻¹ (72%).

**Discussion**

Forests in Garo hills are biologically rich and possess high levels of floristic species and diversity. Species-area curve showed linear increase in cumulative frequency of 132 species until it attained an area of 3.7 ha and thereafter asymptotic or stagnant in species accumulation, indicating no further change in floristic composition in this region. This means, in the present study enough area is chosen and gives fairly good representation of stand density, floristic composition and basal area.

Structurally, floristically the tropical forests characterized by species richness stand density and basal area are comparable to other tropical forests in India and other countries. The floristic richness of 132 species recorded in this study is higher compared to other tropical forests of India (26 to 85 species) and lower compared to wide range of 50 to 285 species (Johnston & Gillman 1995; Oliveira & Mori 1999) in tropical forests of other countries (Table S5). The spatial distribution of species richness as estimated in this study is shown in figure 3. Higher values of species richness correspond largely with the protected forests in the Garo hills. Similar is the findings for other spatially interpolated variables such as Basal area, Tree density, and tree biodiversity this study. This demonstrates the conservation value of protected areas in the state. Species richness in evergreen forest of Garo hills (118 species in 2.2 ha, Table 1) is closer to the values obtained in Western Ghats (173 species in 3.82 ha, as documented by Ganesh et al. (1996) in Kalakad Mundanthurai Tiger Reserve) and lower to the values obtained in tropical forests of other countries (Oliveira & Mori 1999; Table S5). The spatial distribution of species richness as estimated in this study is shown in Figure 3. Higher values of species richness correspond largely with the protected forests in the Garo hills. Similar is the findings for other spatially interpolated variables such as Basal area, Tree density, and tree biodiversity this study. This demonstrates the conservation value of protected areas in the state. Species richness in evergreen forest of Garo hills (118 species in 2.2 ha, Table 1) is closer to the values obtained in Western Ghats (173 species in 3.82 ha, as documented by Ganesh et al. (1996) in Kalakad Mundanthurai Tiger Reserve) and lower to the values obtained in tropical forests of other countries (Oliveira & Mori 1999; Table S5). This could be due to the fact that the present study is concentrated only on tree species rather than shrubs and herbs. Number of species in semi-evergreen forests (81 species, 45 families) of Garo hills is moderately higher than values (33–50 species, 26–35 family) obtained in semi-evergreen forests of Shervarayana hills of Western Ghats (Kadavul & Parthasarathy 1999; Table S5). Mixed moist deciduous forest of present study plot (0.5 ha) reported 31 species and 21 families, which is close to sub-tropical humid forests of Khasi hills in Meghalaya (0.5 ha, 24 species, 19 family, Tripathi & Khongjee 2010). However the study plot size (0.5 ha) being smaller may fail to describe the actual distribution pattern of all the species of a given area.

One of the earlier studies in Meghalaya reported higher species richness in lower elevations and lower species richness in higher elevation areas. Whereas, this study revealed the converse as we found 87 species in lower elevation areas, and 110 species in high elevations. This could be due to difficulty in access for basic needs such as food, fodder, shelter needed for shifting cultivation in high elevations. While in low elevation, shifting cultivation practices by tribal community could be one of the primary causes for degradation (World Resource Institute, WRI 1996).

Species diversity is an important attribute of natural communities within a functioning of an ecosystem (Hengeveld 1996). Greater diversity may lead to higher stability of the natural communities (MacArthur 1955). This implies evergreen forests (diversity index 4.05) in Garo hills is more stable and comparable to wet evergreen forests of Coorg, Karnataka, Western Ghats India which recorded diversity index as 4.3 (Pascal 1988, GBH ≥10 cm). The species diversity (3.02) obtained in the semi-evergreen forest of the present study is closer to sub-tropical semi-evergreen forest (3.7–4.3) in Jainta hills district of Meghalaya India (Jamir 2000). A low diversity index (2.79) was obtained in moist deciduous forest which could have risen due to

<table>
<thead>
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<th>Land-use</th>
<th>Shifting cultivation (Locally: Jhum cultivation)</th>
</tr>
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<tbody>
<tr>
<td>Number of plots studied</td>
<td>10 (50 × 20 m)</td>
</tr>
<tr>
<td>Study area (in ha)</td>
<td>1</td>
</tr>
<tr>
<td>Dominant crops grown</td>
<td>Paddy, Maize, Potato</td>
</tr>
<tr>
<td>Total Standing trees in Jhum land during cultivation</td>
<td>35</td>
</tr>
<tr>
<td>Fell down trees prior to cultivation (cut stumps)</td>
<td>749</td>
</tr>
<tr>
<td>Total initial trees in study area prior to cultivation</td>
<td>784</td>
</tr>
<tr>
<td>Total estimated basal area before shifting cultivation (m² ha⁻¹)</td>
<td>7.888</td>
</tr>
<tr>
<td>Basal area of the standing live trees (m² ha⁻¹) during cultivation</td>
<td>2.246</td>
</tr>
<tr>
<td>Estimated loss of tree basal area (m² ha⁻¹)</td>
<td>5.642</td>
</tr>
</tbody>
</table>
The basal area of tropical forests in the present study area recorded 49.9 m² ha⁻¹ (with range between 22.43 m² ha⁻¹ in mixed deciduous forest and 64.80 m² ha⁻¹ in evergreen forests) were well within the range recorded by other tropical forests in India and other countries (Table S5). Also in evergreen forests of Western Ghats it ranged from 58.79 m² to 64.89 m² ha⁻¹ (Pascal 1988; Vasantraj et al. 2004). However, these values are lower than those 102.7 m² ha⁻¹ reported by Singh et al. (1981) and 94.6 m² ha⁻¹ by Parthasarathy et al. (1992). Despite tree density being lower, the basal area obtained in evergreen forest was highest compared to present other two forest categories. This means lower tree density would not imply lower basal area. However, the difference in density and basal area may be attributed to species composition, age structure, succession stage of the forest and degree of disturbance (Sundarapandian 1997).

The species importance value (SIV) index exhibited typical reverse ‘J’ shape curve followed by exponential distribution with R² = 0.97 (Fig. 5) revealing that this forest is dominated by relatively more number of species. However, the first six species (out of 132) listed in Table S2, comprise about 33% of the importance values. These species were Schima wallichii, Macaranga denticulate, Eugenia claviflora, Michelia oblonga, Callicarpa arborea and Castanopsis purpurella. Species with poor representation in our samples need proper investigation from a plant biologist’s perspective to determine their conservation status. These species include (in increasing order of SIV) Engelharditia polystachya, Corallia brachiata, Premna bengalensis, Pedicularis carnosa, Plumbago indica, Desmodium laxiflorum, Hedyotis scadens, Diospyros lanceaefolia, Bischofia javanica and Symplocos laurina. Keeping consi-deration of areas of these wild tree species and further studies on ecological importance and traditional functions would help to plan an action to conserve these species and dependence of wild life on these species.

Family importance value (FIV) also showed reverse ‘J’ shape curve followed by exponential distribution with R² = 0.94 (Fig. 10).

The most dominant family was Euphorbiaceae with FIV 42.67 (14.22%) comprising 11 genera and 12 species, followed by Theaceae constituting co-dominant family with FIV 24.45 (8.45%) including 2 species and 2 genera. But, in the families Fabaceae, Rubiaceae, Verbenaceae, there were more number of genera (10, 8, 5) and species (10, 9, 5, respectively) compared to co-dominant species.
and constituting FIV as 14.10, 13.68, 14.97, respectively implying tree density is not the deciding factor of dominance. The families Poaceae, Achariaceae, Lythraceae, Arecales and Elaeocarpaceae were constituting least FIV with 0.94, 0.93, 0.92, 0.87, 0.85, respectively. In Amazonian tropical rain forest, tropical forests of Sierra de Manatlan Pasoh reserve of Malaysia (Gentry 1988; Manokaran et al. 1991) and the tropical forests of Meghalaya (Mishra et al. 2004), the recorded dominance of the families are Euphorbiaceae, Rubiaceae, Lauraceae and Moraceae.

Shifting cultivation is one of the primary causes of deforestation in tropics (Yadav et al. 2012). From the present study, it was also recorded that a total of 784 (95%) tree stands per hectare were cut at a level of 1 m to 1.5 m height during shifting cultivation by the local tribes of Garo hills and estimated basal area loss of 5.64 m² ha⁻¹ (72%). According to the studies by Yadav et al. (2012), the shifting cultivation land in Garo hills is estimated to be 421 km² (5.15%) and with increase in the population, it is estimated to rise further until an alternate arrangement is made. The shifting cultivation would continue for 2–3 years and left fallow for a period of 2–5 years. Though agriculture is the principal occupation of the people and provides food crops, it resulted in destruction and degradation of the forest (WRI 1996). Based on ecological importance, the present study reveals that the fallow period between shift cultivation cycles should change from the prevailing 2–5 years to longer period of 20 years. This could help ensure the renewal of some tree species at least.

Spatial analysis of Basal area (Fig. 2), Tree density (Fig. 4), species richness (Fig. 3), Biodiversity (Fig. 7) and special importance value shows higher values in protected areas in Garo hills. This demonstrates the conservation value of protected areas in the state.

Conclusion

The forest vegetation structure and tree composition in 5.1 ha study plot in humid tropical forests of Garo hills exhibited higher species richness (132 species), basal area (254.62 m²) and moderate stand density (2843 individuals) when compared to other tropical forests. Higher elevation clearly showed greater species richness, tree stand structure and more basal area. Further evergreen forests revealed greater species richness and diversity index realizing more stable forest in comparison to other two forest categories in Garo hills. Despite greater tree density in semi-evergreen forest, lesser basal area was obtained compared to evergreen forest, indicating tree density is not the deciding factor for basal area. It is also evident that tree density is concentrated in lower diameter class distribution and conspicuously semi-evergreen forest in Garo hills is regenerating. Shifting cultivation could be the major causes for this. Sustainable management of shifting cultivation in the Garo hills is required to safeguard pristine habitats of wild flora. Spatial maps showing basal area, tree density, species richness, biodiversity and special importance value shows higher biomass and biodiversity in protected areas under government control in Garo hills. This demonstrates the conservation value of protected areas in the state.

Based on ecological importance, this study suggests that the fallow period between shifting cultivation cycles to change from that of existing 2–5 years to longer period of 20 years so as to restore pioneer tree species. The present study concentrated only on tree species and did not include shrub and herb species of the Garo hills forest. This can be a baseline study providing the data on forest composition and structure of tree stands in the region.

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**Supporting Information**

Additional Supporting information may be found in the online version of this article.

**Table S1.** Tree population density, species richness, diversity index and basal area in different elevations and forest categories, in Garo hills.

**Table S2.** Abundance, density, frequency, basal area and species importance value (SIV) of the vegetation in study sites of Garo hills.

**Table S3.** List of species observed in different species categories in Garo hills.

**Table S4.** Species richness, tree abundance, basal area and Family importance value (FIV) of the vegetation in study sites of Garo hills.

**Table S5.** Vegetation characteristics of forest communities in the tropics of India and other countries.