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Biomass and Carbon Storage Pattern in Natural and Plantation Forest Ecosystem of Chhattisgarh, India

Manoj Kumar Jhariya* and Dhiraj Kumar Yadav
Department of Farm Forestry, Sarguja University, Ambikapur-497001 (Chhattisgarh), India

Abstract

We studied natural and plantation forest ecosystem of Sarguja in Chhattisgarh, India in order to understand how vegetation biomass, carbon stock and its allocation patterns vary among the sites. For this, stratified random sampling was opted to measure the different layers of vegetation. Wide floral diversity was found in the natural forest site as compared to the teak stand. Overall, 17 tree species found in natural forest comprising 8 families while in the teak stand 6 species were recorded. In understory strata 23 species were recorded (18 herbs and 5 shrubs) in natural forest whereas in teak stand 20 herb species and 3 shrubs were found. Great variation was also seen in the population dynamics of the different vegetation stratum in concerned sites. The sapling, seedling and herb density was found to be highest in natural stand while tree and shrub density was more in teak stand. Results indicated that stand biomass of the natural site was 321.19 t ha^{-1} while in the teak stand it was 276.61 t ha^{-1}. The total biomass of tree layer in plantation site was 245.22 t ha^{-1} and natural forest 241.44 t ha^{-1}. The sapling, seedling, shrub and forest floor biomass was found highest under natural forest as compared to the teak plantation site. Carbon stock has similar trend as that of biomass accumulation in natural forest and teak stand. Higher biomass accumulation and carbon stock were recorded in the higher girth class gradation of the population structure. Proper efforts are required to manage these diverse ecosystems to obtain higher biomass and sustainable ecological services.

Key Words: biomass, carbon storage, natural forest, stand, teak plantation

Introduction

Ecosystems are typically filled with large numbers of plant species along environmental gradient, making species-centered studies of systemic processes and functions extremely difficult. Tropical forests are globally important because of their economical and ecological perspectives. The forest stands are important as biodiversity habitats, major and minor forest products as well as carbon (C) sinks (Brown and Lugo 1990; UNDP et al. 2000; FAO 2010; Jhariya et al. 2014; Yadav et al. 2017). Tropical forests harbour the greatest wealth of biological and genetic diversity on the earth (Bargali et al. 2015; Baboo et al. 2017; Jhariya 2017a). These biodiversity rich forests have world attention because of the growing awareness of its importance on the one hand and the anticipated massive depletion on the other (Singh 2002; Jhariya 2010; Yadav et al. 2017). Forests are natural storehouses of biomass and C (FAO 2005). Forests fix, store and emit C by photosynthesis, respiration, decomposition and disturbances through a series of stages in the

life cycle from regeneration to harvest.

These forest ecosystems are most used, threatened and large pressures being placed on these forests as a results of different human activities. Anthropogenic activities have contributed to accelerated forest degradation. Land use pattern and disturbance regimes had a profound effect on the abundance, distribution and diversity of vegetation in the area (Kyayesimira and Lejju 2015). The magnitude of the impacts on these forests ecosystem dynamics can be assessed by using the vegetation structure, composition and production variability. Predictions of possible forests ecosystem, structural and functional changes over time can be assessed by these approaches. The magnitude of impact that anthropogenic pressures on forest ecosystem functioning can further be assessed using plant biomass quantification (Vogt and Persson 1991). The rate and intensity of disturbances regulates the level of heterogeneity of the habitat. The forest stands are subjected to various kinds of natural disturbances that emit a range of space of new species introduction in a place (Jhariya et al. 2016; Jhariya and Yadav 2017). These pressures on forest can cause uncontrolled influences that bring changes in floral and faunal diversity, habitat, landscape, soil degradation and may often lead to considerable alterations in the environmental conditions (Jhariya et al. 2012, 2014; Bargali et al. 2014; Kittur et al. 2014a, 2014b; Jhariya 2014, 2017a, 2017b).

To evaluate the status and trends of forest ecosystems along with the structure and its function, the quantification of stand biomass is essential (Ovington 1962; Brown et al. 1999; Jhariya 2014; Behera et al. 2017). Storage pattern and production of organic matter in forests in relation to the biotic and abiotic disturbances is critical for better management and an essential aspect of studies of C cycle (Keller et al. 2001; Cairns et al. 2003; Sahu et al. 2013a; Jhariya 2014; Jhariya et al. 2014; Pawar et al. 2014) which facilitate knowledge regarding changes in forest ecosystem and to compare the stand by forest types. Presently there is a dearth of information on biomass and carbon storage pattern of natural and plantation forest of this region. Therefore, present investigation was done to assess and highlight these aspects of such forest ecosystem.

Materials and Methods

Study sites

The present work is carried out to quantify the biomass and carbon storage pattern in natural forest of Chendra and teak plantation (Established in the year 1962) of Sumerpur (Chendra, range Dhaurpur, Beat No. 2589, Ganjhadand, Coupe No. VII and area about 47 ha). The study area is located between 23° 05' 14.7" to 23° 05' 16.8" north latitude and 83° 16' 29.6" to 83° 16' 31.8"east longitude. Sarguja district is placed in the northern part of Chhattisgarh state of India. The area has over extension between S-E parts of Vindhyachal-Baghelkhand domain of peninsular India. The district Sarguja, is represented by very rich floral and faunal diversity (Sinha et al. 2014, 2015; Yadav et al. 2015; Jhariya and Yadav 2016; Yadav and Jhariya 2017). About 58% of the area in the district lies under forests. The flora of Nazzul and other areas are changing frequently with the human activities and land-use. The physiographic division of the regions are: highlands, uplands and central plain. The climate of district is characterized by hot summer and well distributed rainfall during the monsoon season. Soil of Sarguja district can be broadly classified in four major classes: red and yellow soils, alluvial soils, laterite soils and medium blue soils, respectively.

Experimental design

The stratified random sampling was laid out to analyze the vegetation structure in natural and plantation forest ecosystem. The tree layer was analyzed by randomly laying quadrats of size 10×10 m and girth at breast height (i.e., 1.37 m above the ground) of all the species was measured and recorded individually. In each of these quadrat, a sub-quadrat of 2×2 m size were randomly laid for measuring saplings, seedlings and shrub, while the herb and forest floor biomass were quantified by laying a sub-quadrat of 50×50 cm. The seedlings (＜10 cm GBH) and shrub were measured at the collar height and each species counted separately.

For the measurement of biomass, allometric equation associated with tree circumference to biomass developed by Singh and Misra (1979) and Singh and Singh (1991) for the dry deciduous forest species were used. The individuals were classified into various girth classes. The mean circum-

Table 1. Vegetation statistic in natural forest and teak plantation in Sarguja forest division

Vegetation Layer	Natural Forest		Teak Plantation	
	Density (individuals ha^{-1})	Basal Area (m^{2}ha^{-1})	Density (individuals ha^{-1})	Basal Area (m^{2}ha^{-1})
Tree	520	19.81	860	40.21
Sapling	5,500	8.42	2,500	4.96
Seedling	16,000	3.65	9,500	1.94
Shrub	4,500	5.43	5,500	3.34
Herb	832,000	-	696,000	-

ference at breast height value for each species for a girth class was used in the regression equation to get an estimate of biomass (by component i.e. bole, branch, foliage and root) for that girth class. Then this value was multiplied by the density of trees in that girth class. The girth class values were added to obtain the biomass estimate for each of the quadrates in each site. The forest floor biomass was collected and samples were weighed after drying. Forest floor was collected from each site and then categorized into different components (Singh 1995; Jhariya 2017b). Carbon storage in the vegetation was calculated using the reported carbon concentration values for vegetation pools of dry tropics as 43.5% in bole, 45.67% in branch, 46.67% in leaf and 35.73% in root (Sahu et al. 2013a; Jhariya 2014, 2017a; Pawar et al. 2014).

Results and Discussion

Stand structure and composition

In natural forest, tree layer comprised of 9 species belonging to 8 families, sapling layer represented by 6 species and 6 families, while in seedling layer 7 species belonging to 7 families were found. The teak stand showed less diversity in terms of species presence and family richness (total 6 species, 2 trees species with 2 family, 3 sapling species belonging to 3 family and 6 seedling species comprising 5 families) as compared to natural forest. Natural forest comprised of 5 shrub and 18 herb species whereas in teak stand 3 shrub and 20 herb species were noticed. The density of tree, sapling, seedling and shrub in natural forest was 520, 5,500, 16,000 and 4,500 individuals ha^{-1} with basal area of 19.81, 8.42, 3.65 and 5.43 m^{2}h^{-1}, respectively. Whereas in plantation site it was 860 individuals ha^{-1} for tree, 2500 individuals ha^{-1} for sapling, 9,500 individuals ha^{-1} for seed-

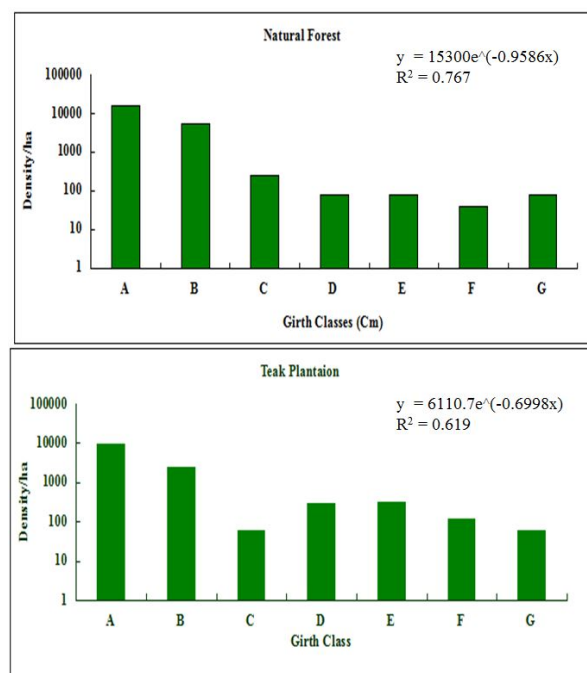**Fig. 1.** Relationship between density with mean girth class (cm) are: A=≤10; B=>10-≤30; C=>30-≤50; D=>50-≤70; E=>70-≤90; F=>90-≤110; G=>110.

ling and 5,500 individuals ha^{-1} for shrub layer (Table 1). The herb density was found more in natural stand while it was lesser in teak stand.

In the present study tree density and girth relationship (Fig. 1) revealed an exponential model [Y=exp (a-bx)]. The sites possessed small structure (≤10 cm girth) as 72.66% and 73.87% individuals, respectively in natural and teak stand. The relationship between density and girth class revealed 1.27-6.22% individuals were distributed in girth class >50 cm. This was due to higher turnover, anthropogenic removal and low biomass accumulation in natural forest and teak stand. Pooled data on density and girth class

gradation were related according to:

(1) Y=exp [15,300−0.9586x] for Natural stand
   r^2=0.767 p＜5%

(2) Y=exp [6110.7−0.6998x] for Teak stand
   r^2=0.619 p＜5%

The species richness in the concerned site is comparable with the report of Pawar et al. (2014), which reflected that 6-12 species of trees, 2-9 species of sapling, 4-14 species of seedlings across the site at same forest types. The density of trees resembles with the findings of various reports. Pawar et al. (2014) reported the tree density between 100-510 stems ha^{-1}, seedling density from 7,750-39,500 stems ha^{-1} and total tree basal area varied from 11.47-26.67 m^2 ha^{-1} which found to be comparable with present estimated values. Jhariya et al. (2010) reported that tree density ranged from 255-630 trees ha^{-1}. Higher value of tree density (650-1,520 trees ha^{-1}) were reported by Bargali et al. (2014). Thakur and Swamy (2010) estimated the density of different forest types and it varied from 324-733 trees ha^{-1}, basal area from 8.13-28.87 m^2 ha^{-1} and number of species from 9-26. Sharma et al. (2010) studied the four forest stands each of twenty major forest types in sub-tropical to temperate zones and reported stem density ranged from 295-850 individuals ha^{-1}. Murphy and Lugo (1986) have measured 17-40 m^2 ha^{-1} basal area in sub-tropical dry forests.

Kumar et al. (2016) reported 4 tree species, 5 sapling species, 18 seedling species and 7 shrub species across the study sites. A total of 440 trees ha^{-1} were encountered in eucalyptus plantation, 480 trees ha^{-1} in teak plantation and 960 trees ha^{-1} in mixed plantation. The total density of saplings, seedlings and shrubs ranged from 60-860 saplings ha^{-1}, 2400-8960 seedlings ha^{-1} and 240-960 shrubs ha^{-1}, respectively across the sites (Kumar et al. 2016). Thapa et al. (2011) reported a very close value of tree density to present investigation (864 ha^{-1} for teak plantation & 1,110 trees ha^{-1} for sal plantation), sapling density (432-2,880 trees ha^{-1} for teak and sal plantation) and seedling density (12,800-14,450 ha^{-1} for teak and sal plantation). Cordero and Kanninen (2003) reported tree density from 156-1,600 individuals ha^{-1} for different aged of teak plantation. Sahu et al. (2013a) reported 1,010-1,380 trees ha^{-1} in teak planta-

Table 2. Biomass (t ha^{-1}) of tree layer in natural forest and teak plantation in Sarguja forest division

Species	Natural forest					Teak plantation				
	Bole	Branch	Leaf	Root	Total	Bole	Branch	Leaf	Root	Total
Aegel marmelous (L.)	5.66±1.13	9.09±1.82	0.53±0.11	2.13±0.43	17.41±3.48	-	-	-	-	-
Anogeissus latifolia Wall.	1.69±0.31	5.03±0.99	0.32±0.05	1.16±0.23	8.20±1.63	-	-	-	-	-
Cassia fistula Linn.	0.81±0.13	0.75±0.12	0.09±0.02	0.31±0.05	1.97±0.36	-	-	-	-	-
Diospyrous melanoxylon Roxb.	0.81±0.14	0.56±0.11	0.08±0.01	0.31±0.05	1.75±0.33	-	-	-	-	-
Lannea coromandelica (Houtt.) Merr.	0.81±0.13	0.75±0.12	0.09±0.02	0.31±0.05	1.97±0.36	-	-	-	-	-
Madhuca latifolia Roxb.	8.45±1.02	12.01±1.62	0.84±0.38	3.17±0.77	24.48±2.22	-	-	-	-	-
Mitragyna parviflora Roxb.	6.97±1.39	11.88±2.35	0.64±0.11	2.62±0.50	22.11±4.40	-	-	-	-	-
Shorea robusta Gaertn.f	50.98±1.32	86.66±2.33	4.80±0.34	19.15±0.81	161.58±2.78	-	-	-	-	-
Tectona grandis Linn.f.	-	-	-	-	-	115.40±1.05	54.09±0.84	24.30±0.45	34.01±0.47	227.80±1.48
Terminalia tomentosa W & A.	0.81±0.16	0.75±0.14	0.09±0.02	0.31±0.06	1.97±0.38	5.66±1.11	9.09±1.80	0.53±0.08	2.13±0.41	17.41±3.45
Total	77.01±1.38	127.49±2.48	7.49±0.40	29.45±0.90	241.44±2.96	121.06±1.19	63.18±1.36	24.83±0.47	36.14±0.61	245.22±1.87

Table 3. Biomass (t ha^{-1}) of sapling and seedling layer in natural forest and teak plantation in Sarguja forest division

Vegetation layer	Natural forest					Teak plantation				
	Bole	Branch	Leaf	Root	Total	Bole	Branch	Leaf	Root	Total
Sapling	27.73±2.69	14.53±2.27	4.19±1.03	10.13±1.62	56.59±4.0	10.19±1.47	3.59±0.79	2.24±0.78	4.58±1.04	20.60±2.10
Seedling	4.27±0.83	0.94±0.17	0.86±0.14	1.59±0.28	7.66±1.51	2.54±0.49	0.56±0.10	0.51±0.09	0.94±0.18	4.55±0.91

Table 4. Shrub biomass (t ha^{-1}) in natural forest and teak plantation in Sarguja forest division

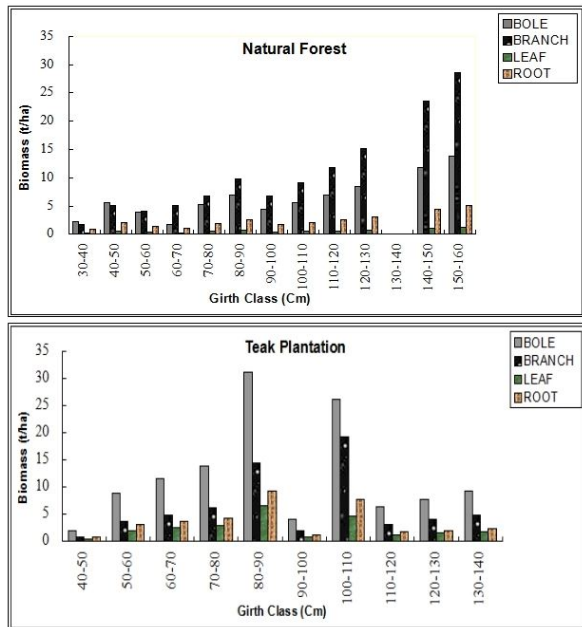| Shrub pools	Stem	Foliage	Root	Total
Natural Forest	11.56±2.80	1.33±0.80	2.61±1.28	15.50±3.17
Teak Plantation	4.42±1.74	0.72±0.15	1.10±0.61	6.24±1.98

Fig. 2. Girth class wise distribution of biomass in natural and plantation forest ecosystem.

tion site which was found higher than present investigation.

Vegetation biomass

The tree biomass among the site found to be significantly different. The total biomass of natural forest and teak stand were 241.44 t ha^{-1} and 245.22 t ha^{-1}, respectively. In natural forest higher biomass were contributed by *Shorea robusta* (66.92%) while in the plantation site *Tectona grandis* (92.90%) shared the highest biomass in total (Table 2). The total aboveground biomass for tree in natural forest was 211.99 t ha^{-1} while in teak plantation it was 209.08 t ha^{-1}. The bole, branch, leaf and root component comprised of 31.90%, 52.80%, 3.10% and 12.20%, respectively to the total biomass in natural forest. Distribution of biomass by components in teak stand were 49.37% by bole, 25.76% by branch, 10.13% by leaf and 14.74% by root, respectively.

The sapling and seedling biomass was found highest under natural stand as compared to teak plantation. The highest sapling biomass in natural forest was recorded by *Shorea robusta* (21.12 t ha^{-1}) followed by *Lagerstroemia parviflora* (21.05 t ha^{-1}) and least by *Buchanania lanzan* (2.21 t ha^{-1}). Teak stand reflected the higher biomass contributed by *Tectona grandis* (14.08 t ha^{-1}). The seedling biomass ranged from 4.55 t ha^{-1} to 7.66 t ha^{-1} being highest under natural forest while least in teak stand (Table 3). The shrub biomass showed similar pattern as of sapling and seedling biomass. It was found maximum in natural forest (15.50 t ha^{-1}) and least unde teak plantation (6.24 t ha^{-1}) (Table 4).

The size class A and B which represented seedling and sapling layer, respectively were found higher in terms of their population but the gross biomass seems to be accumulated in higher girth class (>100 cm) in natural forest while in the teak stand most share of biomass was accumulated in the girth class of 80-90 cm (Fig. 2). It reflected from the study that in natural stand 64.89% of biomass was accumulated under the girth class of >100 cm, 23.26% in girth class of 60-100 cm and 11.85% in the girth class of 30-60 cm, respectively. In teak stand about 42.48% biomass accumulation was found in the girth class of >100 cm, 39.40% in girth class of 70-100 cm and remaining (18.12%) in girth class of 40-70 cm.

Forest floor biomass

The litter mass in natural forest and teak stand varied greatly (Table 5). In the natural stand total litter mass was twice as compared to the teak stand. Total litter biomass was 5.89 t ha^{-1} in natural stand, of which (77.08%) constituted by leaf litter and remaining (22.92%) by wood litter. The teak plantation has 2.43 t ha^{-1}, of which 67.90% contributed by leaf mass and remaining (32.10%) by wood litter. The litter component reflected that the leaf mass was higher in natural stand while the wood litter biomass was found to be highest in teak stand.

The ground materials (forest floor & litterfall) are the key source for nutrients cycling in vegetation stand. Higher litter mass leads towards rich and diverse forest stand (Jhariya 2017b; Kumar et al. 2017a). Kumar et al. (2017b) reported that the total forest floor biomass ranged from 2.61-6.07 t ha^{-1} which supports the present findings. Kumar et al. (2016) found that the total litter biomass in different plantation sites varied from 1.98-4.01 t ha^{-1}, least in teak plantation and highest under eucalyptus plantation. Sahu et al. (2013b) reported the forest floor biomass in teak plantation varied from 2.19-2.66 t ha^{-1}.

Stand biomass

The stand biomass of the study site varied from 276.61-321.19 t ha^{-1} being highest under natural forest and least in teak stand. The total above ground and below ground biomass were 86.37% and 13.63% to the total in natural forest while in the teak plantation it was 84.54% and 15.46% in above ground and below ground compartments, respectively (Table 6). It was found that natural forest consists of 44.58 t ha^{-1} higher total biomass than the teak stand. The tree biomass shared 95.17% to the total vegetation biomass in natural forest while in teak plantation it was 97.74% to the total vegetation biomass, respectively.

The forest biomass rely on type of species, species mix, density, girth class, age, locality factors of the stand or region. It is significantly altered by perturbation, land-use, harvesting and climatic variance (Canadell et al. 2007). Pawar et al. (2014) reported total biomass between 127.69-227.71 t ha^{-1}. Total above ground biomass was 111.20-199.42 t ha^{-1} and total below ground biomass varied from 16.49-28.29 t ha^{-1}, respectively. Alone (2014) reported the above ground biomass of 104.27-196.32 t ha^{-1}, below ground biomass of 21.49-37.78 t ha^{-1} and total biomass of 119.37-235.14 t ha^{-1} for teak plantation in tropics of Chhattisgarh, India. The contribution of bole, branches and foliage to the total above ground biomass ranged between 58.60-60.88%, 25.81-29.37% and 13.30-12.02%, respectively. Jhariya et al. (2014) reported total biomass range from 101.43-192.36 t ha^{-1}. The closer value of above ground biomass (225 Mg ha^{-1}) was reported by Cairns et al. (2003) for Mexican tropical forest. The global pattern of above ground biomass (30-273 t ha^{-1}) and total biomass (78-320 t ha^{-1}) also supports the present estimated values (Murphy and Lugo 1986).

The above ground biomass is very similar to Cairns et al.

Table 5. Forest floor biomass (t ha^{-1}) in natural forest and teak plantation in Sarguja forest division

Components	Natural forest	Teak plantation
Leaf Litter	4.54±0.26	1.65±0.18
Wood Litter	1.34±0.58	0.78±0.41
Total	5.89±0.30	2.43±0.14

Table 6. Stand biomass (t ha^{-1}±1 SE) in natural forest and teak plantation in Sarguja forest division

Components	Natural forest	Teak plantation
	Total tree species	Total tree species
Bole	109.01±4.75	133.79±8.19
Branch	142.96±6.62	67.33±5.30
Foliage	12.54±1.51	27.58±3.84
Root	41.17±2.97	41.66±4.24
Total	305.69±8.56	270.37±11.27
	Total Shrubs	Total Shrubs
Stem	11.56±2.80	4.42±1.74
Foliage	1.33±0.80	0.72±0.15
Roots	2.61±1.28	1.10±0.61
Total	15.50±3.17	6.24±1.98
Stand fine roots	16.65±2.10	14.03±2.76
Litter mass	5.89±0.30	2.43±0.14
	Total vegetation	Total vegetation
Above ground	277.41±8.06	233.85±10.77
Below ground	43.78±2.96	42.76±4.38
Total	321.19±8.54	276.61±11.62

(2000) for the semi-evergreen forest (111.2-225.8 Mg ha^{-1}). Total below ground biomass of present study resembled with below ground biomass of tropical deciduous forest estimated by Singh et al. (2009). Present findings are supported by Borah et al. (2013) where they have reported aboveground tree biomasses from 32.47-261.64 Mg ha^{-1} in tropical forest of Assam. Similarly, Thokchom and Yadava (2013) noted the aboveground biomass in the range of 179.14-246.38 Mg ha^{-1} for subtropical forests of India. Gairola et al. (2011) reported the wide range of aboveground biomass from 172-380 Mg ha^{-1}. Mohanraj et al. (2011) estimated 372 Mg ha^{-1} aboveground biomass of tropical forests of India which was more than present value. Pande and Patra (2010) estimated the biomass of Sal forest and miscellaneous forest of India and found that the above ground biomass ranged from 154.9-345 t ha^{-1}. Yadava (2010) found 130-255 Mg ha^{-1} above ground biomass for sub-tropical broad leaved forest of India. The plantation biomass values also resembles with the biomass values of other plantations such as Eucalyptus (127-242 t/ha) from sub-tropical region (Bargali and Singh 1991; Bargali et al. 1992; Bargali and Singh 1995) and *Pinus patula* (109-151 t/ha) from temperate region (Bargali and Singh 1997a & b).

Ambagahaduwa et al. (2009) estimated 136-194 t ha^{-1} above ground biomass for *Pinus caribaea* plantation. Cordero and Kanninen (2003) studied above ground biomass of teak plantations and found the foliage dry biomass comprised of 1-6% of the total tree dry biomass, 5-30% corresponded to branches and 70-90% to stem dry weight. Devagiri et al. (2013) reported above ground biomass ranged from 7.25-287.047 t ha^{-1}. Navar-Chaidez (2011) found 116.37-167.43 Mg ha^{-1} aboveground biomass which is comparable with the present study. Sharma et al. (2010) reported that the total biomass ranged from 129-533 Mg ha^{-1}. Nascimento and Laurance (2002) found the total above ground biomass values was 397.7 t ha^{-1}. The most important component of above ground biomass were large trees which comprised 81.9% of total above ground biomass followed by downed wood debris (7.0%), small trees, saplings & seedlings (5.3%), lianas (2.1%), litter (1.9%), snags (1.5%) and stemless palms (0.3%). Among large trees above ground biomass was greatest in intermediate sized (20-50 cm DBH) stems (46.7%), with very large ($<$ or $>$ 60 cm DBH) trees also containing substantial biomass

(13.4%). Swamy et al. (2010) concluded that total stand biomass averaged from 440-571 Mg ha^{-1}, of which trees contributed 90.2-92.2% and remaining 8.8-9.8% contributed by shrubs and herbs. Upadhyay et al. (2009) found that the understorey contributed about 32% (172 t ha^{-1}) and overstorey layer constituted about 68% (372 t ha^{-1}) to the total biomass.

Table 7. Stand C stock (t ha^{-1}) in natural forest and teak plantation in Sarguja forest division

Components	Natural Forest	Teak Plantation
	Tree Layer	Tree Layer
Bole	33.50±0.91	52.66±0.78
Branch	58.22±1.68	28.85±0.92
Foliage	3.50±0.28	11.59±0.32
Root	10.52±0.54	12.91±0.36
Total	105.74±1.97	106.02±1.24
	Sapling Layer	Sapling Layer
Bole	12.06±1.77	4.43±0.97
Branch	6.64±1.53	1.64±0.53
Foliage	1.96±0.70	1.04±0.53
Root	3.62±0.97	1.64±0.62
Total	24.28±2.62	8.75±1.37
	Seedling Layer	Seedling Layer
Bole	1.86±0.35	1.10±0.21
Branch	0.43±0.08	0.25±0.04
Foliage	0.40±0.07	0.24±0.03
Root	0.57±0.11	0.34±0.06
Total	3.25±0.65	1.93±0.38
	Total Shrubs	Total Shrubs
Stem	5.12±1.86	1.96±0.58
Foliage	0.62±0.54	0.34±0.15
Roots	0.93±0.76	0.39±0.11
Total	6.67±2.08	2.69±0.76
Stand fine roots	7.46±0.76	6.25±0.80
Litter		
Leaf	1.81±0.16	0.66±0.12
Wood	0.53±0.36	0.31±0.26
Total	2.34±0.19	0.97±0.09
	Total vegetation	Total vegetation
Above ground	124.30±3.0	104.11±3.08
Below ground	15.64±0.87	15.28±1.06
Total	139.94±3.11	119.39±3.25

Carbon stock

The carbon allocation pattern of above ground, below ground compartments and total C stock varied greatly in natural and plantation sites (Table 7). Furthermore, site to site variations by different vegetation stratum were also varied significantly. The total C stock varied from 119.39-139.94 t C ha^{-1}, being highest in natural forest and least in teak stand. The tree layer comprised of 75.56% and 88.80% share to the total C stock, respectively in natural forest and teak stand. The sapling, seedling and shrub shared 17.35%, 2.32% and 4.77% C to the total C stock in natural forest while in the teak stand it were 7.33%, 1.62% and 2.25%, respectively shared by sapling, seedling and shrub layer to the total C stock. The total above ground and below ground contribution were 88.82% and 11.18% to the total C stock in natural forest whereas in teak stand it were 87.20% and 12.80%, respectively to the total C stock. The girth class wise C stock has similar trend of allocation as that of biomass accumulation in both the studied sites.

The higher fraction of biomass accumulation in the higher girth class in natural stand reflects the role of large trees in C capture and storage. The natural forests in tropics are under the pressure due to various anthropogenic interferences. The distribution of trees by size class is a key determinant of C stock (Baishya et al. 2009; Alone 2014; Jhariya 2014). Pawar et al. (2014) found 55.125-98.548 t C ha^{-1} across the sites. Jhariya et al. (2014) have reported the total C stock varied from 50.71-96.18 t C ha^{-1} which is close to the present estimated value. Alone (2014) reported the total C stored in teak plantation varied from 54.06-100.68 t ha^{-1}. The total C in aboveground and belowground components varied from 46.38-87.38 t ha^{-1} and 7.68-13.28 t ha^{-1}, respectively. The relative contribution of aboveground and belowground components in the total C storage was 85.79-86.78% and 13.19-14.20%, respectively.

Thokchom and Yadava (2013) reported the aboveground C stock varied from 81.17-118.29 Mg C ha^{-1} across the forest stand. Borah et al. (2013) reported that the aboveground C stock in tree species ranged from 16.24-130.82 Mg C ha^{-1} which is well within the range of present forest C stock. Tang et al. (2012) reported 155 Mg C ha^{-1} for the tropical forest of China, whereas Hoover et al. (2012) found 116-125 Mg C ha^{-1} in above ground compartment.

Metzker et al. (2011) reported 48-91 Mg C ha^{-1} for tropical forest of Brazil. Sharma et al. (2010) reported the total C storage ranged between 59-245 Mg ha^{-1} which supported the present findings. The present findings are lower than the value documented by Baishya et al. (2009) and Mohanraj et al. (2011). Singh et al. (2009) reported the C storage was varied from 46.25-96.44 Mg ha^{-1} in tropical forests.

Flint and Richards (1996) estimated C stored in Southeast Asia including India, Thailand, Cambodia, Malaysia and Indonesia, and found 17 Mg C ha^{-1} in dry tropical forest and 350 Mg C ha^{-1} in tropical rain forests. The C stored value in present investigation was higher (77 Mg C ha^{-1}) to Sri Lanka's tropical forests, but lower (223 Mg C ha^{-1}) than tropical rain forest of Malaysia (Brown and Lugo 1982). Ogawa et al. (1965) found 60-179 t C ha^{-1} in variety of tropical forest of Thailand.

Conclusion

The plantation can be good substitute for obtaining the higher biomass in addition to its ecological services, but it can not be biologically rich as compared to natural forest. Great variations were recorded in natural and teak stand in terms of the floral diversity, species richness, population dynamics, girth gradation, biomass, littermass and C stock retained by these ecosystems. The tree biomass was found to be higher in teak stand due to its higher age and individuals belonging to higher girth class and less variability among them. The total stand biomass and C stock were significantly higher in natural ecosystem. For proper stocking plantation should be promoted in blank area and in such area where natural regeneration is not up to the mark. Planting the fast growing species in the degraded land or clear felled area of the region was an effective measure in terms of the biomass production, C storage and sequestration. The information related to biomass and carbon allocation patterns of different layer/stratum were pivotal for effective decision making in sustainable forest management and climate change mitigation.

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