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Distribution pattern of aboveground biomass in natural and plantation forests of humid tropics in northeast India

RATUL BAISHYA[1], SAROJ KANTA BARIK[1*] & KRISHNA UPADHAYA[2]

[1]*Centre for Advanced Studies in Botany, School of Life Sciences, North-Eastern Hill University, Shillong 793022, Meghalaya, India*

[2]*Department of Basic Sciences and Social Sciences, School of Technology, North-Eastern Hill University, Shillong 793022, Meghalaya, India*

Abstract: Tree aboveground biomass (AGB) distribution and carbon storage in different DBH (diameter at breast height) classes were compared between natural semi-evergreen forest and sal plantation forest in the humid tropical region of northeast India. The natural forest had lower AGB (323.9 Mg ha^{-1}) than the plantation forest (406.4 Mg ha^{-1}). About 49% of the AGB was present in > 60 cm dbh trees in the natural forest against 24% in the plantation forest. The carbon storage was highest in 60-80 cm and 40-60 cm dbh classes in the natural forest and plantation forest, respectively. The differential AGB and carbon distribution pattern has been related to past disturbance history and age of the forests. Although both the forests had potential for carbon sequestration due to presence of large number of trees belonging to small dbh classes, the plantation forest had an edge over the natural forest because of better silvicultural practices.

Resumen: La distribución de la biomasa arbórea aérea (BAA) y los almacenes de carbono en diferentes categorías de DAP (diámetro a la altura del pecho) fueron comparados entre un bosque natural subperennifolio y una plantación de sal en la región tropical húmeda del nordeste de la India. El bosque natural tuvo una BAA menor (323.9 Mg ha^{-1}) que la plantación (406.4 Mg ha^{-1}). Alrededor de 49% de la BAA se concentró en árboles con DAP > 60 cm en el bosque natural, contra 24% en la plantación. Los almacenes de carbono fueron más grandes en las categorías diamétricas de 60-80 cm y de 40-60 en el bosque natural y la plantación, respectivamente. El patrón diferencial en la distribución de BAA y de carbono estuvo relacionado con la historia de disturbio y la edad de los bosques. Si bien ambos bosques tienen el potencial de secuestrar carbono debido a la presencia de un gran número de árboles en las categorías diamétricas pequeñas, la plantación está en ventaja sobre el bosque natural debido a la aplicación de mejores prácticas silvícolas.

Resumo: A distribuição da biomassa arbórea aérea (AGB) e fixação de carbono para diferentes classes de DAP (diâmetro à altura do peito) foram comparadas entre a floresta natural semi-sempreverde e plantações florestais de "meranti" na região tropical húmida do nordeste da Índia. A floresta natural apresenta mais baixo AGB (323,9 Mg ha^{-1}) do que a floresta plantada (406, 4 Mg ha^{-1}). Cerca de 49% do AGB encontrava-se em árvores com DAP > 60 cm na floresta natural contra 24% na floresta plantada. A fixação de carbono era a mais alta nas árvores das classes de DAP de 60-80 cm e 40-60 cm na floresta natural e plantada, respectivamente. O padrão diferencial de distribuição do AGB e carbono foi relacionado com a história de perturbação e a idade das florestas. Embora ambas as florestas tenham o potencial para o sequestro de carbono devido à presença de um grande número de árvores pertencente às pequenas classes de DAP, a floresta plantada tem uma vantagem sobre a natural por causa das melhores práticas silvícolas.

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[*] *Corresponding Author*; e-mail: sarojkbarik@yahoo.com

Key words: Aboveground biomass, carbon storage, northeast India, sal plantation forest, silvicultural practices, tropical semi-evergreen forest.

Introduction

The tropical forests spread over 13.76 million sq. km area worldwide account for 60% of the global forests (FAO 1988, 2005) and play a key role in global C cycle both in terms of C flux and the volume of C stored. 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). Because of higher net productivity, the tropical forests are more effective in carbon sequestration than any other forests (Brown *et al.* 1989; Soni 2003). The tropical forests store large quantities of carbon in vegetation and soil, exchange carbon with the atmosphere through photosynthesis and respiration. These forests account for 37% of the total 90% of the world's terrestrial C that is stored in forests (Houghton 1996). Very few tropical forests are at their maximum potential level of biomass density because of prevailing or past cultural disturbances, and therefore, have a larger additional carbon sequestration capacity and have the potential to increase the global carbon store beyond the present value (Iverson *et al.* 1993). Consequently tropical forests have attracted a great deal of experimental and theoretical attention in recent years (Malhi *et al.* 1999; Malhi & Grace 2000).

The Amazonian tropical forests have the highest carbon sequestration as well as release among all the ecosystems, because of large area and high productivity associated with large scale deforestation, burning, and fast rate of decomposition and landuse changes (Fearnside 1997). The tropical forests act as sources of atmospheric carbon if disturbed by anthropogenic activities or natural calamities. However, they become atmospheric carbon sinks during land abandonment, forest regrowth after disturbance and due to afforestation, reforestation and forest conservation. Therefore, the role of tropical forests as overall CO_2 sink or source is scale-dependent and site-specific. The need for generating data at high spatial resolution for both above- and belowground phytomass, soil and other pools and fluxes of C has been emphasized by several workers for improving quantification of global C pools and fluxes (Chhabra & Dadhwal 2004).

As a mitigation measure to global climate change due to greenhouse gas emission, it is required to cut the rate of emission either through reducing tropical deforestation or to enhance the natural carbon sequestration potential of degraded forests through forest regeneration and afforestation. The degraded areas have a large potential to sequester carbon in the soil; storage in vegetation is preferable due to their longer residence time and less risk of rapid release to the atmosphere (Lal 2001). This can only be achieved through afforestation or reforestation of such areas. The protection of existing forests, regeneration of degraded forests and raising of forest plantations in India have been contributing to enhanced carbon stock (Ravindranath *et al.* 2008).

The major C pools such as phytomass, soil, litter, and fluxes of C due to litterfall and landuse changes have been estimated for India based on very coarse resolution data and extrapolation, as the primary data for many regions of the country are either non-existent or over-estimated (Dadhwal & Nayak 1993). The data available on carbon sequestration i.e. net woody biomass accumulation in trees for long term storage in tropical forests are extremely limited and incomplete. Because of the lack of reliable data on standing biomass and rates of forest degradation, the net annual carbon emission estimates for India have also been highly variable (Ravindranath *et al.* 1997). Thus, the improved quantification of C pools and fluxes in tropical forest ecosystems is important for understanding the contribution of these forests to net C emissions and their potential for carbon sequestration (Chhabra & Dadhwal 2004).

The potential of tropical forests for increased carbon sequestration capability can be assessed either through the amount of carbon stored or estimating the annual carbon sequestration rate (Iverson *et al.* 1993). The studies on carbon sequestration have been focusing on and expressing the sequestration in terms of biomass and carbon stock. The design and evaluation of global scale carbon models require field estimates of forest biomass. Among the phytomass components i.e. aboveground, belowground and dead wood, the live aboveground wood biomass is the most important because it is involved in the regulation of atmospheric carbon concentration and constitutes about 60% of total phytomass. Therefore, estimation of aboveground biomass (AGB) is the most important aspect of studies of carbon sequestration (Ketterings *et al.* 2001). Estimation of AGB is also a useful measure for comparing structural and functional attributes of forest ecosystems across a wide range of environmental conditions (Brown *et al.* 1999).

The most reliable technique for estimating forest carbon stock is through forest inventories followed by developing allometric relationships between the aboveground biomass (AGB) of a tree and its trunk diameter (Brown 1997; Brown *et al.* 1989; Clark *et al.* 2001). The potential changes in the other carbon pools of the ecosystem such as litter, coarse woody debris, root biomass and soil organic matter are subsequently added to the estimations to obtain the size of the total tree carbon pool. Because AGB represents a large fraction of total forest carbon stock, its estimation offers a practical and reliable way of evaluating the carbon balance of tropical forest.

Several studies have concluded that matured tropical forests with high AGB, contain a large proportion of their aboveground biomass in large trees (Brown *et al.* 1995; Brown & Lugo 1992; Clark & 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). Similarly, in absence of precise data, it is believed that the potential for carbon sequestration of natural forests is manifold greater than the plantation forests. Since most tropical forests are now affected by one or the other form of human interventions, the density-diameter distribution of trees would be an important determinant of the carbon stock in these forests. It is not clear whether (i) carbon sequestration potential is greater in natural forests than the plantation forests, and (ii) young trees have greater carbon sequestration potential than the old trees in a natural forest.

The north-eastern region of India with 99,260 km^2 of tropical forests (Roy & Joshi 2002) that spread up to an elevation of 900 m asl in the Eastern Himalayas and sub-Himalayan areas offers appropriate situation for examining the above two questions. The forests of the region include undisturbed evergreen and semi evergreen forests, secondary forests developed following shifting cultivation and forest degradation, and plantation forests raised by various agencies. Baring a few pockets of undisturbed forests, most tropical forests of the region were affected by one or the other form of cultural disturbances. Therefore, the present work aims to quantify carbon sequestration through estimation of aboveground carbon storage and AGB distribution pattern in different diameter classes in a natural and a plantation forest. The study would not only provide the distribution pattern of carbon in different tree size classes but would also fill the AGB data gap for the tropical forests of northeast India.

Materials and methods

Site description

The study was conducted in two forests *viz.*, tropical semi-evergreen forest and sal (*Shorea robusta*) plantation forest. These two forest types were selected due to the fact that tropical semi-evergreen forests constitute the majority of natural tropical forests of northeast India and sal plantation forests dominate the planted forest in the region. The two forests are part of humid tropical forest of Nongkhyllem wildlife sanctuary in Meghalaya, northeast India. The experimental plots lie between 25°55.578’ - 25°56.062' N latitude and 091°46.453’ - 91°46.546'E longitude. The area was declared as a wildlife sanctuary in 1981 prior to which it was part of the reserve forest. It covers 29 km^2 area on a steep hill slope (20° to > 65°) with an elevation ranging from 208 to 295 m and is 79 km from Shillong, the state capital of Meghalaya. The sal plantation was created during the year 1972 and is well-protected. On the other hand, the natural forest is an old growth forest, where the past disturbance in the form of selective logging took place at least 80 years ago prior to its declaration as a wildlife sanctuary. The forest is currently undisturbed and is characterized by dense canopy. Such forests constitute about 21% of the total sanctuary area.

Climate

The climate of the area is monsoonic with distinct warm-wet (May-October) and cold-dry (December-February) periods. The rainy season starts from May and extends up to October. About 90% of the total annual rainfall occurs during this period. The meteorological data were collected from the meteorological station of District Horticulture office, Government of Meghalaya located at Nongpoh, about 10 km from the study site. The total annual rainfall was 1355 mm during the year 2006-2007. The mean maximum temperature of 35ºC was recorded in August and mean minimum temperature of 14ºC was recorded in January.

Forest inventory

The different types of forests were mapped using IRS LISS III imageries through supervised classification and a forest type map within the wildlife sanctuary was prepared (Fig.1a). Sampling of vegetation in the two forests was carried out by belt transect method. Since the natural and plantation forests were continuous and each forest type was represented by a clearly demarcable single patch, an area of 10 ha was demarcated in each forest and was divided into four quarters of 250 m x 100 m each. In each quarter, a transect of 250 m x 20 m was laid laterally (Fig.1b) (Adapted from Alves *et al.* 1997). Thus four transects with a total 2 ha area were laid in each forest that was considered adequate for sampling, given the structure and size of each forest type. The transects were further divided into 10 x 10 m plots. In each plot, all individuals > 5 cm dbh (diameter at breast height) were tagged, measured and identified. The girth and height of each individual were measured. The plant specimens were identified with the help of regional floras (Balakrishnan 1981-83; Haridasan & Rao 1985-87; Joseph 1982; Kanjilal *et al.* 1934-40). The herbarium at Botanical Survey of India, North-Eastern Circle, Shillong and North-Eastern Hill University, Shillong, were consulted for confirmation. Frequency, density, basal area and importance value index (IVI) were calculated following Misra (1968) and Muller-Dombois & Ellenberg (1974). Trees were grouped into six dbh classes i.e. >5-20 cm, 20-40 cm, 40-60 cm, 60-80 cm, 80-100 cm and > 100 cm, and the density and AGB distribution under each dbh class were analyzed.

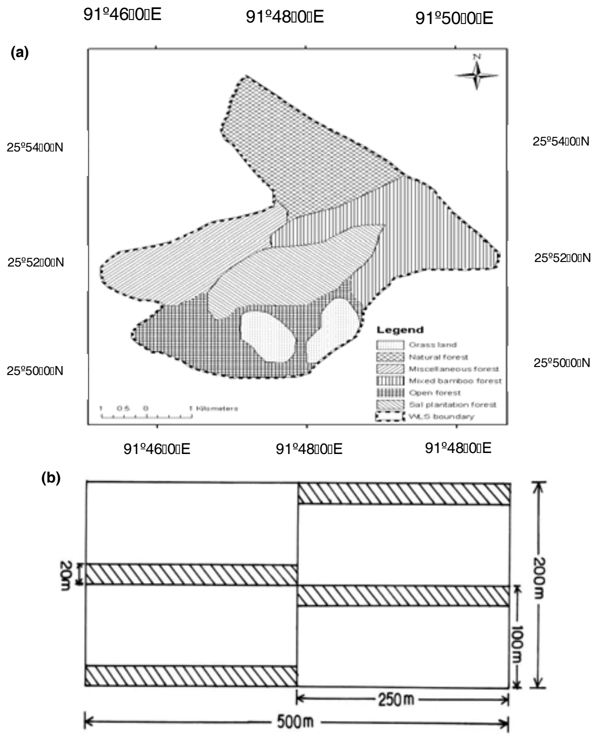

Fig. 1. (a) Map showing different forest types in Nongkhyllem wildlife sanctuary, Meghalaya, northeast India prepared based on IRS LISS III 2006 imagery and (b) diagrammatic presentation of the sampling procedure.

Biomass regression equations

Because of high species richness in tropical forests, it is difficult to use species-specific regression models, as used in the temperate zone (Brown & Schroeder 1999; Shepashenko *et al.* 1998; Ter-Mikaelian & Korzukhin 1997). Therefore, mixed species tree biomass regression models were used for AGB estimation of natural and plantation forests. The regression models for tree biomass used in the studies of Brown (1997), Brown *et al.* (1989), Chambers *et al.* (2001), Chave *et al.* (2001) and Brown & Iverson (1992) were evaluated based on prediction errors, residual analysis, and logical behavior of the models, R^2, and simplicity of the models (Table 1). Diameter at breast height i.e. at 1.37 m above the ground level, and individual tree height were measured during the study using diameter tape and clinometer. These two parameters were used as inputs to the ten models and the best-fit model was selected. The model $Y= \exp [-0.37 + 0.33 \ln(D) + 0.933 \ln(D)^2$ $0.122 \ln(D)^3]$ developed by Chambers *et al.* (2001) was used to estimate the aboveground biomass in the two forests. The best R^2 values of 0.93 and 0.91 were obtained for the natural forest and plantation forest, respectively.

Estimation of AGB

The AGB in different tree diameter classes in each forest was estimated using the above mentioned model, where the variable biomass was AGB. The aboveground biomass for all diameter classes was summed to arrive at the total aboveground biomass in each of the two forests. The values for the natural and the plantation forests were compared using t test.

Estimation of carbon

The aboveground biomass carbon stock was calculated by assuming that the carbon content is 50% of the total aboveground biomass (Brown & Lugo 1982; Cannel *et al.* 1995; Dixon 1994; Ravindranath *et al.* 1997; Richter *et al.* 1995; Schroeder 1992).

Results

Stand characteristics

Ninety four species were recorded from the natural forest, and 67 species were recorded from the plantation forest. The density of woody species (>5cm dbh) was greater in plantation forest (1028 trees ha^{-1}) than the natural forest (996 trees ha^{-1}). Based on density, *Antidesma acuminatum* (120 trees ha^{-1}) and *Polyalthia jenkinsii* (108 trees ha^{-1}) were the dominant species in the natural forest and these two species accounted for 21% of the total stand density. In plantation forest, *Shorea robusta* (386 trees ha^{-1}) and *Litsea monopetala* (102 trees ha^{-1}) were the dominant and co-dominant species, respectively. The basal area was greater in the plantation forest (89.92 m^2ha^{-1}) than the natural forest (73.41 m^2ha^{-1}) (Table 2).

Aboveground biomass distribution

Although the young individuals belonging to 5-20 cm dbh class dominated both forests in terms of density (Fig. 2), the AGB accumulation was greater in the 40-60 cm diameter class in plantation forest and in 60-80 cm dbh class in natural forest (Fig. 3). The AGB contribution by subsequent higher diameter classes got reduced in both the forests. The contribution of trees having >60 cm diameter to AGB was greater in natural forest (6.6%) than the plantation forest (5.6%).

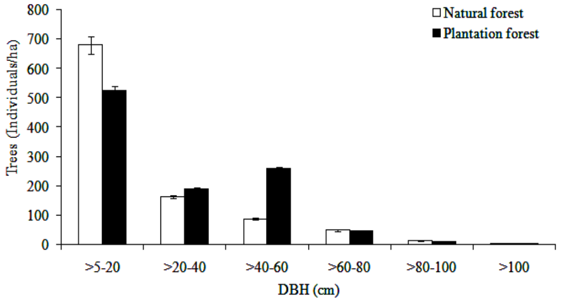

Fig. 2. Tree density in different diameter classes in natural and plantation forests of northeast India.

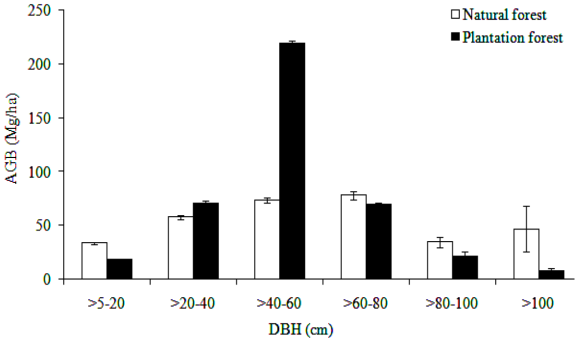

Fig. 3. Aboveground biomass in different tree diameter classes in natural and plantation forests of northeast India.

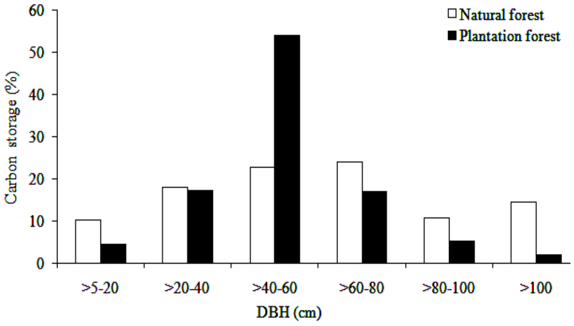

Fig. 4. Carbon storage in different tree diameter classes in natural and plantation forests of northeast India.

Table 1. Regression models run to obtain best fit for estimation of biomass in natural and plantation forests of northeast India.

Model	Regression equation	R^2	
		Natural forest	Plantation forest
FAO. 3.2.3. (1997)	$Y= 42.69-12.800(D) + 1.242(D^2)$	0.87	0.84
FAO. 3.2.4. (1997)	$Y= \exp \{-2.134+2.530*\ln (D)\}$	0.80	0.73
FAO. 3.2.5. (1997)	$Y= 21.297- 6.953 (D) + 0.740(D^2)$	0.87	0.84
Brown *et al.* (1989)	$Y= \exp [-3.114+0.972*\ln (D^2H)]$	0.87	0.65
Brown *et al.* (1989)	$Y= \exp [-2.409+0.952*\ln (D^2HS)]$	0.88	0.67
Chave *et al.* (2001)	$Y= \exp (-2.00+2.42) \ln (D)$	0.82	0.76
Chambers *et al.* (2001)	$Y= \exp [-0.37+0.33 \ln (D) + 0.933 \ln(D)^2\ 0.122 \ln(D)^3]$	0.93	0.91
Brown & Iverson (1992)	$Y= 1.276+0.034 (D^2*H)$	0.86	0.63
Brown *et al.* (1989)	$Y= 38.4908-11.7883 (D) + 1.1926 D^2$	0.88	0.85

Table 2. Stand characteristics of natural and plantation forests of northeast India.

Variables	Forest types	
	Natural	Plantation
Species richness (No. of species)	94	67
Stand density (trees ha^{-1})	996	1028
Density of dominant tree species (trees ha^{-1})		
Antidesma acuminatum Wall. ex Wt.	120	34
Dysoxylum gobara (Buch.-Ham.) Merr.	36	-
Elaeocarpus tectorius (Lour.) Poir.	58	44
Leea alata Edgew.	90	-
Litsea monopetala (Roxb.) Pers.	-	102
Mesua ferrea Linn.	60	24
Polyalthia jenkinsii Benth. & Hk. f.	108	40
Schima wallichii (DC.) Korth.	38	46
Shorea robusta Gaertn.	-	386
Basal area ($m^2\ ha^{-1}$)	73.4	89.9

Total aboveground biomass and carbon stock

The total AGB was significantly greater ($p<0.001$) in the plantation forest (406 Mg ha^{-1}) than the natural forest (324 Mg ha^{-1}). The aboveground carbon stored by natural and plantation forests was 161.97 and 203.18 Mg C ha^{-1}, respectively. The maximum carbon was stored in 60-80 cm dbh class in natural forest (22.5%) and in 40-60 cm dbh class in plantation forest (53.9%). The younger (5-20 cm dbh class) trees, which had highest density in both the forests, stored only 4.4% of total carbon in the natural forest and 8.4% in the plantation forest (Fig.4).

Discussion

The potential of forests to sequester carbon depends on the forest type, age of forest and size class of trees (Terakunpisut *et al.* 2007). The observed AGB value of 324 Mg ha^{-1} in the natural forest was comparable with the findings of Ramachandran *et al.* (2007) who reported a value of 307 Mg ha^{-1} for the tropical evergreen forests of eastern coast of Tamil Nadu, India. However, the present value is less than the AGB values of 607.7 Mg ha^{-1} and 468 Mg ha^{-1} reported for tropical wet evergreen forest and tropical semi evergreen forest of Western ghats of India by Rai (1981) and Swamy (1989), respectively. The AGB value was also close to those reported by Muller (1982) for the tropical forests of eastern hardwood region of USA (330 Mg ha^{-1}), and by Brown & Lugo (1982) for the tropical rain forests in Malaysia (225-446 Mg ha^{-1}) and Cameroon (238-341 Mg ha^{-1}). The value range of 153-221 Mg ha^{-1} reported from Sri Lankan tropical rain forests (Brown & Lugo 1982) is lower than the values found in the present study. Terakunpisut *et al.* (2007) reported an AGB value of 275 Mg ha^{-1} for the tropical rain forests of Thailand which is also less than the present study. The lower AGB values of 170 Mg ha^{-1} for the broadleaved forests of tropical America, 260 Mg ha^{-1} for tropical Africa, 215 Mg ha^{-1} for tropical Asia and 150 Mg ha^{-1} for total tropics were reported by Brown & Lugo (1984). However, the AGB value obtained for this northeast Indian tropical forest is much lower than the highest AGB value reported so far i.e. 500-600 Mg ha^{-1} for the undisturbed deciduous forest in the southern Appalachain Mountains (Whittaker 1996).

The AGB of 406 Mg ha^{-1} obtained for the sal plantation forest in the present study was within the earlier reported ranges of 337 - 698 Mg ha^{-1} estimated for sal-dominated forest in Central

Nepal (Shrestha *et al.* 2000). However, it is much higher than the estimates of 304 Mg ha^{-1} for the forests of Uttar Pradesh (Singh *et al.* 1992) and 261 Mg ha^{-1} for a 10-year old recovering tropical sal forest of eastern ghats, India (Behera & Misra 2006).

The amount of carbon stored in the natural forest of the present study (162 Mg C ha^{-1}) was greater than the disturbed tropical forests of Sri Lanka (77 Mg C ha^{-1}), but lower than the relatively undisturbed matured tropical rain forest of Malaysia (223 Mg C ha^{-1}) reported by Brown & Lugo (1982). Ogawa *et al.* (1965) reported a carbon stock of 60 to 179 Mg C ha^{-1} in different tropical forest types of Thailand. Flint & Richards (1996) estimated carbon sequestration in Southeast Asia including India, Thailand, Cambodia, Malaysia and Indonesia, and reported the value range of 17 Mg C ha^{-1} in severely degraded tropical dry forest to 350 Mg C ha^{-1} in the undisturbed matured tropical rain forests.

The large trees contributed 49% to the total AGB in natural forest. In contrast, the contribution of the smaller trees to total AGB in the plantation forest was significantly higher (76%) than the larger trees. The greater contribution of large trees to AGB in natural forest was in conformity with the findings of earlier workers (Brown 1996; Brown *et al.* 1995; Brown & Lugo 1992; Clark & Clark 1996) who reported up to 50% contribution to AGB by the 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} aboveground biomass. Analyses have shown that forests with reduced biomass either had their large trees removed by past human disturbance or represent regenerating secondary forests which do not yet have large trees. The distribution of biomass in large trees, therefore, could be an indicator of the presence or absence of past anthropogenic disturbance (Brown 1996).

A higher proportion of AGB in the higher diameter classes in natural forest does indicate the important role of large trees in carbon storage, but does not undermine the role of small trees (<60 cm dbh) which would enhance the future carbon stock because of their high carbon sequestration potential. It is well established that forest plantations sequester carbon till maturity that varies from 25 to 75 years depending upon the forest type. Beyond the maturity, the trees generally have marginal carbon sequestration capability (Lal & Singh 2000). The higher AGB in the plantation forest than natural forest may be attributed to the more or less uniform stand structure that results from a combination of site factors and adopted management practices. On the other hand, wide variation in stand structure and tree growth in the natural forest resulted in lower above ground biomass. Other factors responsible for such low total AGB are, different stages of forest growth cycle, habitat and species variabilities, and varying tree density (Terakunpisut *et al.* 2007).

Many workers have reported that in natural forests, there is a net addition to standing biomass leading to carbon storage if most trees are yet to be matured. Such scenarios are applicable to the forests where disturbance events are sporadic and concurrent. On the other hand, the matured forests do not add up any further biomass because most part of the gross primary productivity is either used up in respiration or returned to soil as litter with no net addition to the above ground biomass density. Such matured natural forests thus do not significantly contribute towards carbon uptake, though they are important for regeneration and sustaining biodiversity. However, plantation forests with higher annual productivity were reported to be ideal for carbon storage and sequestration (Lal & Singh 2000). Thus, creation of new plantation on degraded lands is a better option for carbon storage when these are planted and harvested periodically and used as a long-term source of timber.

In agreement with the findings of earlier workers, the sal plantation forest with less AGB in higher diameter class had the greater potential to accumulate significant quantities of biomass, and thus sequestering more atmospheric C than the natural forest. However, given the fact that both the natural and plantation forests had large tree populations under smaller dbh classes (Fig.2), it can be argued that both the forests have high potential to sequester carbon. The present study concludes that the carbon sequestration potential of natural forests of northeast India is high, even with a past disturbance history. The carbon values are comparable with most other tropical forests of the region. Considering the dbh-AGB distribution pattern, the sal plantation forest had, however, greater carbon stock as well as higher sequestration potential than the natural forest because of ongoing scientific management practices, uniform age and stand structure.

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