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ORIGINAL PAPER

Structure, composition and diversity of tree species in tropical moist deciduous forests of Eastern India: a case study of Nayagarh Forest Division, Odisha

Tirthabrata Sahoo[1] · Pratap Chandra Panda[1] · Laxmikanta Acharya[2]

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Abstract Quantitative assessment of tree species diversity from sample plots in seven forest ranges of Nayagarh Forest Division in Odisha state in the Eastern Ghats of India was made during the period April, 2011 to November, 2013. A total of 120 transects (1000 m × 5 m) were laid in Nayagarh, Odogaon, Pancharida, Khandapada, Dasapalla, Mahipur, and Gania forest ranges and tree stems of at least 30 cm GBH were measured. The regeneration potential of trees was assessed from 5 m × 5 m sample plots located within the main transect. A total of 177 tree species belonging to 120 genera and 44 families were recorded from the study area. *Shorea robusta, Buchanania lanzan, Lannea coromandelica, Terminalia alata* and *Cleistanthus collinus* were the predominant tree species. The stand density varied in the range of 355.33–740.53 stems ha^{-1} while basal area ranged from 7.77 to 31.62 m^2 ha^{-1}. The tree density and species richness decreased with increasing girth class. The highest number of species and maximum density was recorded in the girth class of 30–60 cm. The Shannon–Weiner and Simpson Indices with respect to trees with ≥30 cm GBH varied in the range of 2.07–3.79 cm and 0.03–0.37 cm respectively and the values of diversity indices are within the reported range for tropical forests of Indian sub-continent. The families, Dipterocarpaceae, Anacardiaceae, Combretaceae and Euphorbiaceae contributed to maximum species richness, stand density, and basal area. Regeneration of many tree species was observed to be poor. The present study provides baseline data for further ecological studies, forest management, and formulation of site-specific strategies for conservation of biological diversity in moist deciduous forests of Eastern India.

Keywords Eastern India · Nayagarh Forest Division · Odisha · Tree diversity

Introduction

Tropical forest ecosystems host at least two-thirds of the Earth's terrestrial biodiversity and provide significant local, regional, and global human benefits through the provision of economic goods and ecosystem services (Gardner et al. 2009). Over the past century, tropical forests have been suffering from exceptional rates of change as they are degraded or destroyed by human activities.

Approximately half of the tropical forest that was present at the beginning of the twentieth century has already disappeared, with peak deforestation in the 1980s and 1990s (Wright 2005). The combined influence of persistently high rates of deforestation and forest degradation (FAO 2006), over-harvesting, invasive species, and global environmental change threatens to make tropical forests the epicentre of current and future extinctions (Bradshaw et al. 2009). In spite of harbouring 60% of all known species, tropical forests occupy only 7% of the Earth's land surface (Laurance

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✉ Pratap Chandra Panda
pcpanda2001@yahoo.co.in

[1] Taxonomy and Conservation Division, Regional Plant Resource Centre, Nayapalli, Bhubaneswar, Odisha 751015, India

[2] Centre of Biotechnology, Sikshya O Anusandhan University, Ghatikia, Bhubaneswar, Odisha 751003, India

1999; Dirzo and Raven 2003). Many tropical forests are under great anthropogenic pressure and require management intervention to maintain the overall biodiversity, productivity, and sustainability (Kumar et al. 2006).

Species diversity and distribution patterns are important because of their potential usefulness in understanding the relative extent of plant biodiversity across the tropics and its implications for conservation and management. Large-scale destruction of tropical forests worldwide also comes at a time when our knowledge of the structure and functional dynamics of many tropical forests is still rudimentary (Parthasarathy and Sethi 1997). Quantitative plant diversity inventories are the fundamental tool for conservation and management of tropical forests (Campbell 1994) and have mostly been concentrated on tree species rather than other life forms (Rennolls and Laumonier 2000; Huang et al. 2003).

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 (Khan et al. 1997). A wide range of sampling methods like plot sampling, line transect, and fixed tree-count sampling have been employed in tree diversity inventories over the years; these methods vary in the number and size of the plots (1–50 ha) besides the girth threshold of trees.

In India, most of the quantitative plant biodiversity inventories of tropical forests are from the Western Ghats, which are based on field data collected from small sampling areas, measuring from 3 to 8 ha, and mostly pertaining to tropical evergreen forests (Sukumar et al. 1992; Ganesh et al. 1996; Pascal and Pelissier 1996; Ghate et al. 1998; Parthasarathy 1999; Parthasarathy and Karthikeyan 1997; Ayyappan and Parthasarathy 1999; Chittibabu and Parthasarathy 2000; Jayakumar and Nair 2013; Reddy et al. 2008a). Parthasarathy and Karthikeyan (1997) and Parthasarathy and Sethi (1997) made quantitative ecological study of trees of the Coromandel coast. However, the Eastern Ghat region, covering the states of Odisha, Andhra Pradesh, and Tamilnadu, is dominated by tropical moist deciduous and tropical dry deciduous forests in contrast to the tropical evergreen forests of the Western Ghat. In comparison to Western Ghats, limited number of studies on quantitative assessment of plant resources of Eastern Ghats have been done (Kadavul and Parthasarathy 1999a, b; Arul Pragasan and Parthasarathy 2010; Naidu and Aniel 2015; Reddy et al. 2008b, 2011; Sahu et al. 2007; Panda et al. 2013).

Most of the plant diversity inventories of Eastern Ghat—except that of Arul Pragasan and Parthasarathy (2010) and Panda et al. (2013)—are based on quantitative data recorded from a few sample plots, measuring between 1 and 8 ha only. Information on the structure and composition of tree species of Tropical Moist Deciduous Forest types of Eastern Ghat of India through large-scale landscape level inventories are lacking.

The present study focused on a comparative analysis of the diversity, distribution pattern, abundance, and other phytosociological aspects of tree species with ≥30 cm GBH occurring in moist deciduous forests in the seven forest ranges of Nayagarh Forest Division, Odisha, India over a landscape covering 487.37 km^2 area.

Materials and methods

Study area

The study site is situated in the Nayagarh district of Odisha, India and is a part of the Eastern Ghats region. It lies between 84°20′ and 85°19′ E longitude and 19°54′ and 20°28′ N latitude and occupies an area of 3067.28 km^2). The forests, which are comprised of Reserved Forests, Proposed Reserved Forests, Degraded Protected Forests and Village Forests (RFs, PRFs, DPFs, and VFs) cover an area of 1063.16 km^2, which is 34.66% of the geographical area of the division. The forests of the district are comprised of mixed Sal Forest, Dry Peninsular Sal forest, Miscellaneous Forest, Northern tropical dry deciduous forest, and South Indian Moist Mixed Deciduous forest. In the lower hills and plains, the forest is dominated by Sal (*Shorea robusta*) but as altitude increases in the upper hill slopes, miscellaneous species are found abundantly. The altitude varies in the range of 47–932 m above mean sea level (MSL).

The forests are well drained by numerous rivers, rivulets, streams and nallahs. The most important river in this district is the Mahanadi and a major portion of drainage water from the forests flows into this river. Some portion of the Dasapalla forest range located in the southern and south-western part of Nayagarh Forest Division drain into the Rushikulya River of Ganjam District.

Three prominent seasons are observed in this area: hot and dry summer, hot and humid rainy season, and moderate winter season. The highest temperature in summer is around 39–44 °C but in hilly areas it is around 35 °C. The monsoon temperature is around 30 °C with relative humidity varying from 70 to 90%. The winter temperature from December to February goes down to nearly 8–10 °C. The mean annual rainfall is approximately 1500 mm, out of which 80% is received during June–September. Most of the rainy days are distributed in monsoon season that is from the 3rd week of June to the 2nd week of September.

The rocks occupying the greater part of the study area include khondalite, acid charnockite, garnetiferous granite gneiss, granulites, quartz, pegmatite veins, and sandstones. The recent deposits of laterite, alluvium and soil overlie these successions. The soils occurring in the division are dominantly very deep, well drained, fine loamy in texture, and are acidic in reaction. They are slightly eroded and

have moderate available water capacity. The soil types of such characteristics have been classified as typic haplustalfs with deep well drained and moderately eroded soil.

Field methods

The moist deciduous forest patches in seven forest divisions of the Nayagarh Forest Division—Nayagarh, Odogaon. Pancharida. Khandapada, Dasapalla, Mahipur, and Gania—were identified based on information available in the Revised Working Plan of Nayagarh Forest Division for 2007–2008 to 2016–2017, interaction with forest officials, ground truthing, and analysis of dominant species and their common associates by the authors. A total of 120 transects of 0.5 ha area (5 m × 100 m) were laid randomly over the seven forest ranges of the division. The number of individual standing tree with ≥30 cm GBH were counted physically and girth at breast height (GBH) was taken at a height of 1.37 m above the ground level. Regeneration status of tree species was determined by counting the number of individuals belonging to different regeneration classes (seedlings, saplings, and adults) in two quadrates of 5 m × 5 m size located within each transect. Individual trees having <10 cm GBH were considered as seedlings and those having GBH between 10 and 30 cm were considered as saplings (Knight 1963).

Plants were identified using regional floras (Haines 1921–1925; Mooney 1950; Gamble and Fischer 1915–1935; Saxena and Brahmam 1994–1996) and by matching them with authentic herbarium specimens housed in different Indian Herbaria. The voucher specimens were housed in the Herbarium of Regional Plant Resource Centre (RPRC), Bhubaneswar, India.

Data analysis

The phytosociological characteristics of individual species and their communities are as follows: (a) frequency (percent of all transects in which a species was present); (b) density (ratio of total number of trees to total number of transects), and (c) abundance (ratio of total number of trees to total number of transects of occurrence) were recorded. The relative importance of any species in the community was assessed by determining: the importance value index (IVI) following Curtis and Mcintosh (Curtis and McIntosh 1951), where the relative values of frequency, density, and basal cover for a species was derived as the value expressed in terms of percentage of the sum of the values for all the species in the plant community (Mueller-Dombois and Ellenberg 1974). The density and basal area (BA) of species were calculated on the basis of data recorded from all the transects (0.5 ha each) of the particular forest range and the values were expressed per hectare basis for comparison. The GBH was converted into basal area (BA) as $BA = GBH^2/4\pi$.

The family importance value (FIV) was taken as the sum of relative density, relative diversity, and relative basal cover of all species belonging to a botanical family. The relative diversity of a family was evaluated as the number of species within the family expressed as percentage of total number of species within all the families represented in the community (Mori et al. 1983).

The dominance was determined by Simpson's index $\left(Cd = \sum (n_i/N)^2\right)$ (Simpson 1949) and diversity as Shannon's Index $(H = -\sum(n_i/N)\log(n_i/N))$, where n_i = importance value index of species i, N = sum of importance value index for the community (Shannon and Weaver 1963). Evenness was calculated by Pielou's index $\left(D = -\sum p_i^2/InS\right)$ (Pielou 1975), where *S* is the species richness of the community (Magurran 1988). Species similarity among different regions was computed using Jaccard's Coefficient of Similarity (Jaccard 1908).

Results

Species richness and diversity

A tree diversity inventory was carried out in the seven forest ranges of the Nayagarh Division of Odisha; an area of 60 ha was sampled, which revealed the occurrence of 177 species of trees belonging to 120 genera under 44 families. A maximum of 128 species are reported to occur in Nayagarh range with GBH of 30 cm or more followed by Mahipur (119 species); Khandapada (103 species); Pancharida (100 species); Dasapalla (89 species); and Odogaon (74 species) ranges. The Gania forest range harbored the minimum number of tree species (73 species). Interestingly, in spite of low sampling intensity (10 ha), the maximum species of tree (128 species) were observed in Nayagarh forest range, as compared to the Khandapada, Mahipur, Dasapalla ranges where sample size was much higher (Table 1).

Analysis of the Jaccard coefficient of similarity (Jaccard 1908) showed that all the ranges in the Nayagarh Forest Division have an average similarity of more than 53% in terms of tree species presence. Khandapada and Mahipur forest ranges shared maximum similarity of 0.687 followed by Nayagarh and Mahipur forest ranges (0.633). However, the least similarity (0.500) in tree species occurrence was observed between the Gania and Nayagarh ranges (Fig. 1).

In general, no correlation was seen between tree species diversity and stand density. However, in the Gania forest range, the lowest species richness (73 species) and lowest stand density (355.33 trees ha^{-1}) was recorded. Though

Table 1 Consolidated details of tree diversity in seven forest ranges of Nayagarh Forest Division, Odisha

Forest ranges	Number of tree species	Number of genera	Number of families	Number of individuals	Stand density (number of stems ha^{-1})	Total basal area (m^2)	Stand basal area (m^2 ha^{-1})	Shannon–Weiner index	Simpson index	Evenness index
Dasapalla (10 ha)	89	71	34	4695	469.5	316.23	31.62	3.54	0.06	0.79
Gania (3 ha)	73	59	33	1066	355.33	32.2	10.73	3.77	0.03	0.88
Khandapada (13 ha)	103	83	37	5760	443.08	100.97	7.77	2.99	0.2	0.65
Mahipur (13 ha)	119	92	41	6065	466.54	222.66	17.13	3.51	0.11	0.73
Nayagargh (10 ha)	128	96	40	5303	530.3	131.59	13.16	3.61	0.1	0.74
Odogaon (3.5 ha)	83	62	34	2531	723.14	99.9	28.54	2.07	0.37	0.47
Pancharida (7.5 ha)	100	83	36	5554	740.53	111.21	14.83	3.79	0.05	0.82
Total number of species (60 ha)	177	120	44	30,974	516.23	1014.65	16.91	3.66	0.1	0.71

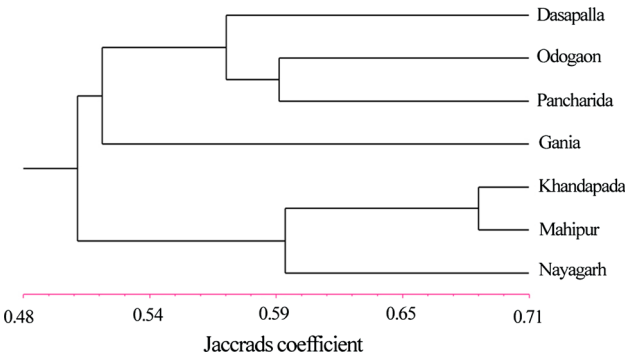

Fig. 1 Dendrogram showing similarity of tree species composition in seven ranges of Nayagarh forest diversion of Odisha

the Pancharida range had the highest stand density (740.53 trees ha^{-1}), it was not species-rich (100 species) as compared to the Nayagarh, Mahipur, and Khandapara ranges. In contrast, Nayagarh forest range had the most species (128 species) but the stand density of trees was low in comparison to the Odogaon and Pancharida forest ranges.

The Shannon and Simpson diversity indices were 3.66 and 0.10 respectively for the whole 60 ha area studied. The values of the two diversity indices varied greatly across the studied ranges. The Shannon Index was maximum (3.79) for the Pancharida range and minimum (2.07) for Odogaon range. Similarly, the Simpson index ranged between 0.03 for the Gania range and 0.37 for Odogaon range. The evenness index varied in the range of 0.47 (Odogaon) and 0.88 (Gania) (Table 1).

Species-area curve

Species-area curves for the seven major ranges were initially steep, up to 4–6 ha, followed by gradual species accumulation and flattening until the sampling area reached 13 ha (Fig. 2). The curve was quite steep for the Gania and Odogaon forest ranges where the area of sampling was very small. In the Dasapalla, Khandapada, Nayagarh, and Mahipur forest ranges, the species-area curve reached an asymptote between 10th and 13th hectares of sampled area. The rate of climb of curve for the Mahipur forest range was moderate. In all forest ranges, except for Gania and Odogaon, about 50% of the total tree species fell within 2.5–4.5 ha of area sampled.

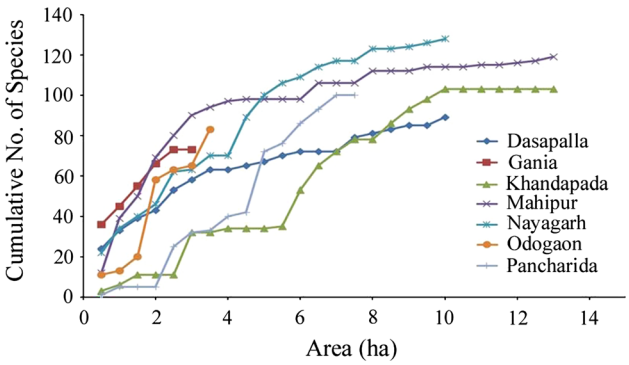

Fig. 2 Tree species accumulation curve for all seven ranges of Nayagarh Forest Division of Odisha

Species abundance and rarity

The abundance of species in the tree layer varied considerably across seven ranges of the division and ranged from merely one individual for species like *Cordia macleodii* and *Ficus amplicissima* to 12,193 plants of *Shorea robusta*. Based on abundance, tree species were grouped into five categories: very rare (1–2 individuals), rare (3–20 individuals), common (21–100 individuals), dominant (101–500 individuals), and predominant (>501 individuals) for the entire 60 ha area, following Arul Pragasan and Parthasarathy (2010). Overall, six species were found to be very rare, 47 species as rare, 33 species as common, 30 species as dominant, and 60 species as predominant ones. The predominant species contributed to 94.08% (29,143 individuals) of forest composition in the forests of Nayagarh Division.

The predominant species are *S. robusta, Buchanania lanzan, Cleistanthus collinus, Terminalia alata, Anogeissus latifolia, Lannea coromandelica, Madhuca indica, Mallotus philippensis, and Diospyrus melanoxylon. Protium serratum* had wider distribution across the Eastern Ghat. Of the enumerated tree species, six species were categorized as very rare and 47 species, including *C. macleodii, Melia dubia, Aglaia spectabilis, Trichilia connaroides, and Ficus mollis,* were placed under the rare category.

Importance value index (IVI)

As in other tropical deciduous forests of Odisha state, the single tree species *S. robusta* was found to be predominant. *S. robusta* scored the highest IVI of 88.619 followed by *B. lanzan* (9.811); *L. coromandelica* (9.022); *T. alata* (8.483); *C. collinus* (7.814); and *M. indica* (7.671). Out of 177 tree species, the IVI of the 20 dominant species contributed to 66.66% of the total IVI of all species in the forests of Nayagarh Forest Division (Table 2). The IVI of the 20 dominant tree species contributed to 74.33, 76, 74.56, 68.333, 65, 90.333, and 65% of total IVI values in the Dasapalla, Gania, Khandapada, Mahipur, Nayagarh, Odogaon, and Pancharida forest ranges respectively (data not provided). *Shorea robusta* had the highest IVI in all forest ranges for Nayagarh Division, except Gania, where the maximum IVI was recorded for *L. coromandelica*.

Family composition

In terms of tree diversity, the maximum number of species (14) belonged to the family Rubiaceae followed by Moraceae (13 species), Meliaceae (12 species), Euphorbiaceae (11 species), and Fabaceae (10 species). Ten families were represented by single species only. However, in terms of stem density and basal area, the lone species *Shorea robusta* of Dipterocarpaceae with 12,193 individuals dominated the moist deciduous forests of the Nayagarh Division and recorded the highest FIV of 86.158 (Table 3). The families with high FIV in decreasing order are Fabaceae (21.108), Anacardiaceae (20.191), Euphorbiaceae (19.461), and Rubiaceae (14.028). Moraceae and Meliaceae, represented by 13 and 12 species respectively in the studied area, had low FIV in view of their low density and consequently smaller basal area.

Stand density and basal area

A total of 30,974 individuals of trees were counted from the sampled area of 60 hectare located in seven ranges of Nayagarh Forest Division. The mean tree density on a landscape level was 526.23 stems ha^{-1}. Stand density varied from 355.33 stems ha^{-1} in Gania forest range to as high as 740.53 stems ha^{-1} in Pancharida forest range. The total basal area for the 60 ha area inventoried was 1014.65 m^2. Dasapalla forest range (316.23 m^2) contributed maximum to the total basal area followed by Mahipur (222.66 m^2), Nayagarh (131.59 m^2) and the minimum basal area (32.20 m^2) was recorded for Gania forest range. Overall, the mean stand basal area for the whole forest division 16.91 m^2 ha^{-1} and it ranged from 7.77 m^2 ha^{-1} in Khandapada to a 31.62 m^2 ha^{-1} in Dasapalla forest range. Lowest stand density and lowest basal area were recorded for Gania forest range.

In terms of basal area, the family Dipterocarpaceae with the lone species *Shorea robusta* contributed maximum to total basal area (469.064 m^2) followed by Fabaceae (80.462 m^2), Anacardiaceae (77.152 m^2), Euphorbiaceae (53.692 m^2), Combretaceae (43.591 m^2) and Ebenaceae (38.642 m^2). It is interesting to note that the family Rubiaceae with 14 species could not figure in the list of important families contributing more to basal area. The highest contribution to basal area by Dipterocarpaceae signifies the predominance of Sal in the moist deciduous forests of Nayagarh Division.

Distribution of girth class

In general, the species richness decreased with increasing girth class in the study region. Out of 177 tree species enumerated, maximum number of species (170 species) were recorded in the lowest girth class (30–60 cm) followed by 135 species in the GBH range of 61–90 cm, 83 species for GBH class of 91–120 cm (Table 4). Overall, 96.59% of all tree species recorded from Nayagarh division were represented by individuals belonging to the lowest category of girth class (30–60 cm).

In the moist deciduous forests of the region, density of individual tree species decreased with increasing girth

Table 2 Dominant tree species and their contribution to density, frequency, basal area and IVI in Nayagarh Forest Division, Odisha

S no.	Species	Family	No. of individuals	Total basal area (m^2)	Relative frequency	Relative density	Relative dominance	IVI
1	*Shorea robusta*	*Dipterocarpaceae*	12,193	469.064	3.025	39.365	46.229	88.619
2	*Buchanania lanzan*	*Anacardiaceae*	1418	25.315	2.738	4.578	2.495	9.811
3	*Lannea coromandelica*	*Anacardiaceae*	832	34.892	2.897	2.686	3.439	9.022
4	*Terminalia alata*	*Combretaceae*	949	31.725	2.292	3.064	3.127	8.483
5	*Cleistanthus collinus*	*Eupherbiaceae*	971	22.280	2.483	3.135	2.196	7.814
6	*Madhuca indica*	*Sapotaceae*	737	25.913	2.738	2.379	2.554	7.671
7	*Anogeissus latifolia*	*Fabaceae*	842	24.136	2.006	2.718	2.379	7.103
8	*Diospyros melanoxylon*	*Ebenaceae*	610	20.749	2.802	1.969	2.045	6.816
9	*Protium serratum*	*Borceraceae*	582	25.952	1.910	1.879	2.558	6.347
10	*Schleichera oleosa*	*Sapindaceae*	379	23.126	2.388	1.224	2.279	5.891
11	*Semecarpus anacardium*	*Anacardiaceae*	550	14.020	2.356	1.776	1.382	5.513
12	*Mallotus philippensis*	*Euphorbiaceae*	643	12.210	1.719	2.076	1.203	4.998
13	*Dalbergia paniculata*	*Fabaceae*	394	17.679	1.910	1.272	1.742	4.925
14	*Bridelia retusa*	*Euphorbiaceae*	514	12.952	1.974	1.659	1.277	4.910
15	*Pterocarpus marsupium*	*Fabaceae*	459	13.077	1.624	1.482	1.289	4.394
16	*Morinda pubescens*	*Rubiaceae*	336	7.647	2.101	1.085	0.754	3.940
17	*Aegle marmelos*	*Rutaceae*	331	5.622	2.069	1.069	0.554	3.692
18	*Diospyros montana*	*Ebenaceae*	351	7.932	1.624	1.133	0.782	3.539
19	*Lagerstroemia palviflora*	*Lythraceae*	342	6.467	1.719	1.104	0.637	3.461
20	*Careya arborea*	*Lecythidaceae*	248	7.523	1.910	0.801	0.741	3.452
21	*Syzygium cumini*	*Myrtaceae*	303	8.017	1.592	0.978	0.790	3.360
22	*Haldina cordifolia*	*Rubiaceae*	210	9.136	1.528	0.678	0.900	3.107
23	*Desmodium oojeinensis*	*Fabaceae*	284	12.952	0.891	0.917	1.276	3.085
24	*Pterospermum xylocarpum*	*Sterculiaceae*	307	7.567	1.337	0.991	0.746	3.074
25	*Diospyros sylvatica*	*Ebenaceae*	331	6.215	1.369	1.069	0.613	3.050
26	*Cassia fistula*	*Caesalpiniaceae*	252	4.598	1.783	0.814	0.453	3.050
27	*Albizia lebbeck*	*Mimosaceae*	201	7.183	1.433	0.649	0.708	2.790
28	*Terminalia bellirica*	*Combretaceae*	144	3.988	1.433	0.465	0.393	2.291
29	*Terminalia chebula*	*Combretaceae*	183	4.278	1.242	0.591	0.422	2.254
30	*Guazuma ulmifolia*	*Sterculiaceae*	184	5.355	1.082	0.594	0.528	2.204
31	*Dalbergia latifolia*	*Fabaceae*	172	6.022	1.019	0.555	0.593	2.168
32	*Chloroxylon sweitenia*	*Meliaceae*	150	3.459	1.178	0.484	0.341	2.003
33	*Casearia elliptica*	*Flacourtiaceae*	146	2.550	1.210	0.471	0.251	1.932
34	*Holarrhena pubescens*	*Apocynaceae*	155	2.138	1.210	0.500	0.211	1.921
35	*Bombax ceiba*	*Bombacaceae*	117	4.579	1.082	0.378	0.451	1.911
36	*Strychnos potatorum*	*Loganiaceae*	112	2.776	1.146	0.362	0.274	1.781
37	*Wrightia arborea*	*Apocynaceae*	175	3.514	0.860	0.565	0.346	1.771
38	*Mitragyna parvifolia*	*Rubiaceae*	75	4.936	0.955	0.242	0.487	1.684
39	*Stereospermum chelonoides*	*Bignoniaceae*	164	3.795	0.764	0.529	0.374	1.668
40	*Ixora pavetta*	*Rubiaceae*	115	2.087	1.082	0.371	0.206	1.659

Table 2 continued

S no.	Species	Family	No. of individuals	Total basal area (m^2)	Relative frequency	Relative density	Relative dominance	IVI
41	*Albizia odoratissima*	*Mimosaceae*	175	4.701	0.541	0.565	0.463	1.570
42	*Ehretia laevis*	*Boraginaceae*	135	2.328	0.828	0.436	0.229	1.493
43	*Antidesma ghaesembilla*	*Euphorbiaceae*	119	2.141	0.891	0.384	0.211	1.487
44	*Gardenia latifolia*	*Rubiaceae*	95	2.386	0.828	0.307	0.235	1.370
45	*Dillenia pentagyna*	*Dilleniaceae*	93	5.045	0.541	0.300	0.497	1.339
46	*Phyllanthus emblica*	*Euphorbiaceae*	72	1.518	0.891	0.232	0.150	1.273
47	*Strychnos nux-vomica*	*Loganiaceae*	89	3.032	0.637	0.287	0.299	1.223
48	*Azadirachta indica*	*Meliaceae*	68	1.279	0.828	0.220	0.126	1.173
49	*Alangium salvifolium*	*Alangiaceae*	70	1.015	0.796	0.226	0.100	1.122
50	*Sterculia urens*	*Sterculiaceae*	60	1.741	0.732	0.194	0.172	1.098
Total of 1–50 species			28,437	938.611	75.995	91.809	92.506	260.310
Remaining 126 species			2537	76.043	24.005	8.191	7.494	39.690
All species (176 species)			30,974	1014.654	100	100	100	300

classes. Maximum density of trees per unit area (371.433 stems ha^{-1}) was observed in the girth class of 30–60 cm, which contributed to 71.95% of the total tree population. On a land-scape level, the average stand density under 61–90 cm girth class was 88 stems ha^{-1}, which is 17.10% of total tree cover. The stand density under this girth class varies from 36 stems ha^{-1} in Khandapada to 147 stems ha^{-1} in Odogaon forest range. Only 600 individual trees in the girth class of 150 cm or more (GBH $\geq$ 150 cm) were present in the study area of 60 ha, which constitutes merely 1.93% of total number of trees. Lowest number of trees (0.154 stems ha^{-1}) under GBH class of 150 cm or more were found in Khandapada range and highest stand density of 37.80 stems ha^{-1} under this girth class was recorded for Dasapalla forest range.

Trees of lower girth class (GBH of 30–60 cm and 61–90 cm) were predominant in the forests of Nayagarh Forest Division and contributed to the bulk of total basal area i.e., 551.67 m^2 (54.35%). Of the total basal area, 327.39 m^2 was occupied by trees of 30–60 cm girth class and 224.27 m^2 (22.9%) by trees of 61–90 cm GBH (Table 4). The trees of lower girth class (GBH = 30–60 cm) contributed to maximum stand basal area in all the forest ranges except Dasapalla where maximum basal area was recorded in respect of trees of 150 cm or more GBH class. The total basal area contributed by trees of 91–120 cm GBH class was more than the basal area of trees of the next higher class (121–150 cm) in Dasapalla, Khandapada and Nayagarh forest ranges. In general, the average stand basal area of trees having GBH $\geq$ 150 cm was much higher than basal area occupied by trees of the two preceding girth classes (121–150 cm and $\geq$150 cm GBH) in spite of their lower population size.

Regeneration

Among the 7 forest ranges of Nayagarh division, the best tree regeneration was observed in Mahipur forest range with 18,76 seedlings and saplings per hectare. The number of seedlings and saplings was the lowest (6180 nos. ha^{-1}) in the sampled areas of Dasapalla range. Adequate regeneration of trees was noticed in Nayagarh (14,000 ha^{-1}) and Khandapada range (13,547 ha^{-1}) as compared to other forest ranges under study. The regeneration status of species like *S. robusta, Holarrhena pubescens, D. melanoxylon, B. lanzan,* and *C. collinus* on the forest floor is better than other species. *S. robusta*, with 2895.23 seedlings ha^{-1} and 6247.61 saplings ha^{-1}, topped the list followed by *H. pubescens* (1095.23 seedlings and 2114.28 saplings per hectare) (Table 5).

The density of adult plants was found to be disproportionately low compared to seedlings and saplings in all sampling sites in the Nayagarh Forest Division. In case of *Shorea robusta*, density of mature individuals was 203.21 per ha, whereas the numbers of seedlings and saplings were 2895.23 and 6247.61 per hactare respectively. Among 172 tree species for which regeneration data could be collected, the populations of seedlings and saplings were high for species like *S. robusta, H. pubescens, D. melanoxylon, B. lanzan, C. collinus,* and moderate for *Careya arborea, Dalbergia latifolia, Chloroxylon swetenia, Oroxylum indicum* and *Terminalia chebula.* On the other hand, the

Table 3 Family composition and FVI of tree species in seven forest ranges of Nayagarh Forest Division, Odisha

Family	No of genera	No of species	No of individuals	Total basal area (m^2)	Relative diversity	Relative density	Relative basal area	FIV
Dipterocarpaceae	1	1	12,193	469.064	0.565	39.365	46.229	86.158
Fabaceae	7	10	2332	80.462	5.650	7.529	7.930	21.108
Anacardiaceae	6	6	2849	77.152	3.390	9.198	7.604	20.191
Eupherbiaceae	9	11	2464	53.692	6.215	7.955	5.292	19.461
Rubiaceae	13	14	987	29.749	7.910	3.186	2.932	14.028
Ebenaceae	1	7	1341	38.642	3.955	4.329	3.808	12.092
Combretaceae	2	5	1381	43.591	2.825	4.458	4.296	11.579
Meliaceae	11	12	342	8.867	6.780	1.104	0.874	8.758
Moraceae	2	13	213	11.745	7.345	0.688	1.158	9.190
Mimosaceae	3	9	555	16.447	5.085	1.792	1.621	8.497
Sapotaceae	2	2	820	27.350	1.130	2.647	2.696	6.473
Sterculiaceae	4	5	559	14.801	2.825	1.805	1.459	6.088
Rutaceae	7	7	416	6.905	3.955	1.343	0.681	5.978
Borceraceae	2	2	600	26.978	1.130	1.937	2.659	5.726
Sapindaceae	3	3	391	23.255	1.695	1.262	2.292	5.249
Caesalpiniaceae	3	6	362	6.959	3.390	1.169	0.686	5.244
Bignoniaceae	3	5	260	7.197	2.825	0.839	0.709	4.374
Verbenaceae	5	6	122	2.944	3.390	0.394	0.290	4.074
Flacourtiaceae	2	5	245	4.546	2.825	0.791	0.448	4.064
Myrtaceae	1	2	396	10.631	1.130	1.278	1.048	3.456
Apocynaceae	3	3	345	5.961	1.695	1.114	0.587	3.396
Annonaceae	2	5	47	0.701	2.825	0.152	0.069	3.046
Lythraceae	1	2	367	6.885	1.130	1.185	0.679	2.993
Lecythidaceae	2	2	257	7.851	1.130	0.830	0.774	2.733
Boraginaceae	2	3	151	2.649	1.695	0.487	0.261	2.444
Loganiaceae	1	2	201	5.808	1.130	0.649	0.572	2.351
Dilleniaceae	1	2	124	7.754	1.130	0.400	0.764	2.294
Oleaceae	2	3	50	0.660	1.695	0.161	0.065	1.921
Rhamnaceae	1	3	19	0.288	1.695	0.061	0.028	1.785
Malvaceae	2	2	82	2.542	1.130	0.265	0.251	1.645
Tiliaceae	1	2	102	1.386	1.130	0.329	0.137	1.596
Lauraceae	1	2	55	1.555	1.130	0.178	0.153	1.461
Bombacaceae	1	1	117	4.579	0.565	0.378	0.451	1.394
Celastraceae	1	2	36	1.060	1.130	0.116	0.104	1.351
Ulmaceae	2	2	16	0.435	1.130	0.052	0.043	1.225
Myrsinaceae	2	2	9	0.205	1.130	0.029	0.020	1.179
Alangiaceae	1	1	70	1.015	0.565	0.226	0.100	0.891
Ochnaceae	1	1	45	0.756	0.565	0.145	0.074	0.785
Arecaceae	1	1	23	1.161	0.565	0.074	0.114	0.754
Melastomataceae	1	1	12	0.135	0.565	0.039	0.013	0.617
Cochlospermaceae	1	1	9	0.172	0.565	0.029	0.017	0.611
Santalaceae	1	1	6	0.052	0.565	0.019	0.005	0.589
Opilliceae	1	1	3	0.048	0.565	0.010	0.005	0.579
Burseraceae	1	1	1	0.020	0.565	0.003	0.002	0.570

Table 4 Species richness, density and basal area for different girth classes of trees in Nayagarh Forest Division, Odisha

Girth class(cm)	Species richness	Density (number of stems ha^{-1})	% contribution to density	Basal area (m^2 ha^{-1})	% Contribution to basal area
30–60	170	371.4333	71.95	5.457	32.269
61–90	135	88.2833	17.101	3.7379	22.103
91–120	83	29.1333	5.643	2.5158	14.876
121–150	73	17.3833	3.3673	2.482	14.677
>150	42	10	1.9371	2.7198	16.0834

Table 5 Regeneration status of top 20 tree species in Nayagarh Forest Division, Odisha

Tree species	Seedling ha^{-1}	Sapling ha^{-1}
Shorea robusta	2895.238	6247.619
Holarrhena pubescens	1095.238	2114.286
Diospyros melanoxylon	942.857	2200.000
Buchanania lanzan	466.667	1085.714
Cleistanthus collinus	495.238	904.762
Morinda pubescens	457.143	723.810
Mallotus philippensis	390.476	657.143
Caesaria elliptica	276.190	761.905
Albizia lebbeck	590.476	257.143
Anogeissus latifolia	314.286	495.238
Madhuca indica	190.476	600.000
Terminalia alata	180.952	609.524
Dalbergia paniculata	209.524	552.381
Antidesma acidum	333.333	285.714
Pterospermum xylocarpum	238.095	352.381
Aegle marmelos	276.190	285.714
Guazuma ulmifolia	295.238	257.143
Antidesma ghaesembilla	266.667	266.667
Bridelia retusa	266.667	266.667
Pterocarpus marsupium	200.000	266.667

regeneration potential for *Polyalthia suberosa, Ardisia solanacea, Bahaunia variegata, Alstonia venenatus* and *Litsea monopetala* was extremely low in the region.

Discussion

The density, abundance and distribution of individual species are the measurable indicators of plant diversity (Wattenberg and Breckle 1995). The occurrence of 177 species of trees over the 60 ha sampled area reflects a moderate level of diversity in Nayagarh Forest Division. The tree species diversity is at par with other inventories conducted in Indiantropical forests and elsewhere, taking GBH of trees of more than 30 cm (Kumar et al. 2006; Sunil et al. 2016). Studies conducted in 20 ha (for individual ≥10 cm GBH) sample plots in the Tiruvannamalai district, Tamilnadu, India recorded the presence of 60 species (Durai and Sundarapandian 2014) and 996 species in a 52 ha area at Lambir, Malaysia (Condit 2000).

Tropical forests of the world are highly diversified and the density and richness of species vary widely between dry and humid zones. As reported, species richness can be as low as 20 species ha^{-1} in the flooded Varzea forest of Rio Xingu, Brazil (Campbell et al. 1992) to 307 species ha^{-1} in Amazonian Ecuador (Valencia et al. 1994).

The mean stand density of trees of comparable girth threshold (≥30 cm GBH) on large-scale inventory in tropical forests of in the Indian subcontinent varies from 298 stems per ha^{-1} in Mudumalai Forest Reserve, India to 689 stems ha^{-1} at Sinharaja, Sri Lanka (Condit 2000). The mean stand density of 516.23 stems ha^{-1} now reported for Nayagarh Forest Division is within the above range. In a recent assessment of species richness in tropical deciduous forests in the Eastern Ghats, Panda et al. (2013) recorded 882 species in the 222 ha area using similar sampling and data collection protocols (≥30 cm GBH) and the range of tree density was found between 268 and 655 stems per ha^{-1}. Under the same girth class, the number of individual trees per hectare varied between 266 and 632 in Koli Hills of Western Ghats of India (Chittibabu and Parthasarathy 2000), between 640 and 986 in Kalrayan hills of Eastern Ghats (Kadavul and Parthasarathy 1999a) and between 270 and 673 in the Anamalais (Ayyappan and Parthasarathy 1999). Density of trees (30 cm GBH and above) in tropical forests is reported to vary between 245 and 859 stems ha^{-1} (Ashton 1964; Campbell et al. 1992; Richards 1996) with intermediate values of 448–617 stems ha^{-1} in Costa Rica (Heaney and Proctor 1990) and 639–713 stems ha^{-1} in Central Amazonia (Ferreira and Prance 1998). The tree density in moist deciduous forests in the Eastern Ghat reported in the present work is modest in comparison to other tropical forests.

The species diversity depends on the adaptation of species and increases with the stability of community (Knight 1975) and Shannon index (H′) is generally higher

for tropical forests. However, for Indian forests, the Shannon Index ranges from 0.83 to 4.0 (Singh et al. 1984). In the present study, Shannon's Index varied from 2.07 to 3.79 which are within the reported range (0.83–4.1) for the forests of Indian sub-continent (Durai and Sundarapandian 2014; Ayyappan and Parthasarathy 1999; Pandey and Shukla 2003; Panda et al. 2013).

The mean stand basal area of Nayagarh Forest Division is calculated at 16.91 m^2 ha^{-1} and varies in the range of 7.77 m^2 ha^{-1}–31.62 m^2 ha^{-1}. Based on quantitative assessment of forest vegetation of 222 ha sampling plots in 10 districts of Odisha located in southern Eastern Ghat region, Panda et al. (2013) reported the mean basal area to be 10.47 m^2 ha^{-1}; the range of variation of basal area being between 6.65 and 22.28 m^2 ha^{-1}. In tropical dry evergreen forests of Eastern Ghat, Arul Pragasan and Parthasarathy (2010) observed basal area to vary from 5.6 to 24.4 m^2 ha^{-1} among the six selected sites; the mean basal area being 16.9 m^2 ha^{-1}. The average basal area of 16.9 m^2 ha^{-1} reported in the present inventory is well within the reported range of variation. Sahu et al. (2007) recorded mean stand density of 591 stems ha^{-1} and basal area of 25.59 m^2 ha^{-1} from forests of Boudh district of Odisha taking only 4 ha sample plots and enumerating trees of $\geq$10 cm GBH. Such inflated figures could be due to low sampling intensity and reveals the limitations of data accuracy on biodiversity inventories.

Species abundance is considered to be dependent and directly related to species richness (Condit et al. 1998; Denslow 1995; Hayek and Buzas 1997; Preston 1962). The most abundant species are often used to describe forest composition and categorize forest types (Valencia et al. 2004). In Nayagarh Forest Division, eleven predominant species (species with >500 individuals) such as *S. robusta, L. coromandelica, M. indica, D. melanoxylon, T. alata, C. collinus, P. serratum, B. lanzan* etc, contributed to 67.2% (20,841 individuals) of the total tree population. Rubiaceae, Moraceae, Meliaceae and Euphorbiaceae with 14, 13, 12 and 11 species respectively were observed to be most diverse families in terms of species content.

Interestingly, Arul Pragasan and Parthasarathy (2010) in a recent large-scale inventory of southern Eastern Ghats established Euphorbiaceae as the most diverse family followed by Rubiaceae and Moraceae. In tropical low land forests of Little Andaman island, Euphorbiaceae (17 species), Moraceae (12) and Rubiaceae (11) were reported to be most species-rich families (Rasingam and Parthasarathy 2009). Similar findings were reported by Panda et al. (2013) for the tropical deciduous forests of Eastern Ghats of India. They found Euphorbiaceae and Moraceae as the two most diverse families with 24 species each. It appears there exists a greater similarity in family composition of trees across various tropical forests of India and elsewhere.

The vegetation composition of trees in tropical forests of Nayagarh Division is seen to be at moderately diverse. The mean stand basal area (GBH of more than 30 cm) of 16.91 m^2 ha^{-1} reported for Nayagarh Division is lower than the pan-tropical average of 32 m^2 ha^{-1} (Dawkins 1959). It is also lower than those reported for the forests of Eastern Ghats of India (Kadavul and Parthasarathy 1999b) and tropical forests of other region such as Malaysia (Poore 1968), Brazilian Amazon (Campbell et al. 1986, 1992); Costa Rica (Lieberman and Lieberman 1987). Basal area acts as an important attributes of vegetation composition and site quality of forests (Mani and Parthasarathy 2005; Parthasarathy and Karthikeyan 1997; Srinivas and Parthasarathy 2000; Williams-Linera 1990).

Our effort was therefore to estimate the basal area and exploring its relationship to tree density and girth classes. In the present study, the basal area of tree species varied greatly across the seven forest ranges now studied. While the mean basal area was as low as 7.77 m^2 ha^{-1} for Gania forest range, it was 31.62 m^2 ha^{-1} for Dasapalla range. It reveals that the stand structure of forest trees is considerably poor in Gania forest range. The mean basal area of Nayagarh Division of 16.91 m^2 ha^{-1}, as determined in the present study is in the medium range compared to other Indian tropical forests i.e. from 1.3 m^2 ha^{-1} at Vindhyan hills (Sagar et al. 2003) to 98.6 m^2 ha^{-1} at Namdapha National Park, North east India (Nath et al. 2005).

The diameter distribution reflects the disturbance effect within the forests (Denslow 1995; Hett and Loucks 1976) and helpful in detecting trends in regeneration patterns (Poorter et al. 1996). In the present study, while only 42 species has individuals with GBH of >150 cm, they contributed to only 1.937% of the tree density. On the other hand, the contribution to tree density by individuals of lower girth class (30–60 cm and 61–90 cm) was as high as 89.05% (Table 4). The low diversity and density of trees of higher girth class and predominance of plants of lower GBH observed in this study reveals the extent of forest disturbance. Further, tree density distribution across different girth classes indicates how well the growing forest is utilizing site resources. A few small-to-medium sized trees per hectare may imply that land is not being fully utilized by the tree crop (Hitimana et al. 2004). Distribution curves that drop exponentially with increasing GBH are characteristic for many sites in India (Khamyong et al. 2004) and the same is also corroborated by our results.

Conclusion

A quantitative assessment of tree diversity was carried out in the seven forest ranges of Nayagarh Forest Division of Odisha in Eastern Ghats of India. This was done by laying

120 belt transects and measuring trees of more than 30 cm GBH. Though the overall species diversity was moderate, the stand basal area and stand density were much lower compared to tropical forests of similar type and habitat elsewhere.

The presence of only a few individual tree of higher girth class, an abundance of trees in the lower girth class of 30–60 cm, and poor regeneration potential of many tree species are matters of immediate concern for the forest managers. Selective removal of trees of higher girth class, collection of forest produce, habitat alteration, recurring forest fire in summer, and livestock grazing are the factors responsible for destruction and degradation of forests of Nayagarh Forest Division and other deciduous forests of Eastern Ghats of India.

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