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Forest Structure, Composition and Above Ground Biomass of Tree Community in Tropical Dry Forests of Eastern Ghats, India

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Abstract

The study of biomass, structure and composition of tropical forests implies also the investigation of forest productivity, protection of biodiversity and removal of CO_2 from the atmosphere via C-stocks. The hereby study aimed at understanding the forest structure, composition and above ground biomass (AGB) of tropical dry deciduous forests of Eastern Ghats, India, where as a total of 128 sample plots (20 x 20 meters) were laid. The study showed the presence of 71 tree species belonging to 57 genera and 30 families. Dominant tree species was *Shorea robusta* with an importance value index (IVI) of 40.72, while Combretaceae had the highest family importance value (FIV) of 39.01. Mean stand density was 479 trees ha^{-1} and a basal area of 15.20 m^{2}ha^{-1}. Shannon's diversity index was 2.01 ± 0.22 and Simpson's index was 0.85 ± 0.03. About 54% individuals were in the size between 10 and 20 cm DBH, indicating growing forests. Mean above ground biomass value was 98.87 ± 68.8 Mg ha^{-1}. Some of the dominant species that contributed to above ground biomass were *Shorea robusta* (17.2%), *Madhuca indica* (7.9%), *Mangifera indica* (6.9%), *Terminalia alata* (6.9%) and *Diospyros melanoxylon* (4.4%), warranting extra efforts for their conservation. The results suggested that C-stocks of tropical dry forests can be enhanced by in-situ conserving the high C-density species and also by selecting these species for afforestation and stand improvement programs. Correlations were computed to understand the relationship between above ground biomass, diversity indices, density and basal area, which may be helpful for implementation of REDD+ (reduce emissions from deforestation and forest degradation, and foster conservation, sustainable management of forests and enhancement of forest carbon stocks) scheme.

Keywords: above ground biomass, biodiversity, carbon, REDD+, tree species diversity, tropical forest

Introduction

Tropical forests are biodiversity rich centres on Earth. Primary forests of Asia, particularly those from the Western and Eastern Ghats of peninsular India are disappearing at an alarming rate due to anthropogenic activities and are replaced over time by forests comprising of inferior species as their land use patterns changed (Bahuguna, 1999). Tropical dry deciduous forests are rich in economically important species. Dry deciduous forests are known to provide high potential timber revenue (Mohapatra and Tewari, 2005). Tropical rain forests are extensively studied compared to dry forests (Losos and Leigh, 2004); however there is a growing interest on dry forests (Miles *et al*., 2006; McShea *et al*., 2010). Dry deciduous forests are among the most exploited and endangered ecosystems of the biosphere (Murphy and Lugo, 1986; Janzen, 1988; Gentry, 1992). Fire susceptibility during the dry season allows more rapid exploitation and conversion of these forests when compared to evergreen forests (Goldammer, 1993). In contrast to tropical rainforests, deciduous forests have received relatively little scientific and political attention, whereas degradation and conversion of these forests are of high interest (Bullock *et al*., 1995; Rundel *et al*., 1995).

Documenting basic patterns of biodiversity is fundamental for prioritizing areas for conservation and management actions (Villasenor *et al*., 2007). Information on structure and composition of tropical dry deciduous forests is needed to conserve and restore these threatened ecosystems.

Forests form an active carbon pool that accounts over 60% of carbon storage in the earth's land surface (Wilson and Daff, 2003) and play a key role in global carbon cycle. The tropical forests store large quantities of carbon within vegetation and soil, exchange carbon with the atmosphere through photosynthesis and respiration. A recent estimate indicates that tropical forests account for 247 Gt vegetation carbon, of which 193 Gt are stored above ground (Saatchi *et al*., 2011). Even more, forests contribute with about 17.4% of the total greenhouse gas (GHG) emissions (IPCC, 2007). As a result, forests are at the centre stage of global negotiations under United Nations Framework Convention on Climate Change (UNFCCC), while the Intergovernmental Panel on Climate Change (IPCC) has recognized the significant opportunity that forests provide as 'carbon sink'. Maintaining carbon storage within tropical forests is the main objective of the UN Programme for Reducing Emissions from Deforestation and Forest Degradation in developing countries (UN-REDD, 2014).

The rationale for estimating above ground biomass is supported by the need of information about the status of forest carbon density, which is an indicator of ecosystem productivity

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and associated ecosystem services. Estimation of above ground biomass (AGB) is essential for carbon stocks studies and for investigating the effects of deforestations and carbon sequestration on global carbon balance (Ketterings *et al.*, 2001).

Biodiversity and the relationship with carbon cycle have become an important aspect, taken into consideration within international efforts to mitigate climate change, through reducing the conversion of natural ecosystems (Midgley *et al.*, 2010). The UN Programme for Reducing Emissions from Deforestation and Forest Degradation (REDD) has the potential to provide significant benefits for biodiversity conservation, through the protection of diverse forests species (Harvey *et al.*, 2009; Gardner *et al.*, 2012). Further, a functional relationship is required between diversity and carbon sequestration, which has implications for carbon management projects. Some studies were under taken regarding the potential functional relationship between diversity and C sequestration and storage (Chapin *et al.*, 2000; Tilman *et al.*, 2001; Srivastava and Vellend, 2005; Kirby and Potvin, 2007; Day *et al.*, 2013). However, direct relationships between biodiversity and the carbon cycle in mature tropical forests have not been extensively studied (Talbot, 2010).

The Eastern Ghats are a long chain of fragmented hills and elevated plateaus extending along the Indian coast to the state of Odisha, Andhra Pradesh, Tamil Nadu and Karnataka. Studies exploring the structure and composition of forests in Eastern Ghats of Odisha are limited (Reddy *et al.*, 2007; Sahu *et al.*, 2007; Sahu *et al.*, 2010, Sahu *et al.*, 2012 a, b). Further, studies above ground biomass of the tree community are almost lacking in Eastern Ghats of India (Mohanraj *et al.*, 2011), while some studies covered this aspect for the forest in Western Ghats of India.

The objectives of this study were (1) to understand the diversity, structure and composition of tropical dry deciduous forests, with special emphasis on tree species; (2) to understand the relationships of tree species above ground biomass and diversity indices, density and basal area.

Materials and Methods

Deogarh district, belonging to the Eastern Ghats of Odisha, India (Fig. 1), lies between longitude 84° 28′ - 85° 15′ E and latitude 21° 11′ - 21° 43′ N in the North-Western Plateau Zone and shares borders with Sambalpur, Sundargarh and Angul districts. The climate of the district is characterized by a very hot dry summer and a cool winter during the months of November to February. There is a pronounced fluctuation in temperature which range between 19 °C to 45 °C. The mean annual rainfall is 1262.34 ± 382.35 mm (Range = 782-1903.5 mm, N=9). The topography ranges from 250 m to 700 m asl, thus harbouring a vast range of flora and fauna. The district is largely covered with alluvial type of soil and a small percent (2%) is of black soil type. The predominant forest type of the district is tropical dry deciduous (Champion and Seth, 1968).

Field methods

Random sampling method was followed by collection of data for tree species. A total of 128 sample plots (20 x 20 meters) were laid, covering different areas of tropical dry deciduous forests in Deogarh district, in order to investigate forest structure, composition and above ground biomass of tree species. The spatial location (latitude, longitude and altitude) of each quadrat was collected using a Global Positioning System (GPS). Trees greater than or equal to 15 cm diameter at breast height (DBH) were recorded in these plots (Marimon *et al.*, 2002; Mishra *et al.*, 2005). Trees having buttresses were measure above the buttress root. Herbarium specimens were prepared and identified with the help of standard floras and deposited in the herbarium (RRL-B) at Institute of Minerals and Materials Technology (CSIR), Bhubaneswar.

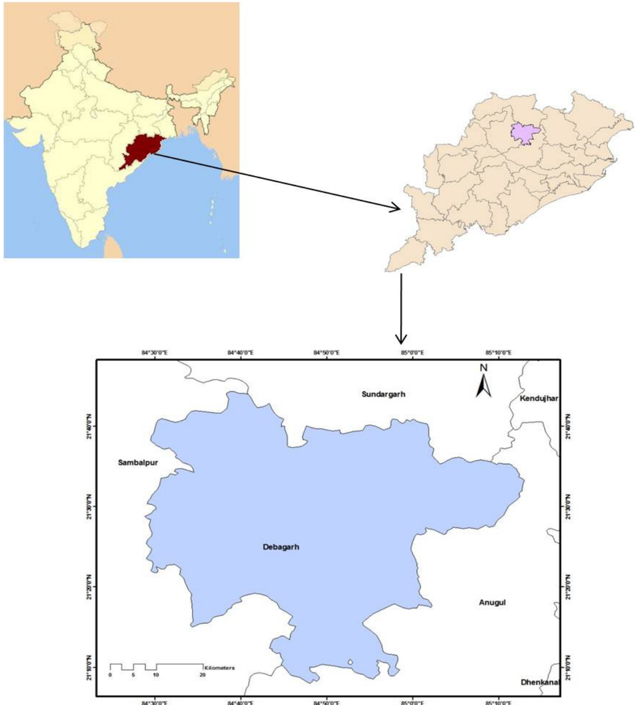

Fig. 1. Map of the study site

Data analysis

The vegetation data were quantitatively analyzed for the 71 tree species: frequency (F%), relative frequency (RF), density (D), relative density (RD), dominance (DO), relative dominance (RDO), importance value index (IVI), Shannon-Weiner index (Shannon and Weaver, 1949) and Simpson's index (Simpson, 1949). IVI of each species was calculated by summation of the RF, RD and RDO (Curtis, 1959; Mishra, 1968). Abundance to frequency ratio (A/F) of each species was determined to obtain the distribution pattern of various species as regular (0.02), random (0.02-0.05) and contiguous (0.05) distribution (Curtis and Cotton, 1956). Population structure of tree species were analyzed across fixed girth classes.

Basal area (m^2) = Area occupied at breast height (1.3 m) = [pi* $(DBH/2)^2$].

Relative density = (Density of the species/Total density of all species) x 100.

Relative frequency = (Frequency of the species /Total frequency of all species) x 100.

Relative dominance = (Basal area of the species/Total basal area for all species) x 100.

Importance value index (IVI) = Sum of relative density + relative frequency + relative dominance.

Species diversity of each forest type was determined (Shannon and Weaver 1963).

$H' = -\Sigma pi^* \ln pi$

where *pi* is the proportion of individuals of its species and total number of individuals of all species.

Concentration of dominance was also measured (Simpson, 1949).

$C = \Sigma (pi)^2$

where *pi* is same as those for the Shannon-Weiner information function. These indices were calculated using PAST (Hammer *et al.*, 2001).

The family importance value (FIV) was also calculated according to Mori *et al.* (1983). Population structure of tree species was analyzed across fixed girth classes.

For dominance-diversity (D-D) curve graph, tree species were ranked serially from 1, 2, 3, ..., 71 and placed in x-axis of the graph followed by their respective IVI value in the y-axis.

Statistical analyses employed student "t" test to determine the differences in the means assuming the equal variances. Pearson's correlation was used to understand the relationship between structural and diversity parameters. Statistica version 4 (Statsoft Inc) was used for all the statistical analysis.

Estimation of above ground biomass

Due to the richness of very high tree species in tropical forests, it is very difficult to use species specific regression models. Therefore, the general above ground biomass equation for tropical dry forests given by Chave *et al.* (2005) was used:

AGB= ρ*exp (-0.667+1.784*ln(D) + 0.207*(ln(D)) ^2-0.0281*(ln(D)) ^3)

where ρ = wood specific gravity (g/cm^3), ln = natural logarithm, D = DBH (cm).

Since area specific wood density values were not available, universal value (mean of all species) of wood density (0.6) was used to estimate the above ground biomass.

The above ground biomass carbon stock was calculated by assuming that the carbon content was 50% of the total above ground biomass (Brown and Lugo, 1982; Dixon, 1994; Ravindranath *et al.*, 1997). AGB was calculated for all the individuals of each tree species, within each plot, and finally summed for overall AGB per hectare.

Results and Discussion

Forest composition

The investigation of tropical forest composition enumerated 2,452 individuals higher than 15 cm DBH, belonging to 71 species, 57 genera and 30 families. The tree species that dominated (according to IVI) the district were *Shorea robusta* Gaertn.f. (40.72), *Terminalia alata* Heyne ex Roth. (25.55), *Diospyros melanoxylon* Roxb. (18.39), *Madhuca indica* Gmel. (16.73), *Buchnania lanzan* Spreng. (15.19) (Table 2). Among families, Combretaceae had the highest Family Importance Value (FIV) of 39.01, followed by Dipterocarpaceae (33.47), Anacardiaceae (32.46), Rubiaceae (24.51), Euphorbiaceae (22.48). Family-wise distribution revealed that Euphorbiaceae, Fabaceae and Rubiaceae had maximum numbers of species (7 species), followed by Combretaceae, Moraceae (5 species), Anacardiaceae, Caesalpiniaceae, Sterculiaceae (4 species), Ebenaceae, Rutaceae (3 species), Burseraceae, Strychnaceae (2 species) and others with one species each.

Diversity parameters and dominance-diversity (D-D) curve

The Shannon-Weiner index (H') was 2.01 ± 0.02 and Simpson's value was 0.85 ± 0.03 (Table 1) which suggested that the tropical dry deciduous forests were also species diverse ecosystems. Several researchers have reported diversity indices (H') value for Indian forests in the range of 0.8 to 4.1 (Parthasarthy *et al.*, 1992; Visalakshi, 1995). Thus, the diversity values of tree species obtained in the present study were situated within the limits reported for Indian tropical forests. However, these values are lower than other tropical forests (Knight, 1975), which may perhaps be due to climatic differences and high degree of natural disturbances, which are critical factors in governing the tropical forest species diversity (Foster, 1990). The lower diversity values for Indian forests may also be due to anthropogenic disturbances such as burning, grazing and wood collection (Jayasingam and Vivekanantharaja, 1994).

Dominance diversity (D-D) curve (Fig. 2) indicated the decreasing correlation among tree species of the studied site. It shows high IVI of *Shorea robusta* and low equitability among the species.

Forest structure

Mean stand density was 479 ha^{-1} trees ≥ 15 cm DBH. The mean stand density in Deogarh site is well within the density range reported from other sites in India (Jha and Singh, 1990; Murali *et al.*, 1996; Ghate *et al.*, 1998; Sundarapandian and Swamy, 2000).

The mean basal area was 15.20 m^2 ha^{-1}. The value of basal area is in the range of values reported for different forest sites in India. However, the differences in basal area of tree layer among different parts of India may be due to difference in altitude, species composition, age of trees, degree of disturbance and succession stages of the stands. The value obtained for basal area in the present study is comparable to the Indian tropical forests (Visalakshi, 1995).

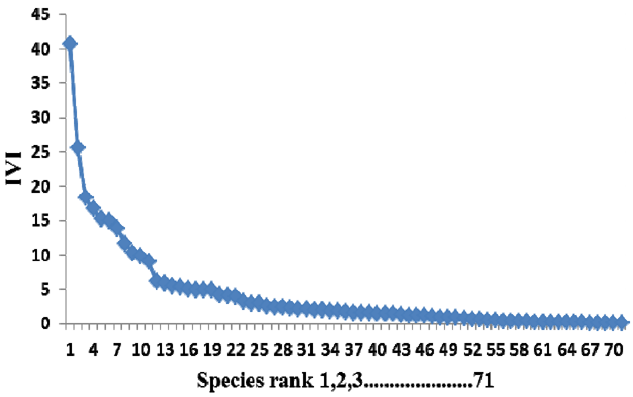

Fig. 2. Dominance diversity (D-D) curve for tree species in dry decidous tropical forests

Table 1. Diversity parameters (per quadrat) in dry deciduous tropical forests

Taxa_S	8.11 ± 2.04
Individuals	19.15 ± 2.49
Shannon_H	2.01 ± 0.02
Simpson_1-D	0.85 ± 0.03

Stem density and species richness consistently decreased with increasing girth class of tree species, except young individuals of 5-10 cm DBH class (Fig. 3). The distribution of trees based on the basal area across different DBH intervals showed that the DBH class having 9.99-14.99 cm and 14.99-19.99 cm contributed to about 30.38% and 23.77% of total individuals respectively. This result indicated that species of smaller DBH dominated the majority of available resources (Fig. 3). The highest DBH was measured in the case of *Ficus benghalensis* (458 cm), followed by *Mangifera indica* (378 cm), *Dalbergia latifolia* (234 cm), *Shorea robusta* (230 cm), *Madhuca indica* (215 cm). The presence of large number of individuals in the lower size classes indicated a growing forest, with significant potential and thus protection against continuous exploitation by local communities is to be needed.

DBH class frequency exhibited a J-shaped population structure for the trees in the study sites, data in conformity with many other forest stands in Eastern and Western Ghats such as Shervarayan hills (Kadavul and Parathasarthy, 1999a), Kalrayan hills (Kadavul and Parthasarathy, 1999b), Kakachi (Ganesh *et al*., 1996), Uppangala (Pascal and Pelissier, 1996), Mylodai-Courtallum reserve forest (Parthasarathy and Karthikeyan, 1997), Himalayan forests (Saxena and Singh, 1984), North-East India (Upadhaya *et al*., 2004; Mishra *et al*., 2005; Khumbongmayum e*t al*., 2006). This is the typical characteristic of a tropical forest. The DBH size class distribution showed a decline in the number of individuals from lower class to higher class, indicating expanding population.

Distribution pattern of tree species

The data on species/genus ratio supported the comparison of the rate of species development as recent diversification as suggested by the values obtained. Tropical areas have low species/genus ratio, indicating that the tropical forests have emerged over a long period of time (Ricklefs and Miller, 2000). In the present research, all the study sites show low S/G ratio in the tree layer (1.25) thus conforming to the findings of Ricklefs and Miller (2000).

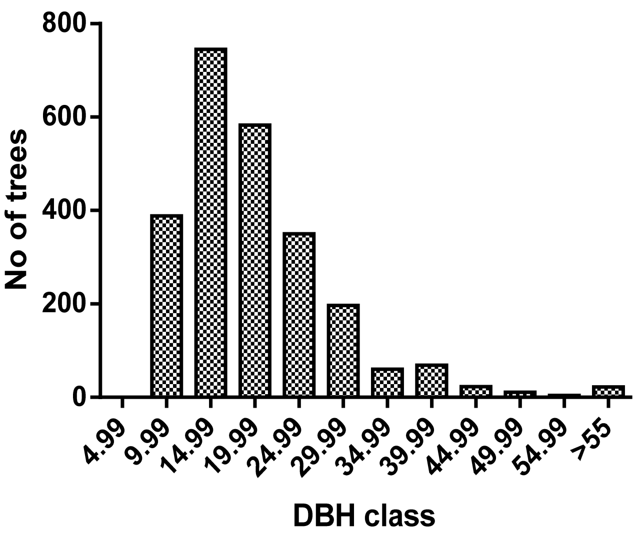

Fig. 3. Distribution of tropical forest trees in different diameter classes

Distribution pattern analysis showed that out of 71 tree species, one was regular (*Erythrina variegata*), four were randomly (*Bowsellia serrata, Diospyros melanoxylon, Shorea robusta* and *Terminalia alata*) and other sixty six species were contiguously distributed. It indicated contiguous distribution to be prevalent and this could have been attributed to the interaction of several factors that are acting together, affecting the population. While comparing dispersion pattern of trees in tropical to temperate climates of the world, Armesto *et al.* (1986) concluded that clumping is characteristic of most natural forests which confirms the prevalent contiguous distribution of tree species.

Above ground biomass carbon stock

Total above ground biomass varied considerably between plots, ranging from 514.50 Mg ha^{-1} to 13.96 Mg ha^{-1}. Mean above ground biomass was 98.87 ± 68.8 Mg ha^{-1} (Mean ± Standard deviation). The biomass was in the range of values reported elsewhere (Hall and Uhling, 1991; Ravindranath *et al*., 1997; Haripriya, 2000; Bhatt and Ravindranath, 2011; Mohanrai *et al*., 2011). The above ground biomass carbon stock ranged from 257.25 Mg C ha^{-1} to 6.98 Mg C ha^{-1}. The above ground carbon density in the present study was more than the value reported by Singh and Singh (1991) for an individual Tropical Dry Forest (TDF) site in India and the global range reported by Murphy and Lugo (1986).

Tree biomass allocation by different species

Tree species contributed with 82.64% to the total above ground biomass (AGB) along with herbs, climbers, litter and dead wood, which together summed up to 17.36%. Among tree species, the top ten species that contributed the most to the obtained AGB were *Shorea robusta* (17.2%), *Madhuca indica* (7.9%), *Mangifera indica* (6.9%), *Terminalia alata* (6.9%), *Diospyros melanoxylon* (4.4%), *Lannea coromandelica* (3.2%), *Anogeissus latifolia* (3.1%), *Ficus benghalensis* (3.0), *Boswellia serrata* (2.5%) and *Buchnania lanzan* (2.4%) (Fig. 4). This proved the dominance of a single species, which contributed the most within the forest ecosystem, indicating the need for

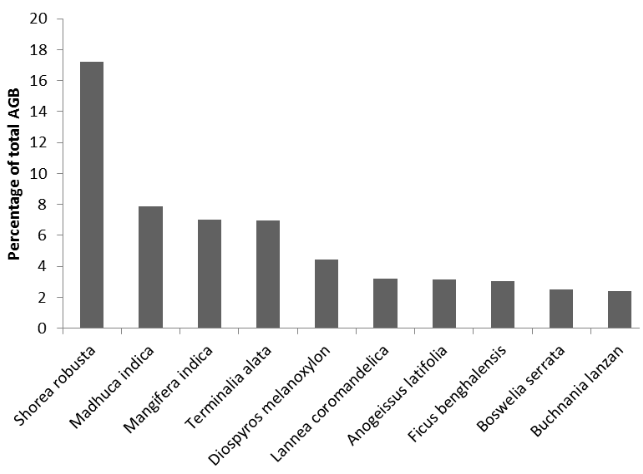

Fig. 4. Tree species contributing the most to above ground biomass (%) of the dry deciduous tropical forest

Table 2. Enumeration of tree species indentified in the dry deciduous tropical forest under study

Slot No.	Species	Family	IVI	AGB (Mg ha^{-1})	AGB carbon stock (Mg C ha^{-1})
1	*Adina cordifolia (Roxb.) Hook. f. ex Brand.*	Rubiaceae	8.98	2.01	1.008
2	*Aegle marmelos* (L.) Corr.	Rutaceae	2.40	0.39	0.199
3	*Albizzia lebbeck* (L.) Benth.	Mimosaceae	0.61	0.21	0.106
4	*Alstonia scholaris* (L.) R.Br.	Apocynaceae	0.23	0.04	0.024
5	*Anogessius latifolia* (Roxb. Ex DC.) Wall.ex Guill. & Perr.	Combretaceae	13.80	3.77	1.888
6	*Antidesma acidum* Retz.	Euphorbiaceae	0.14	0.01	0.005
7	*Bauhinia purpurea* L.	Caesalpiniaceae	0.69	0.14	0.074
8	*Bauhinia variegate* L.	Caesalpiniaceae	0.25	0.07	0.037
9	*Bombax ceiba* L.	Bombacaceae	0.51	0.05	0.028
10	*Bowsellia serrata* Roxb.ex Colebr.	Burseraceae	4.97	2.99	1.499
11	*Bridellia retusa* (L.) Spreng.	Euphorbiaceae	1.43	0.24	0.121
12	*Buchmania lanzan* Spreng	Anacardiaceae	15.19	2.85	1.428
13	*Butea monosperma* (Lam.) Taub.	Fabaceae	0.44	0.08	0.040
14	*Careya arborea* Roxb.	Barringtoniaceae	3.22	0.61	0.307
15	*Casearia graveolens* Dalz.	Flacourticeae	9.82	1.03	0.517
16	*Cassia fistula* L.	Caesalpiniaceae	4.97	0.62	0.310
17	*Chloroxylon swietiana* DC.	Rutaceae	6.22	1.37	0.688
18	*Cleistanthus collinus* (Roxb) Benth.ex.Hook.f.	Euphorbiaceae	15.02	1.36	0.684
19	*Dalbergia latifolia* Roxb.	Fabaceae	2.22	1.46	0.730
20	*Dalbergia paniculata* Roxb.	Fabaceae	2.21	0.83	0.418
21	*Dalbergia sisoo* Roxb.	Fabaceae	0.17	0.03	0.018
22	*Dillenia pentagyna* Roxb.	Dilleniaceae	1.87	0.86	0.434
23	*Diospyros malabarica* (Desr.) Kostel.	Ebenaceae	5.91	2.38	1.193
24	*Diospyros melanoxylon* Roxb.	Ebenaceae	18.39	5.27	2.637
25	*Diospyros montana* Roxb.	Ebenaceae	2.27	0.84	0.423
26	*Erythrina variegate* L.	Fabaceae	1.17	0.26	0.131
27	*Ficus tomentosa* Roxb. Ex Willd.	Moraceae	0.22	0.08	0.044
28	*Ficus benghalensis* L.	Moraceae	3.94	3.61	1.806
29	*Ficus racemosa* L.	Moraceae	0.17	0.03	0.015
30	*Ficus religiosa* L.	Moraceae	0.35	0.24	0.123
31	*Ficus semicordata* Buch.Ham.ex J.E.Sm.	Moraceae	0.13	0.01	0.005
32	*Gardenia latifolia* Ait.	Rubiaceae	2.01	0.30	0.151
33	*Glochidion velutinum* Wight	Euphorbiaceae	0.84	0.20	0.103
34	*Gmelina arborea* Roxb.	Verbenaceae	1.25	0.31	0.155
35	*Helecteres isora* L.	Sterculiaceae	0.97	0.04	0.020
36	*Ixora pavetta* Andr.	Rubiaceae	0.56	0.20	0.103
37	*Lagerstroemia parviflora* Roxb.	Lythraceae	4.29	0.66	0.333
38	*Lannea coromandelica* (Houtt) Merr.	Anacardiaceae	10.26	3.79	1.899
39	*Macaranga peltata* (Roxb.) Muell-Arg.	Euphorbiaceae	0.18	0.01	0.002
40	*Madhuca indica* Gmel.	Sapotaceae	16.73	9.44	4.722
41	*Mangifera indica* L.	Anacardiaceae	11.71	8.36	4.184
42	*Melastoma malabathricum* L.	Melastomataceae	0.34	0.02	0.011
3	*Mitragyna parviflora* (Roxb.)	Rubiaceae	5.52	1.01	0.508
44	*Morinda pubescens* Sm. in Rees	Rubiaceae	4.87	0.70	0.351
45	*Murraya paniculata* (L.) Jack	Rutaceae	0.14	0.01	0.002
46	*Nyctanthes arbor-tristis* L.	Oleaceae	1.62	0.16	0.084
47	*Ougenia ojeinensis* (Roxb.) Hochr.	Fabaceae	1.15	0.07	0.036
48	*Phyllanthus emblica* L.	Euphorbiaceae	2.99	0.23	0.119
49	*Polyalthia cerasoides* (Roxb.) Bedd.	Anonaceae	1.05	0.10	0.050
50	*Protium seratum* Wall ex Colebr	Burseraceae	0.22	0.09	0.045
51	*Pterocarpus marsupium* Roxb.	Fabaceae	5.09	0.87	0.435
52	*Pterospermum acerifolium* (L.) Willd.	Sterculiaceae	1.59	0.25	0.129
53	*Pterospermum xylocarpum* (Gaertn.) Sant & Wagh	Sterculiaceae	0.87	0.10	0.050
54	*Randia malabarica* Lam.	Rubiaceae	0.33	0.01	0.005
55	*Schleichera oleosa* (Lour.) Oken	Sapindaceae	5.32	1.60	0.800
56	*Semecarpus anacardium* L.f.	Anacardiaceae	1.49	0.30	0.153
57	*Shorea robusta* Gaertn.f.	Dipterocarpaceae	40.72	20.62	10.311
58	*Soymida febrifuga* (Roxb.) A.Juss.	Meliaceae	0.99	0.27	0.138
59	*Sterculia urens* Roxb.	Sterculiaceae	0.28	0.10	0.050
60	*Strychnos nux-vomica* L.	Strychnaceae	0.20	0.02	0.012
61	*Strychnos potatorum* L.f.	Strychnaceae	2.06	0.71	0.355
62	*Symplocos racemosa* Roxb.	Symplocaceae	1.67	0.14	0.072
63	*Syzygium cumini* (L.) Skeels	Myrtaceae	4.10	1.26	0.632
64	*Terminalia alata* Heyne ex Roth.	Combretaceae	25.55	8.32	4.162
65	*Terminalia arjuna* (Roxb.ex DC) Wight & Arn.	Combretaceae	2.49	1.81	0.909
66	*Terminalia bellirica* (Gaertn.) Roxb.	Combretaceae	1.89	0.69	0.346
67	*Terminalia chebula* Retz.	Combretaceae	2.64	0.94	0.470
68	*Trewia nudiflora* L.	Euphorbiaceae	1.41	0.23	0.116
69	*Wendlandia tinctoria* (Roxb.) DC.	Rubiaceae	3.04	0.43	0.219
70	*Xylia xylocarpa* (Roxb.) Taub.	Caesalpiniaceae	1.80	0.33	0.167
71	*Ziziphus xylocarpus* (Retz.) Willd.	Rhamnaceae	1.49	0.10	0.054

IVI- Importance value index, AGB- above ground biomass; DBH class ≥ 15 cm prioritization of *Shorea robusta* conservation, in order to achieve significant biomass stocks in the dry deciduous tropical forests of Eastern Ghats.

Above ground biomass distribution

The AGB accumulation was greater in the 10-30 cm DBH class, followed by 30-50 cm and > 50 cm classes (Fig. 5). DBH class of 10-30 cm contributed with about 60% of the total AGB. Higher size classes' stems did not contribute significantly to the biomass pool of this forest, which was not in conformity with the findings of earlier researchers (Brown and Lugo, 1992; Brown *et al*., 1995; Brown, 1996; Clark and Clark, 1996) who reported up to 50% contribution to AGB by the large trees (> 70 cm DBH). This result can be attributed to a lower density of stems in higher size classes in the hereby study site. A higher proportion of AGB in lower diameter class indicated the importance of young trees in carbon sequestration process, which can lead to enhanced future carbon stock. Beyond maturity, trees generally have marginal carbon sequestration capability (Lal and Singh, 2000).

Relationship of AGB with basal area, density and diversity indices

The relationship of AGB with basal area, density and diversity indices was analyzed using Statistica version 4 (Statsoft Inc) and the results are shown in Table 3. The analysis showed that AGB was positively correlated to basal area; the correlation coefficient value (r) was 0.99, significant at 0.05 probability level. A strong positive relationship was observed between AGB and basal area, which was in agreement with the earlier findings of Mani and Parthasarathy (2007), Murali *et al*. (2005) and Kumar *et al*. (2011). Shannon index and Simpson index were negatively correlated to AGB, whereas density was positively correlated to AGB (r = 0.01), but weakly significant. Day *et al*. (2013) studied the relationship between species diversity and AGB in central African rain forests and found that there was a complex and highly variable relationship between biomass and species diversity. Further, Wang *et al*. (2011) had shown a positive relationship between structural diversity and above ground carbon stocks supported by complex forest structures, allowing greater light infiltration and promoting a more efficient resources' use by trees, thus leading to an increase in biomass production. In India, Borah *et al*. (2013) had also found that there was positive correlation between tree species diversity and above ground biomass, even though it was not significant. In the present study, there was no significant relationship among species diversity and above ground biomass. However, it was found that plots with higher biomass had fewer number of species ($t = 3.08$, $p < 0.003$, $df = 18$). The hereby results are in agreement with Days *et al*. (2013) who concluded that plots with high biomass had less number of species.

Negative relationship between tree species diversity and biomass was also reported in the temperate forest ecosystems of central Europe (Szwagrzyk and Gazda, 2007; Jacob *et al*., 2010).

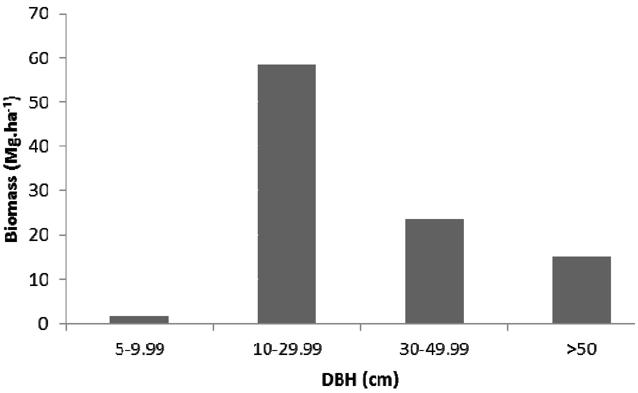

Fig. 5. Distribution of above ground biomass of tree species in different DBH classes

Implications for REDD+

REDD+ scheme would mitigate climate change by conserving the forests threatened by deforestation and degradation. It would also contribute to conservation of the biodiversity, by enhancing carbon stocks. Further, high biomass and higher species diversity facilitates REDD+ mechanism. In the present study, the biomass and species diversity had negative correlation to each other. However, if forests are properly managed, carbon stock enhancement can also provide additional benefits to biodiversity through forest restoration and afforestation (SCBD, 2011). In particular, the high carbon accumulating tree species such as *Shorea robusta, Madhuca indica, Mangifera indica, Terminalia alata*, *Diospyros melanoxylon* etc. should be given priority for conservation and sustainable management, by avoiding deforestation. In the coming decades, the estimation of carbon stocks would be useful as a baseline data for implementation of REDD+.

Conclusions

Quantitative analysis with reference to IVI, density, diversity and frequency distribution could act as indicators of anthropogenic disturbances that are affecting various forest types. Reverse J-shaped population structure of the dry deciduous tropical forest studied denoted an evolving or expanding population of trees, which needs to be maintained within specific limits. This study might help conservation managers, researchers and scientists in understanding the structure and composition of the tropical

Table 3. Pearson's correlation for diversity parameters

	Simpson index	Shannon index	Evenness	Density	Above ground biomass	Basal area
Simpson index	1	*0.978	-0.162	*0.585	-0.090	-0.078
Shannon index		1	-0.281	*0.605	-0.085	-0.072
Density				1	0.011	0.032
Above ground biomass					1	*0.999
Basal area						1

* Indicates significant; marked correlations are significant at $p < 0.05$ (N = 128)

dry forests. It can be concluded that younger trees contributed more to AGB and carbon stocks than older trees. However, the rate of such contribution may vary from forests to forests depending upon age, forest type, climate and soil conditions. The obtained results revealed that AGB was positively correlated to basal area, where as diversity indices were negatively correlated to AGB. More research is required to establish the relationship between these parameters at different spatial scales and range of taxa. Further, when implementing REDD+ mechanism, priority should be given towards conserving the potential carbon accumulating tree species such as *Shorea robusta, Madhuca indica, Mangifera indica, Terminalia alata*, *Diospyros melanoxylon*, for enhancing the carbon stocks of tropical dry forests.

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