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Assessment of Vegetation Structure and Above Ground Biomass Carbon Pools in Evergreen and Deciduous in Kodagu District of Western Ghats, India.

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ABSTRACT

Floristic diversity, above ground biomass (AGB) and carbon density was compared between different vegetation types of Kodagu district in Western Ghats. Results revealed significant differences across different vegetation types for different parameters studied. Maximum species richness (62 species) and diversity (H'=3.57) was recorded in evergreen forest followed by deciduous (38 species, H'=2.33). On the other hand, maximum density of 380 stems/ha was recorded in Evergreen forest followed by Deciduous (276 stems/ha). However, higher basal area of 50.44 m2/ ha was recorded in Evergreen forest and lowest in Deciduous forest (13.03 m2/ha). The tree layer contributed about (416.8 tonnes/ ha) to the total AGB, among different vegetation types Evergreen forest contributed (314.768 tonnes/ ha) and Deciduous forest contributed (102.04 tonnes/ ha). Carbon density was estimated about (195.89 tonne C/ ha) across different forest types, Evergreen forest (147.94 tonne C/ ha) and Deciduous forest (47.95tonne C/ ha). The majority of AGB and carbon pool in our study was found within taller trees and trees with a larger diameter therefore, their removal substantially alters the C storage and dynamics in this region. Land-use systems with higher C sequestration potential are currently supported under REDD+ projects that focus on forest conservation and management.

Introduction

India's Western Ghats landscapes are the unique mosaics of natural forests interspersed with agricultural lands, agro forests, coffee and tea plantations, mono-culture plantations and various other tree based production systems which are known to be the most species diverse terrestrial ecosystems. The majority of the 34 global biodiversity hotspots identified worldwide occur within tropical regions and Western Ghats in South India is one among them (Meyers *et al*., 2000). Forests of Western Ghats contain the most diverse plant communities, with up to 350-400 tree and liana species coexisting in a single hectare (Ganesh *et al*., 1996; Swamy *et al*. 2010; Murthy *et al*., 2016). In addition to the rich biodiversity, these forests are also acting as natural sinks of carbon, with a sequestration potential of 80-150 Mg -1 C ha (Devagiri *et al*., 2013) and thus playing a fundamental role in the global carbon cycle. Biodiversity loss and climate change due to habitat destruction and fragmentation are the current environmental challenges. Understanding the pattern of tree diversity and above-ground biomass (AGB) in natural forests is essential for conservation planning and climate change mitigation strategies. Biomass assessment is important for national development planning as well as for scientific studies of ecosystem productivity, carbon budgets etc. (Zheng *et al*., 2004; Pande *et al*., 2010). Biomass analysis is an important element in the carbon cycle especially, carbon sequestration. Recently biomass is being increasingly used to help quantify pools and fluxes of greenhouse gases (GHG) from terrestrial biosphere associated with land use and land cover changes (Cairns *et al*., 2003). The importance of terrestrial vegetation and soil as significant sinks of atmospheric CO and its other 2 derivatives is highlighted under Kyoto Protocol (Wani *et al*., 2010). Vegetation especially, forest ecosystems store carbon in the biomass through photosynthetic process, thereby sequestering carbon dioxide that would have been present in the atmosphere. Undisturbed forest ecosystems are generally highly productive and accumulate more biomass and carbon per unit area compared to other land use systems like agriculture. It is estimated that the carbon stored globally in the forest biomass amounts to 240439 Mt with an average carbon density of 71.5 t ha. A recent estimate indicates that tropical forests account for 247 Gt vegetation carbon, of which 193 Gt is stored above ground (Saatchi *et al*., 2011). Many researchers have estimated biomass and C stocks present in India's forests. Hingane (1991) estimated total phytomass carbon pool and carbon density of India's forests at 2587 Tg C and 49.2 Mg C ha, respectively based on ecological studies and mean phytomass density for each forest type. Ravindranath *et al*. (1997) estimated the standing biomass (both above and below ground) in India to be 8375 Mt for the year 1986, of which the carbon storage was reported to be 4178 Mt. The total carbon stored in forests of India including soil was estimated at 9578 Mt. Dadhwal *et al*., (1998) using FAO inventory for ecological zones estimated the carbon pool at 3117 Tg C and carbon density at 60.2 Mg C -1 ha . However, these estimates exhibit large temporal and spatial variation in biomass and C stocks. Hence, developing appropriate biomass estimation methods for accurate and consistent reporting of forest carbon inventories is important. This study was under taken in Kodagu district which lies in the southern part of the Western Ghats of Karnataka with a research hypothesis that floristic diversity and AGB are expected to vary among forest types with the highest diversity and AGB expected in evergreen forests which enjoys more protection status and then expected to decrease with increasing land-use intensity and disturbances in deciduous forest. In accordance with the set hypothesis we aimed at three important objectives to (1) assess and compare the tree species diversity, structure and dominance among different forest types (2) examine how the basal area, AGB and carbon density differs between forest types and (3) know which girth classes and species contribute more to AGB and carbon.

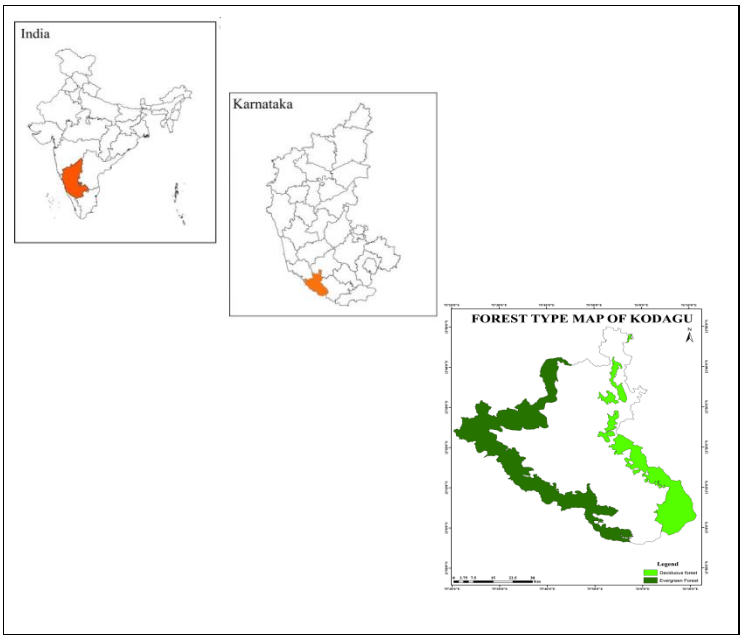


Fig 1: Map of study Area

Material and methods

Study area

This study was conducted in two forest types of Kodagu district which lies in the southern Western Ghats region (N 11° 56'- 12° 52' and E 75°22' - 76° 12') covering an area of 4102 km^2. The notified forest area is 1500.66 km^2 under that Evergreen (947.23 km^2) and Deciduous (553.43 km^2), with 36.5% of the geographical area. The study area, with an altitudinal range of 900m to 1715m above MSL, receives average annual rainfall ranging from 3000 mm to 4000 mm with maximum rainfall during monsoon season (June to September), The western slope of the mountains experience heavy Annual rainfall (with 80% during the southwest monsoon from June to September), while the Eastern slope are direr and rainfall also decreases from south to North. April and May have the highest mean maximum temperature (34.5°C), while December and January have the lowest mean minimum temperature (19 C). Two forest type's namely Evergreen forest (EF), Deciduous forest (DF) were selected for the present study and location of the selected sites within each forest type is depicted in Fig 1.

Sampling method

For collection of data on trees; the strata considered for the estimation of AGB were only trees. Height of all trees ≥6m and GBH of all trees ≥30cm obtained in all plots (20x20m) were measured. Thus sample plots across different forest types and this sampling scheme was implemented for representing spatial heterogeneity of plots in each forest type. In each of (20x20m) plots, all the woody plants were counted and identified as far as possible in-situ at species level using field keys of Flora of Karnataka (Saldanha, 1996). Voucher specimens of species, which could not be identified in the field, were collected for identification at College of Forestry, Ponnampet with help of taxonomist. Height and Girth at Breast Height (GBH) of all the trees with ≥30 cm GBH in 40 sample plots within each were measured using Blume Leiss Hypsometer (which is based on the trigonometric method) and digital tree caliper (Haglof, Sweden), respectively. Species richness (SR) was estimated by counting individuals of different species per unit area using species area accumulation curve as suggested by Chazdon *et al*. (1999).

Species diversity (Shannon–Wiener diversity index H') and dominance (Simpson's index-D) were calculated as per Magurran (1988). Tree population structure was characterized using GBH and total tree height classes. Importance Value Index (IVI) for each species was computed and expressed as the sum of relative density, relative dominance and relative frequency of the species within and among plots (Curtis, 1959). Based on the IVI values, we identified top ten species for estimation of density (stems/ha) and basal area m^2 ha^{-1}) and their contribution to AGB (Mg^2 ha^{-1}) and carbon density (Mg C ha). The strata considered for the estimation of AGB were only trees. The data collected on tree parameters such as GBH (> 30 cm) and height were used for volume estimations using volume equations published by Forest Survey of India (FSI 2006). We used local as well a regional volume equations depending on the availability for each species and mostly these regression equations follow 2 general linear model (GLM) of the form of V= a+bD+D or 2 V=a+bD H. Tree biomass was estimated by multiplying volume with species specific wood specific gravity values. Wood specific gravity data were obtained from Forest Research Institute (FRI 1996) (Appendix-I). AGB of stems with < 30 cm GBH was estimated by adopting the methodology developed by Devagiri *et al*. (2013) which is based on the large dataset of 1834 trees. Biomass thus obtained from 40 sample plots in different stratum for each land use type was summed up to obtain total AGB and expressed. Finally, based on the assumption that living biomass (tissues) is composed of 47% carbon, we calculated above-ground carbon stock as 0.47 x AGB and expressed as Mg C ha^{-1} for different forest types (Dadhwal *et al*., 2009).

Results and discussion

Across different vegetation types, floristic diversity, tree density and basal cover varied considerably (Table 1). Maximum species richness (62 species) and diversity (H'=3.57) was recorded in Evergreen forest followed by Deciduous (38 species, H'=2.33). On the other hand, Simpson's index of dominance (D) was higher in deciduous forest (0.189) and lowest in Evergreen forest (0.04). Tree height varied considerably across forest types with mean tree height ranged from 12.53 to 19.47 m (Table 1). None of the forest type showed reverse-J shaped curve for tree height. Higher number of individuals was found in 9-12m height-class in deciduous and comparatively taller trees (> 15 m) were noticed only in evergreen forest. A comparison of size-class distribution of Girth at breast height (GBH) across the land-use types revealed significant variation. As expected a normal reverse-J shaped curve was observed only in Evergreen forest while near normal distribution was noticed in deciduous forest types for stem diameter.

Table 1: Tree diversity, structure and above ground biomass (AGB) and carbon pool in different forest types of Kodagu district.

Sl. No.	Parameters	Vegetation Type Evergreen Forest	 Deciduous Forest
1	Species richness	62	38
2	Shannon Weiner Index (H)	3.5764	2.3324
3	Simpson's Index (D')	0.04016	0.18982
4	Tree height (m)	19.47	12.53
5	Tree density (Stems ha^{-1})	380	276
6	Basal Area ($m^{-2}ha^{-1}$)	49.97	14.58
7	AGB Trees (t ha^{-1})	50.44	13.03
AGB Total		314.76	102.04

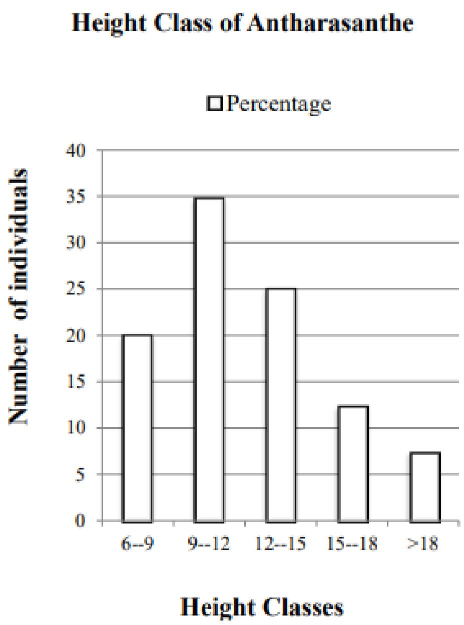


Fig 2: Height class Distribution of Evergreen

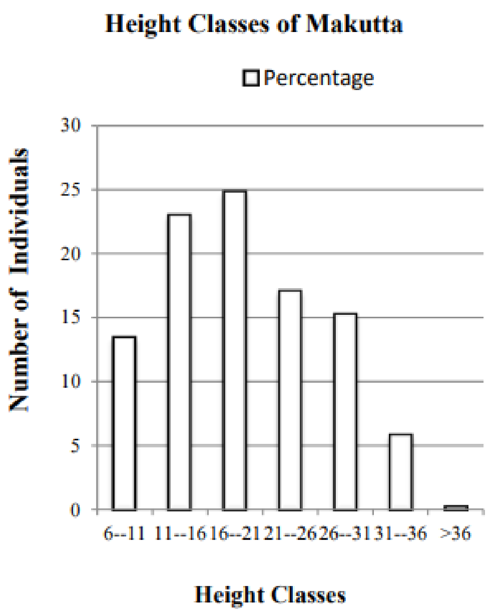


Fig 3: Height class Distribution of deciduous forest

Table 2: Height class Distribution of Evergreen

Height class (m)	No. of individuals	Percentage (%)
6-11	82	13
11-16	140	23
16-21	151	25
21-26	104	17

26-31	93	15
31-36	36	06
>36	2	01
Total	**N= 608**	

Table 3: Height class Distribution of deciduous forest

Height class (m)	No. of individuals	Percentage (%)
6-9	89	20
9-12	154	35
12-15	111	25
15-18	55	12
>18	33	08
Total	**N= 442**	

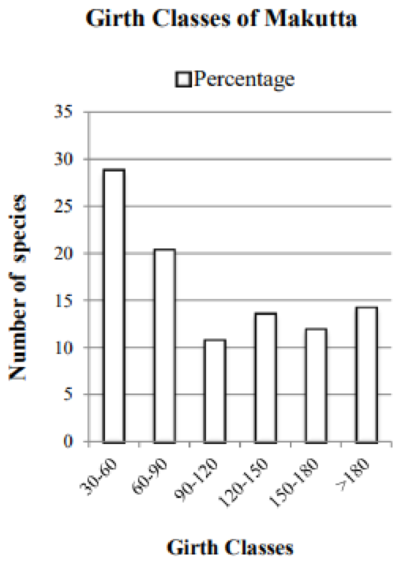


Fig. 4. Girth class distribution of Evergreen forest

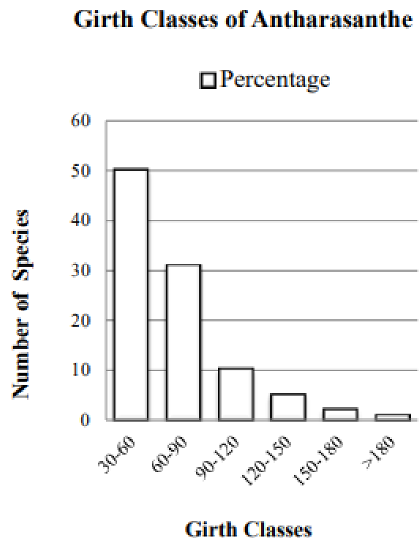


Fig 5: Girth class distribution of deciduous forest

Table 4: Girth class distribution of Evergreen forest

Girth class (cm)	No. of individuals	Percentage (%)
30-60	175	29
60-90	124	20
90-120	66	11
120-150	83	14
150-180	73	12
>180	87	14
Total	N=608	

Table 5: Girth class distribution of deciduous forest

Girth Class (cm)	No. of individuals	Percentage (%)
30-60	221	50
60-90	137	31
90-120	46	11
120-150	23	5
150-180	10	2
>180	5	1
Total	**N= 442**	

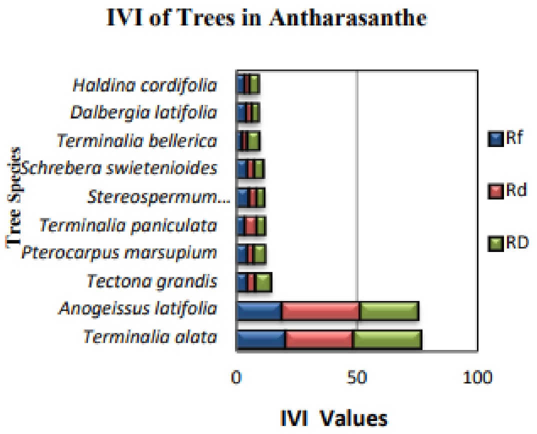


Table 6: IVI of trees in Deciduous Forest

Tree Species	IVI
Terminalia alata	76.05
Anogeissus latifolia	74.77
Tectona grandis	14.37
Pterocarpus marsupium	12.22
Terminalia paniculata	11.93
Stereospermum personatum	11.75
Schrebera swietenioides	11.28
Terminalia bellerica	9.69
Dalbergia latifolia	9.54
Haldina cordifolia	9.39

Fig 6: IVI of trees in Deciduous Forest

Inference: *Terminalia alata* is dominant and is of ecological importance in Antharasanthe.
These results indicate that deciduous forest found to be short stature as compared to Evergreen forests of this region. Further, we found lesser number of trees in lower diameter classes (90-120 cm GBH) and higher number of trees in intermediate class (30- 60 cm GBH) in all the forests. Is probably due to the fact that these land-use types face continuous pressure in the form of wood removal, primarily fuel wood and poles for domestic use, by the people leaving in the fringe areas. Similar effects of disturbance on stem density and forest stand structure have been reported in Western Ghats (Pascal and Pelissier, 1996; Pomeroy *et al*., 2003). Similarly, maximum density of 380 stems ha^{-1} was recorded in Evergreen forest followed Deciduous (276 stems ha-1) (Table 1). However, higher basal area of 12.16 m ha^{-1} was recorded in Evergreen forest and lowest in scrub forest (1.68 m² ha^{-1}). These values compare with tree density and basal area reported by Devagiri *et al*., (2013) for different forest types of South-western part of Karnataka and Swamy *et al*. (2000) for forests of Tamil Nadu. While on the higher side of the tree density range of 257-664 stems ha^{-1} and basal area range of m² ha^{-1} was reported by Swamy *et al*. (2010) for tropical evergreen forests of Western Ghats region in Karnataka. Furthermore, though the density appears to be low in deciduous forests, the basal area was also low (13.03 m^2 ha^{-1}) which indicates abundance of trees in lower diameter classes. This is consistent with many other dry deciduous forests which are characterized by the presence of lower diameter class individuals (Krishnamurthy *et al*., 2010). Above-ground biomass (AGB) ranged between 102.04 to 314.76 tonne ha^{-1} across different vegetation types in the region (Table 1).

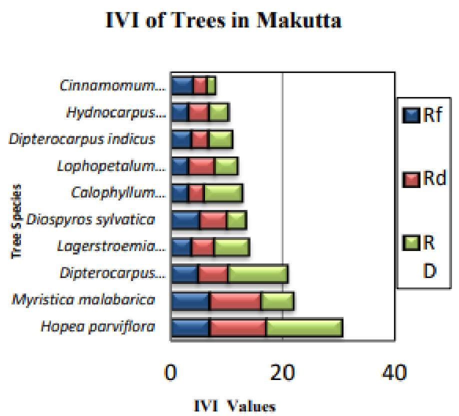


Table 7: IVI of trees in Evergreen Forest

Tree Species	IVI
Hopea parviflora	30.31
Myristica malabarica	21.87
Dipterocarpus bourdilloni	20.75
Lagerstroemia lanceolata	14.07
Diospyros sylvatica	13.49
Calophyllum tomentosum	12.79
Lophopetalum wightianum	12.04
Dipterocarpus indicus	11.08
Hydnocarpus pentandra	10.42
Cinnamomum malabatrum	8.15

Fig 7: IVI of trees in Evergreen Forest

Inference: *Hopea parviflora* is dominant and is of ecological importance in Makutta.
As expected, the maximum biomass (314.76 tonne ha^{-1}) was recorded in Evergreen forest and minimum in scrub forest (102.04 tonne ha^{-1}). These estimates are towards the lower end of the range as compared to the Indian pattern of AGB estimates of 42-78 t ha^{-1} (Singh and Singh, 1991) and 420-649 t ha^{-1} (Rai and Proctor, 1986) and global pattern of AGB estimates of 30-273 t ha^{-1} and 213-1173 t ha^{-1} (Murphy and Lugo, 1986b) for tropical dry and wet forests, respectively. The tree layer contributed high AGB (29.68-220.78 Mg ha^{-1}) followed by shrub (10.13-21.19 Mg ha^{-1}) and herb layer (0.81-1.31 Mg ha $^{-1}$) to the total AGB among different vegetation types. The order of contribution of biomass by the tree layer across the types was in the order of evergreen forest>deciduous forest. The two layer biomass values obtained in the present study are towards the lower side as compared to the values 397-527 t ha^{-1} reported by Swamy *et al*. (2010) for evergreen forest, 46.7 t ha^{-1} reported by Singh and Singh (1991) for dry deciduous forest. Carbon density in the present study ranged from 47.95 tonne C ha^{-1} in deciduous forest to 147.94 tonne C ha^{-1} in evergreen forest. These results could be compared with available biomass and carbon estimates of different forest types in India. Bhat *et al*. (2003) estimated the biomass accumulation in tropical rain forests of Uttar Kannada in the Western Ghats ranging from 92 to 268.49 t ha^{-1}. Chaturvedi *et al*. (2011) reported carbon density ranging from 15.6 to 151 t-C ha^{-1} in tropical dry forests of India.

Table 8: Major tree species contribution to AGB in Dry deciduous forest of Antharasanthe

Sl. No.	Tree species	No of individuals/ha	AGB (tonne/ha)	C-stock (t/ha)
1	*Terminalia alata*	76.3	39.59	10.87
2	*Anogeissus latifolia*	88.8	23.14	3.07
3	*Terminalia bellerica*	5.6	6.54	2.33
4	*Tectona grandis*	8.8	4.95	1.91
5	*Pterocarpus marsupium*	6.9	4.06	1.70
6	*Adina cordifolia*	5.6	3.61	1.05
7	*Dalbergia latifolia*	6.3	2.23	1.04
8	*Terminalia paniculata*	13.8	2.22	0.97
9	*Chukrasia tabularis*	5.0	2.07	0.80
10	*Schrebera swietenioides*	2.5	1.70	0.63
11	*Scheichera oleosa*	0.6	1.34	0.44
12	*Mitragyna parviflora*	1.2	0.93	0.43
13	*Syzygium cumini*	1.3	0.91	0.38
14	*Cassia siamea*	6.3	0.80	0.36
15	*Diospyros melanoxylon*	4.4	0.76	0.34
16	*Bauhinia variegate*	1	0.72	0.33
17	*Stereospermum personatum*	8.8	0.70	0.30
18	*Lagerstroemia parviflora*	2.5	0.63	0.28
19	*Gardenia gummifera*	3.1	0.60	0.27
20	*Semecarpus anacardium*	1.6	0.57	0.26

Table 9: Major tree species contribution to AGB in evergreen forest of Makutta

Sl. No.	Tree species	No of individuals/ha	AGB (t/ha)	C-stock (t/ha)
1	*Hopea parviflora*	38	51.40	24.16
2	*Dipterocarpus bourdilloni*	20	45.10	21.20
3	*Dipterocarpus indicus*	13	20.97	9.86
4	*Calophyllum tomentosum*	11	18.71	8.79
5	*Lagerstroemia microcarpa*	13	13.87	6.52
6	*Myristica malabarica*	35	13.79	6.48
7	*Hydnocarpus pentandra*	14	12.86	6.05
8	*Artocarpus hirsutus*	3	8.98	4.22
9	*Mangifera indica*	7	8.85	4.16
10	*Kingiodendron pinnatum*	7	8.81	3.52
11	*Vateria indica*		7.10	3.34
12	*Diospyros nilagirica*	9	7.08	3.33
13	*Lophopetalum wightianum*	18	6.83	3.21
14	*Diospyros sylvatica*	18	6.40	3.01
15	*Calophyllum macrocarpa*	2	6.30	2.96
16	*Canarium strictum*	4	5.55	2.61
17	*Tetrameles nudiflora*	8	5.27	2.48
18	*Diospyros ebenum*	6	5.09	2.39
19	*Hemicyclia elata*	10	4.65	2.19
20	*Terminalia bellerica*	1	3.89	1.83

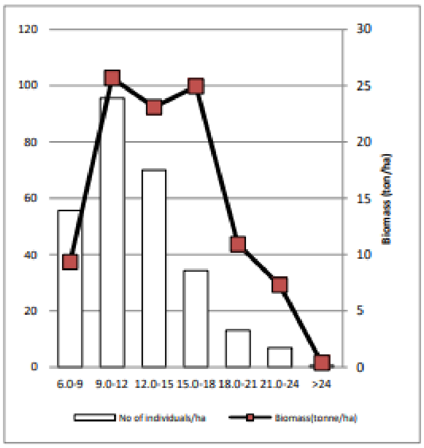


Fig 8a: Allocation of ABG to height classes in deciduous forest

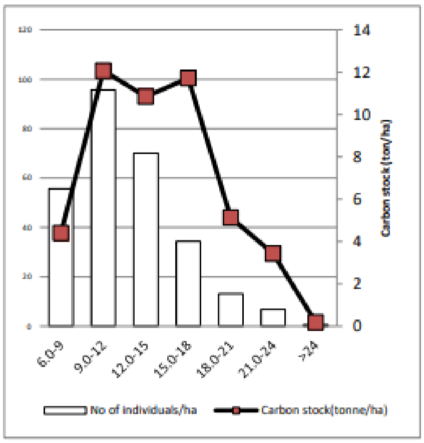
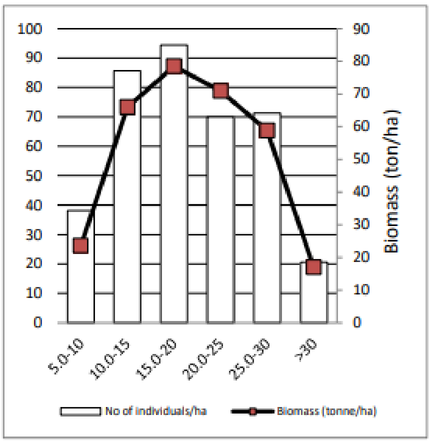


Fig 8b: Allocation of ABG to height classes in deciduous forest

Srinath (2008) reported above ground biomass in the sacred groves of Kodagu district to the tune of 279.4 t ha^{-1}. According to Clark and Clark (2000), biomass accumulation in tropical forests was found to the extent of 161 to 186 t ha^{-1} while FAO (2007) estimated the average carbon density in India at 35t ha^{-1}.

Size-class contribution to biomass was analyzed to know which diameter and height classes have contributed to total AGB. In evergreen forest higher biomass was contributed by 150-180 cm GBH while in deciduous and scrub forest 60-90 cm GBH classes contributed for higher biomass (Fig. 4a). Similarly, higher biomass was accumulated in trees of 15-20 m height in evergreen forest while trees having 9-12 m height contributed more to the AGB in deciduous forest. We found notable difference in species composition between forest types (Table 2). A total of 10.03% of all the trees present in evergreen forest belonged to species *Hopea parviflora* while, rest of the species accounted more or less uniformly to the species composition. A substantial proportion of the total tree species was contributed by a one or two species such as *Anogeissus latifolia* (32.12%) and *Terminalia alata* (27.60%) in deciduous forest. These results indicate that certain species in this area could only be found in particular forest type and not in others which calls for conservation priorities. Dawson *et al*. (2013) emphasized the consequences of rare species for the long term conservation value of forest fragments.

The authors argued that low density implies restrictions for regeneration, especially cross-pollination and an increased vulnerability to management interventions. Thus, the protection of existing forest fragments with specific attention to species present at low densities should have priority. Tree species contribution to density, basal area and AGB was analyzed across different



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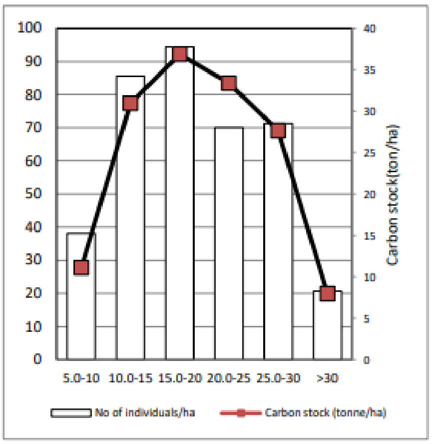

Fig 9b: Allocation of ABG to height classes in evergreen forest

Forest types and presented in Table 9. In evergreen forest *Hopea parviflora*, with 38 stems ha^{-1} accounted for 6.58 m^2 ha^{-1} basal area and contributed 51.40 tonne ha^{-1} to the total AGB and 21.16 tonne C ha^{-1} to the carbon stock.

Dipterocarpus bourdilloni was the next dominant tree species (20 stems ha^{-1} with 4.85 m^2 ha^{-1} basal area) which contributed 45.10 tonne ha^{-1} and 21.20 tonne C ha^{-1} of AGB and carbon stock in evergreen forest. In dry deciduous type, *Anogeissus latifolia* and *Terminalia alata* contributed more to AGB and carbon density. Different degrees of disturbance result in forests with different AGB values and lower values are associated with more human or natural disturbance (Laumonier *et al*., 2010). In the present study disturbance intensities ranged from old-growth evergreen forests. The estimated AGB and carbon values in the secondary forest, with a recovery time of almost thirty years after fire, were 2.5 times lower compared to the values in the primary forest. This is due to a lower density of stems ≥ 30 cm GBH, lower stand basal area and the occurrence of smaller trees in the secondary forest. Toma *et al*., (2005) compared their AGB value in the LDS (originally dipterocarp forest) with the AGB values in primary, dipterocarp forests in the region. The LDS contained 315 Mg ha^{-1}, while primary forest contained 481 to 542 Mg ha^{-1}, which means that the secondary forest contained approximately 1.5 times less AGB compared to the primary forests.

Conclusion
This study was under taken in Kodagu district which lies in the southern part of the Western Ghats of Karnataka with a research hypothesis that floristic diversity and AGB are expected to vary among forest types with the highest diversity and AGB expected in evergreen forests which enjoys more protection status and then expected to decrease with increasing land-use intensity and disturbances in deciduous forest. In accordance with the set hypothesis we aimed at three important objectives to (1) assess and compare the tree species diversity, structure and dominance among different forest types (2) examine how the basal area, AGB and carbon density differs between forest types and (3) know which girth classes and species contribute more to AGB and carbon. Floristic diversity, above ground biomass (AGB) and carbon density was compared between different vegetation types of Kodagu district in Western Ghats. Results revealed significant differences across different vegetation types for different parameters studied. Maximum species richness (62 species) and diversity (H'=3.57) was recorded in evergreen forest followed by deciduous (38 species, H'=2.33). On the other hand, maximum density of 380 stems/ha was recorded in Evergreen forest followed by Deciduous (276 stems/ha). However, higher basal area of 50.44 m2/ ha was recorded in Evergreen forest and lowest in Deciduous forest (13.03 m2/ha). The tree layer contributed about (416.8 tonnes/ ha) to the total AGB, among different vegetation types Evergreen forest contributed (314.768 tonnes/ ha) and Deciduous forest contributed (102.04 tonnes/ ha). Carbon density was estimated about

(195.89 tonne C/ ha) across different forest types, Evergreen forest (147.94 tonne C/ ha) and Deciduous forest (47.95tonne C/ ha). The majority of AGB and carbon pool in our study was found within taller trees and trees with a larger diameter therefore, their removal substantially alters the C storage and dynamics in this region. Land-use systems with higher C sequestration potential are currently supported under REDD+ projects that focus on forest conservation and management.

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