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Aboveground Biomass and Carbon Stocks of Tree Species in Tropical Forests of Cachar District, Assam, Northeast India

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ABSTRACT

The tropical forest biomass plays an important role in global carbon cycle. Estimation of above-ground biomass (AGB) is an essential aspect of carbon stocks. Estimated C pools in different forest types can be used to in making decisions about C management within forests. The present study was carried out in ten tropical forests of Cachar district to estimate AGB, carbon stocks and their relationship with density, basal area and diversity indices. The AGB was ranged from 32.47 Mg ha^{-1} to 261.64 Mg ha^{-1} and C-stocks ranged from 16.24 Mg ha^{-1} to 130.82 Mg ha^{-1}. The small to medium trees contributed more AGB and C-stocks than the large trees. *Cynometra polyandra, Artocarpus chama, Sapium baccatum*, *Ficus bengalensis, Trewia nudiflora, Xerospermum glabratum, Pterygota alata* and *Semecarpus anacardium* were top contributor of AGB and C-stocks in different tropical forests of Cachar district of Assam. AGB showed significant relationship with basal area and diversity indices. The AGB, however, did not show significant relationship with tree densities.

Key Words: Basal Area; Diversity Indices; Carbon Sequestration;

INTRODUCTION

In the global carbon cycle, tropical forests play an important role, which represent 30%-40% of the terrestrial net primary production (Clark et al. 2001). The significant influence of tropical forests on carbon cycle is attributed to the high rate of primary production besides the large pool and flux sizes (Brown & Lugo 1982, 1984). The forest biomass in addition also play important global environmental role. The quantity of biomass in a forest determines the potential amount of C (carbon) that can be added to atmosphere or sequestered on the land when forests are managed for meeting emission targets (Brown et al. 1999). Estimation of above ground biomass (AGB) is an essential aspect of studies of carbon stocks and effects of deforestations and carbon sequestration on global carbon balance (Ketterings et al. 2001). It is also a useful measure for comparing structural and functional attributes of forest ecosystems across a wide range of environmental condition (Brown 2002).

With the intense focus on the increasing levels of atmospheric CO_2 and the potential for global climate change, there is an urgent need to assess the feasibility of managing ecosystem to sequester and store C (Johnson & Kern 2002). If the existing C pools in different forest types can be estimated, it can be used to in making decisions about C management within forests (Sharma et al. 2010). Ecologists have also become interested in potential functional relationship between diversity and C sequestration and storage (e.g. Chapin et al. 2000, Tilman et al. 2001, Srivastava & Vellend 2005, Kirby & Potvin 2007). A functional relationship of either form between diversity and C storage and sequestration could important implications for management of C sink projects, not only for reforestation and aforestation type projects, which are currently supported international agreement (UNFCCC 1997, 2005).

In this paper we examine the above ground tree biomass, carbon stock and their relationship with tree diversity and basal area in ten tropical forest sites of Cachar district in Assam, India.

STUDY AREA

The present study was carried out in Cachar district of Assam, in northeast India. The area has a tropical monsoon climate with high annual precipitation and high temperature. Mean annual rainfall over a four year period (2007-2010) was 2508 mm, 93% of which was received during the monsoon season from Aril to October. Annual mean relative humidity was recorded 80.2% in the present study area. The mean annual minimum and maximum temperatures were 20.2 ºC and 30.7ºC respectively (Figure 1). The vegetation is mostly characterized by tropical moist evergreen and tropical semi-evergreen forests. The study was carried out in ten different tropical forest sites. Their location, latitude and longitude values are given in Table 1.

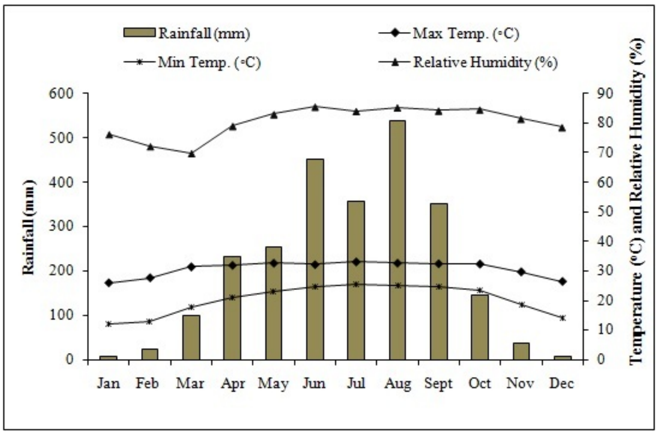

Figure 1. Rainfall and temperature data for the study area during January to December (mean of years 2007-2010). Data collected from Tocklai Tea Research Centre, Silcoorie, Silchar.

Table 1. Location, latitude and longitude of ten forest sites of Cachar district, Assam.

Study sites	Latitude (N)	Longitude (E)
Bhubandhar	24° 35' 17.7"	92° 55' 13.7"
Dolu	24° 56' 49.6"	92° 50' 05.9"
Nagathol	24° 38' 33.2"	92° 46' 51.2"
Bhuban Hill	24° 39' 50.5"	93° 00' 02.5"
Monbel	24° 41' 50.2"	93° 01' 18.9"
Kalakhal(Bhuban)	24° 35' 26.5"	92° 59' 26.6"
Dargakona	24° 41' 01.7"	92° 46' 31.6"
Loharbond-1	25° 35' 02.2"	92° 44' 29.9"
Rosekandy	24° 41' 47.7"	92° 41' 28.4"
Loharbond-2	24° 36' 08.2"	92° 43' 59.1"

METHODS

Ten forest sites were selected based on density, diversity, age, disturbances etc. In each forest, a 250 m × 250 m site was selected following ISRO-GBP/NCP-VCP (Singh and Dadhwal 2009). In each forest site, four 0.1 ha plots (31.62 m × 31.62 m) were laid at four corners of the site. In each plot, all the trees ≥ 10 cm girth at breast height (at 1.37 m from the base) were measured. Then density and basal area of each plot were calculated. Diversity index was calculated following Shannon and Wiener (1963) as follows

$$H = -\sum_{i=1}^{s} p_i \ln p_i$$

Where p_i is the proportion of individuals of ith species and total number of individuals of all species.

The concentration of dominance was calculated following Simpson (1949) as follows:

$$Cd = \sum_{i=1}^{s} (p_i)^2$$

where p_i is the proportion of individuals of ith species and total number of individuals of all species.

The aboveground biomass (AGB) was estimated using the regression equation developed by Brown (1997). The regression model is

$Y= 21.297-6.953 (D) + 0.740 (D^2)$ $[R^2 = 0.87]$,

where Y is the aboveground biomass (AGB) and D is diameter of the tree.

All biomass values were converted to carbon equivalents by multiplying dry weight with 0.5 as in many other similar studies (Brown and Lugo 1982, Montagnini and Porras 1998).

RESULTS

Forest characteristics

The species richness in different forests of Cachar district ranged from 22 species to 62 species (Table 2).

Table 2. Summary of tree diversity in ten tropical forests of Cachar district, Assam.

Study sites*	BHD	DLU	NGT	BHL	MNB	KLK	DGK	LHB-1	RSK	LHB-2
Number of Families	29	31	36	23	35	17	27	14	35	32
Number of Species	47	52	61	42	58	27	47	22	62	47
Density (trees ha^{-1})	500.0	397.5	687.5	367.5	782.5	295.0	512.5	370.0	712.5	965.0
Shannon diversity index (H)	1.43	1.37	1.51	1.46	1.47	1.02	1.55	1.08	1.62	1.28
Simpson index of dominance (Cd)	0.049	0.071	0.045	0.045	0.047	0.194	0.033	0.126	0.046	0.101
Basal area (m^2 ha^{-1})	10.13	13.85	37.09	16.88	25.02	5.37	24.88	8.74	19.95	17.14

*BHD- Bhubandhar forest, DLU-Dolu forest, NGT-Nagathol forest, BHL-Bhuban Hills, MNB-Monbel, KLK-Kalakhal, DGK-Dargakona forest, LHB-1 –Loharbond forest-1, RSK-Rosekandy fortest and LHB-2- Loharbond forest-2.

The highest species richness was recorded in Rosekandy forest (62 species from 35 families) and lowest in Loharond forest-1 (22 species from 14 families).

The Shannon diversity index (H) ranged from 1.02 to 1.55 (Table 2). The highest Shannon diversity index was recorded in Dargakona forest (1.55) and lowest in Kalakhal forest (1.02). The Simpson index of concentration of dominance (Cd) ranged from 0.032 to 0.176. The lowest concentration of dominance recorded Dargakona forest (0.033) and highest in Kalakhal forest (0.194). The highest tree density was recorded in Loharbond forest-2 (965 tree ha^{-1}) and lowest tree density in Kalakhal forest (295 tree ha^{-1}) (Table 2).

The basal area at the study sites ranged from 5.37 m^2 ha^{-1} to 37.09 m^2 ha^{-1} (Table 2). The maximum basal area was recorded in Nagathol forest (37.09 m^2 ha^{-1}) followed by Monbel forest (25.02 m^2 ha^{-1}), Dargakona forest (24.88 m^2 ha^{-1}), Rosekandy forest (19.95 m^2 ha^{-1}), Loharbond forest-2 (17.14 m^2 ha^{-1}), Bhuban hills (16.88 m^2 ha^{-1}), Dolu forest (13.85 m^2 ha^{-1}), Bhubandhar forest (10.13 m^2 ha^{-1}), Loharbond forest-1 (8.74 m^2 ha^{-1}) and Kalakhal forest (5.37 m^2 ha^{-1}).

Aboveground Biomass and Carbon Stocks

The aboveground biomass (AGB) of tree species in this study ranged from 32.78 Mg ha^{-1} to 261.64 Mg ha^{-1} (Table 3). The highest AGB was recorded in Nagathol forest (261.64 Mg ha^{-1}) followed by Dargakona forest (187.0 Mg ha^{-1}), Monbel forest (166.94 Mg ha^{-1}), Rosekandy (144.01 Mg ha^{-1}), Bhuban hill 116.8 (Mg ha^{-1}), Dolu forest (99.10 Mg ha^{-1}), Loharbond forest-2 (96.16 Mg ha^{-1}), Loharbond forest-1 (71.78 Mg ha^{-1}), Bhubandhar forest (65.12 Mg ha^{-1}) and Kalakhal forest (32.78 Mg ha^{-1}). The aboveground carbon stocks in tree species ranged from 10.06 Mg ha^{-1} to 105.37 Mg ha^{-1}. The highest carbon stock was recorded in Nagathol forest (130.82 Mg ha^{-1}) and lowest in Kalakhal forest (16.24 Mg ha^{-1}).

Table 3. Aboveground biomass (AGB) and C stock of tree species in ten tropical forests of Cachar district, Assam.

Study sites	AGB (Mg ha^{-1})	C stock (Mg ha^{-1})
Bhubandhar	65.12	32.56
Dolu	99.10	49.55
Nagathol	261.64	130.82
Bhuban Hill	116.80	58.40
Monbel	166.94	83.47
Kalakhal (Bhuban)	32.47	16.24
Dargakona	187.00	93.50
Loharbond-1	71.78	35.89
Rosekandy	144.01	72.00
Loharbond-2	96.16	48.08

Species' Contribution to AGB and C Storage

Cynometra polyandra contributed highest AGB and C stocks in Bhubandhar and Nagathol forests while *Artocarpus chama* was the top contributor of AGB and C stocks in Bhuban hill and Kalakhal forest. *Sapium baccatum*, *Ficus bengalensis, Trewia nudiflora, Xerospermum glabratum, Pterygota alata* and *Semecarpus anacardium* were top contributor of AGB and C stocks respectively in Dolu, Loharbond-1, Monbel, Dargakona, Rosekandy and Loharbond-2 (Figure 2).

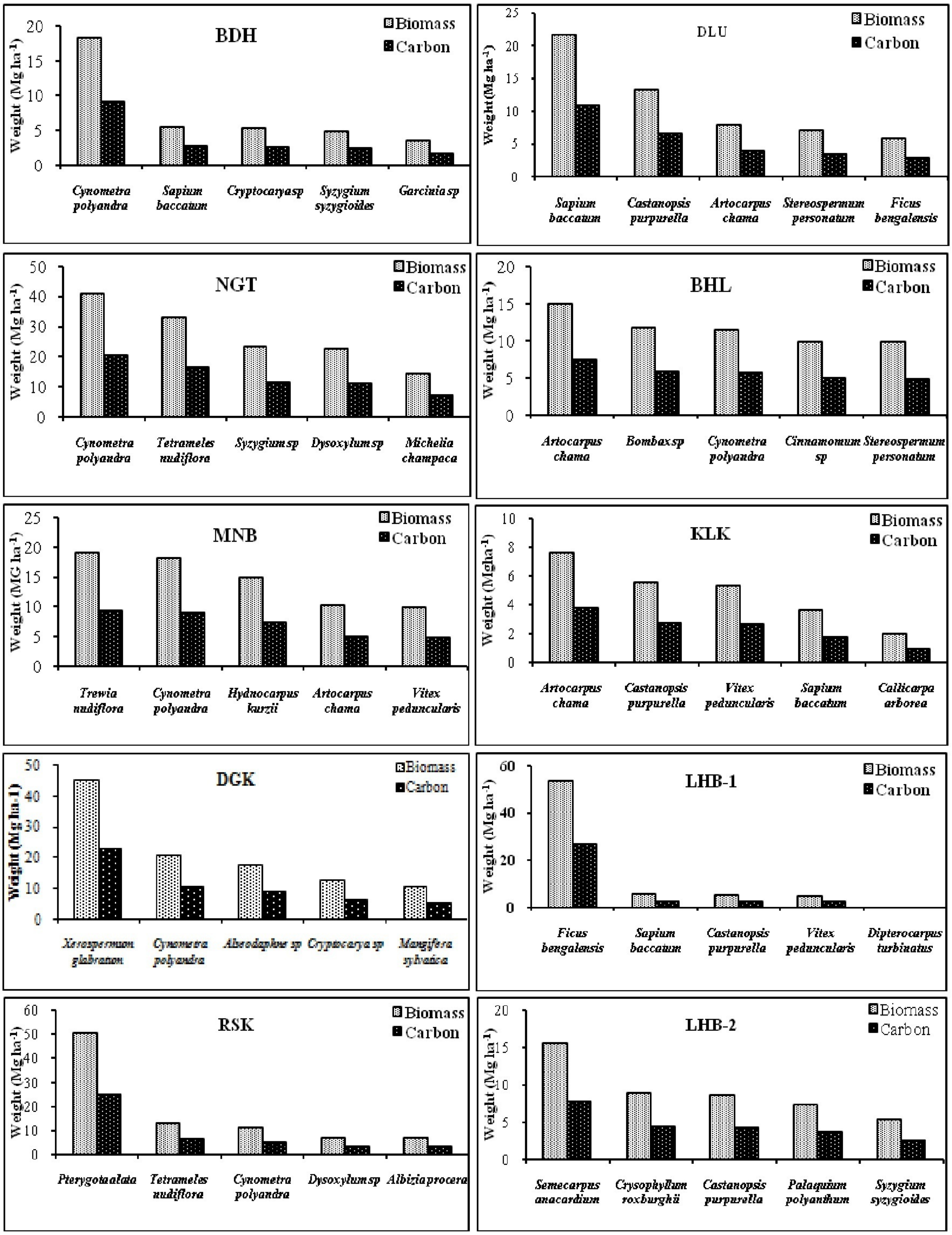

Figure 2. Top five contributor of AGB and C stock in different forests of Cachar district of Assam. (BHD- Bhubandhar forest, DLU-Dolu forest, NGT-Nagathol forest, BHL-Bhuban Hills, MNB-Monbel, KLK-Kalakhal, DGK-Dargakona forest, LHB-1 –Loharbond forest-1, RSK-Rosekandy fortest and LHB-2- Loharbond forest-2).

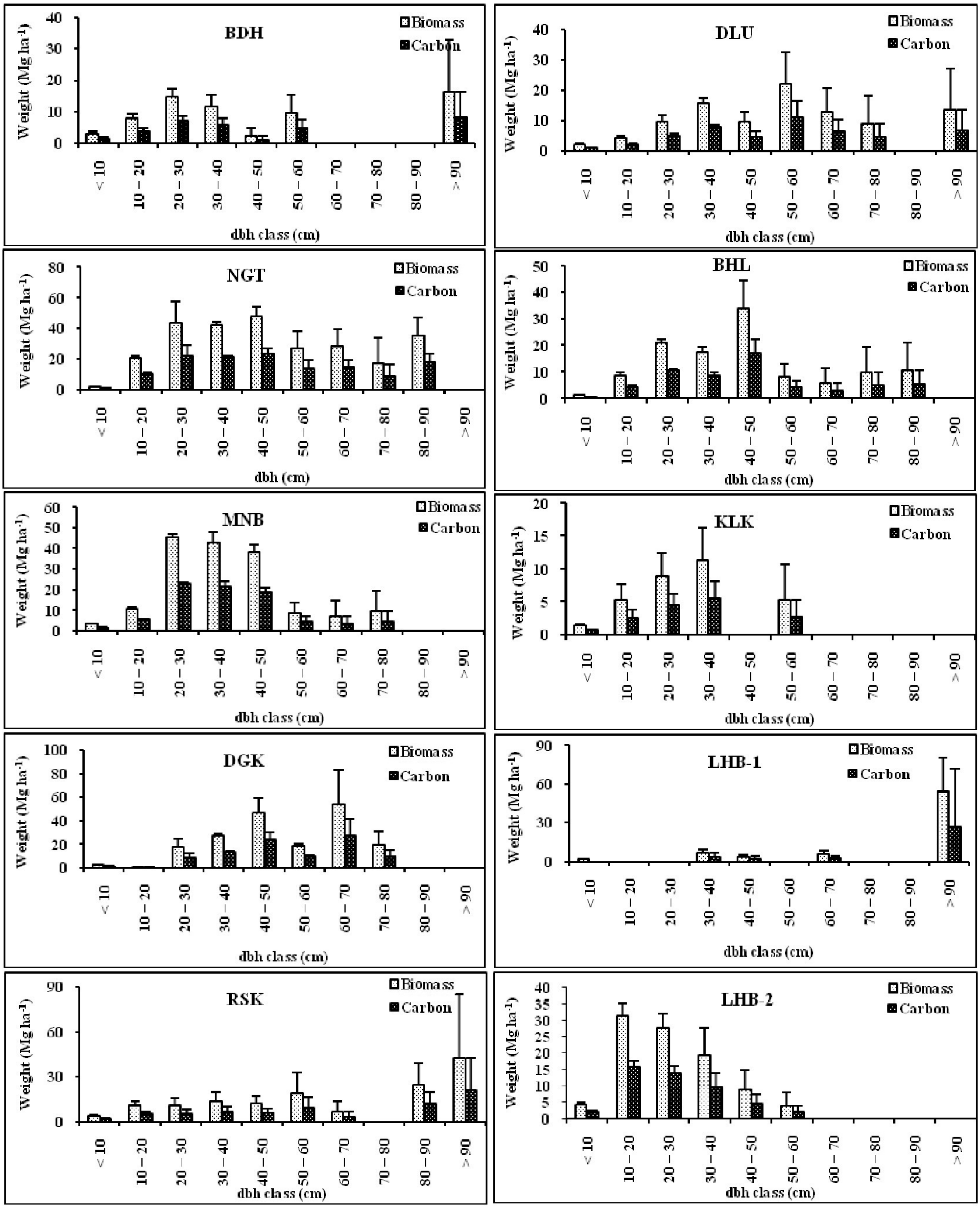

Figure 3. Distribution of AGB and C stock of tree species in different dbh classes in ten forests of Cachar district, Assam, India. (BHD-Bhubandhar forest, DLU-Dolu forest, NGT-Nagathol forest, BHL-Bhuban Hills, MNB-Monbel, KLK-Kalakhal, DGK-Dargakona forest, LHB-1 –Loharbond forest-1, RSK-Rosekandy fortest and LHB-2- Loharbond forest-2).

Distribution of AGB and C in Different dbh Classes

Figure 3 shows that maximum AGB and C stocks occur in different dbh classes in different forest. In most of the forests (except Loharbond-1 and Rosekandy forest) small to medium sized trees (<70 cm dbh) contributed more AGB and C stocks than the large trees. In Loharbond-2 and Kalakhal forests large tree (>70 cm dbh) was not recorded.

Relationship of AGB with Basal Area, Density and Diversity Indices

The relationship of aboveground biomass (AGB) with basal area, density and diversity indices were shown in Table 4. In the present study, basal area was positively correlated with aboveground biomass (AGB) with correlation co-efficient value (r) 0.988 which is significant at 0.01 level. The tree density had positive correlation with biomass but not significant. The species richness and Shannon diversity index were also showed positive correlations which were significant at 0.05 level. Simpson index of concentration of dominance (Cd) was negatively correlated with aboveground biomass (AGB) which was significant at 0.05 level.

Table 4. Correlation between aboveground biomass (AGB) and basal area, density and tree species diversity. Three indices of diversity were used: species richness, Shannon diversity index (H), and Simpson's index of concentration of dominance (Cd), the Pearson Correlation coefficient (r), P value and significance level are given.

Parameters	r	P	Significance level
Basal area	0.988	0.000	**
Density	0.444	0.198	NS
Species richness	0.705	0.023	*
Shannon diversity index (H)	0.711	0.021	*
Simpson's index (Cd)	-0.677	0.031	*

*. significant at the p = 0.05 level, ** significant at p = 0.01

DISCUSSION

The values of species diversity, density and basal area were comparable to those reported for other forests of the country and outside the country. The Shannon diversity index in present study ranged from 1.02 to 1.55 which is comparable with the findings of Parthasarathy et al. (1992), Visalakshi (1995) and Mishra et al. (2000) who reported Shannon diversity index as 0.83 to 4.1 for different Indian forests. The tree density in the present study (295-965 trees ha^{-1}) is within the range reported for several tropical forests (550-1800 trees ha$^{-1)}$ by Visalakshi (1995). The tree density of present studied forests is comparable to the tropical forests of Western Ghats (446-1576 trees ha^{-1} reported by Ayyappan and Parthasarathy 1999, Ganesh et al. 1996, Parthasarathy 1999, Parthasarathy and Karthikeyam 1997). The tree basal area measured in the present study (5.02– 37.09 m^2 ha^{-1}) were comparable with the tropical forests of Garo Hills (16-118 m^2 ha^{-1}) by Kumar et al. (2006), Western Ghats (6.12-49.0 m^2 ha^{-1}) by Reddy et al. (2008), Arunachal Pradesh (18.3-49.7 m^2 ha^{-1}) by Deb et al. (2009) and Barak valley of Assam (9.47-42.12 m^2 ha^{-1}) by Borah and Garkoti (2011).

The forest type, age of the forest, size class of tree etc. influence the potential of forest to sequester carbon (Terakunpisut et al. 2007). The AGB of present study ranged from 32.47 Mg ha^{-1} to 261.64 Mg ha^{-1} which is comparable with findings of Hall and Uhling (1991), Ravindranath et al. (1997) and Haripriya (2000). The value of aboveground C stock in this study ranged from 16.24 Mg ha^{-1} to 130.82 Mg ha^{-1} which is comparable to Atjay et al. (1979), Hall and Uhlig (1991), Cairns et al. (2003), Sierra et al. (2007) and Chaturvedi et al. (2011). The C stocks of the present study are within the earlier reported ranges of 60-179 Mg ha^{-1} (Orawa et al. 1965), 17-350 Mg ha^{-1} (Flint and Richards 1996) and less than the values (Table 5) reported by Boonpragob (1998), Baishya et al. (2009), Mohanraj et al. (2011). In Kalakhal forest, Bhubandhar forest and Loharbond forest-1, AGB and aboveground C stock were recorded comparatively lower than other sites. This result may be attributed to the disturbance in these forests. In Nagathol forest, AGB and aboveground C stock were recorded higher which indicate the forest is mature and less disturbed compared to the other studied forest sites.

Studies on diversity and functional relationship have very recently started in forest ecosystems and have yet to produce results (Scherer-Lorenzen et al. 2005, Vila et al. 2005). Different authors have different opinion regarding this. According to Caspersen and Pacala (2001), there is a positive relationship between diversity and productivity. According to Enquist and

Table 5. Estimates of aboveground biomass (AGB) and C stocks of tropical forests in different Asian countries

Study	Forest Type and Location	AGB (Mg ha^{-1})	C Stock (Mg ha^{-1})
Ogawa et al. (1965)	Tropical forest, Thailand	-	60.0-179.0
Brown and Lugo (1982)	Tropical forest, Sri Lanka	154.0	77.0
Hall and Upling (1991)	South and Southeast Asia	35.0-116.0	17.5-58.0
Flint and Richards (1996)	Southeast Asia, including India, Cambodia, Malaysia and Indonesia	-	17.0-350.0
Ravindranath et al. (1997)	India	126.0	-
Boonpragob (1998)	Tropical forests of Thailand	-	138.0-182.0
Haripriya (2000)	India	67.4	
Cairns et al. (2003)	Tropical dry deciduous forest, Mexico	-	113.0
Sierra et al. (2007)	Tropical evergreen forest, Colombia	-	112.0
Baishya et al. (2009)	Tropical forest, India	324.0	162.0
Mohanraj et al. (2011)	Tropical forests, India	372.0	186.0
Chaturvedi et al. (2011)	Tropical dry deciduous forest, India	-	87.0
Present study	Tropical forest of Cachar, Assam, India	32.47-261.64	16.24-130.82

Niklas (2001), there is no relationship while Frivold and Frank (2002) said there may be positive or negative relationship depending on the identity of dominant species in a mixed species forest stand. In present study, significant relationship was found between diversity indices and AGB. Species richness and Shannon diversity index showed positive relationship with AGB, while Simpson index of concentration of dominance showed negative correlation with AGB. Ealier findings of Kirby and Potvin (2007) contrasts the present findings. Kirby and Potvin (2007) were not able to find any evidence for relationship between tree species diversity and aboveground biomass.

A strong and positive relationship was found between basal area and AGB. Finding of this relationship confirms the earlier findings of Mani and Parthasarathy (2007), Murali et al. (2005), Kumar et al. (2011). The relationship between AGB and basal area in forest stand is likely to be associated with tree architectural development because the lower part of the tree trunk must contain the growth process of the tree since initiation (Chiba 1998).

We tried to show top five relative contributing species of AGB and aboveground C stocks. It will help forest management and selective logging of tree species. The selective logging could lead to C impoverished forests because of preferences for timber species that disproportionately important C-store (Kirby and Potvin 2007). In different forests of this study, *Cynometra polyandra, Tetrameles nudiflora, Castanopsis purpurella, Stereospermum personatum, Ficus bengalensis, Palaquium polyanthum*, *Artocarpus chama, Sapium baccatum, Xerospermum glabratum, Semecarpus anacardium,* and *Syzygium sp.* etc were the important contributor of AGB and aboveground C stock. Removing or conserving these species from study forests will therefore have important effect on overall AGB and C stock.

Several ecologists mentioned that mature tropical forest with high AGB; contain a large proportion of their aboveground biomass in large trees (Brown et al. 1995, Brown and Lugo 1992, Clark and Clark 1996). In contrast, several other workers have argued that old growth forests have less potential for carbon sequestration as the constituent older trees cease to grow (Terakunpisut et al. 2007). It is not clear whether young trees have greater carbon sequestration potential than the old trees in natural forest. As the tropical forests are now affected by anthropogenic activities, the density diameter distribution of trees would be important determinant of carbon stock (Baishya et al. 2009). In present study, the smaller trees to medium sized trees contributed more than 50% of AGB and C stock in eight forest (except Loharbond forest-1 and Rosekandy forest). It contrasts the findings of earlier workers (Brown et al. 1995, Brown and Lugo 1992, Clark and Clark 1996, Baishya et al. 2009). They reported up to 50% contribution to AGB by large trees (> 70 cm dbh). On the other hand Brown et al. (1997) reported that smaller trees contribute to most AGB in forests with < 300 Mg ha^{-1}). Finding of present study may be interpreted as most of the trees in these forests are yet to be matured and there is a net addition to standing biomass leading to carbon storage. Such scenarios are applicable to the forests where disturbance events are sporadic and concurrent (Baishya et al. 2009).

From the above study, we concluded that the AGB and C stock of present tropical forest sites were comparable with the findings of earlier workers. In most of the forests in the present study, younger trees contributed more AGB and C stock than the older trees. We found that basal area had significant positive relationship with AGB.

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