International Journal of Ecology and Environmental Sciences 40 (1): 29-40, 2014
ISSN: 0377-015X (Print); 2320-5199 (Online)


# Assessment of Aboveground and Soil Organic Carbon Stocks in *Dipterocarpus* Forests of Barak Valley, Assam, Northeast India

DEBAJIT RABHA [1], NEPOLION BORAH [2] AND ASHESH KUMAR DAS*

*Department of Ecology and Environmental Science, Assam University Silchar-788011, Assam, India*
* Corresponding author: *E.mail: asheshdas684@hotmail.com*
[1] E.mail: *d10rabha@gmail.com,* [2] E.mail: *nepoaltim123@gmail.com*

ABSTRACT

The aboveground and soil organic carbon storage were assessed by using non-destructive method in four Dipterocarpus forests of South Assam, northeast India. The AGB and AGC was estimated as 284.53 Mg $ha^{-1}$ and 142.26 Mg $ha^{-1}$ respectively. *Dipterocarpus turbinatus* the critically endangered species contributed 70.5% to 94.3% of total AGC stocks. Girth class distribution of AGC shows that Site I is mainly carbon storing patch while Site IV has the highest potential to sequester carbon in the near future. The distribution of aboveground carbon in different girth classes and percentage of soil organic carbon in different soil depths were found significant. Soil organic carbon was estimated as 118.44 Mg $ha^{-1}$. Soil organic carbon decreased with increasing soil depth while bulk density showed no significant difference between the soil depths. The importance of Dipterocarpus forest stands for carbon conservation has been discussed.

Key Words: Aboveground Biomass; Girth Class Distribution; Critically Endangered; *Dipterocarpus turbinatus*

## INTRODUCTION

The increase of carbon dioxide in atmosphere and its potential to global climate change and the role of terrestrial vegetation and soil as significant sinks of atmospheric $CO_2$ was well addressed in the Kyoto Protocol (Ravindranath et al. 1997; Wani et al. 2010). Forests are being considered as one option for stabilising or reducing atmospheric carbon dioxide by storing carbon in biomass, soils and its products (Birdsey and Heath 2001). Saatchi et al. (2011) estimated that tropical forests account for 247 Gt vegetation carbon of which 193 Gt was stored aboveground. Soil organic carbon (SOC) is the largest terrestrial carbon pool with global estimated 684-724 Pg of C in upper 30 cm and 1462-1548 Pg of C in the upper 100 cm (Batjes 1996). Approximately 40 % of the global soil carbon inventory resides in forest ecosystems (Hudson et al. 1994). Brown and Lugo (1982) assessed that tropical forests store 46 % of the world's living terrestrial carbon pool and 11 % of the world's soil carbon pool. Estimations of aboveground biomass play significant role in studying of carbon stocks, effect of deforestation and carbon sequestration on the global carbon balance (Ketterings et al. 2001). It also provides valuable information on structural and functional attributes of forest ecosystems across a wide range of environmental conditions (Brown et al. 1999). Dipterocarp forests are found very dominant in tropical Asian rainforests. These forests are ecologically important and economically significant and occupied a significant portion of Southeast Asian forests (Bawa 1998; Kettle 2010). The present study is conducted in *Dipterocarpus turbinatus* dominant forests of Barak Valley, Assam in northeast India. The species is recently included as critically endangered category in the IUCN Red List of Threatened Species, native to Bangladesh, Cambodia, India, Lao People's Democratic Republic, Myanmar, Thailand and Vietnam. In India the species is distributed in Assam, Arunachal Pradesh, Manipur, Meghalaya, Tripura and Andaman Islands (IUCN 2013).

In Assam *Dipterocarpus turbinatus* is prominent in Barak Valley, southern part of Assam (Chatterjee 2006). Champion and Seth (1968) reported that it was dominant in Cachar tropical semi-evergreen forests. *Dipterocarpus turbinatus* is a slow-growing, lofty, evergreen timber tree attaining 50 meters or more, which is higher than rainforests elsewhere with a clean, cylindrical bole and elevated crown (Corlett and Primack 2005). Also, trees do not typically fall over or get blown over as is seen in many Neotropical trees. *Dipterocarpus turbinatus* often die standing, gradually losing their branches until only the trunk remains unlike Africa and the Amazon forests. Because of these characteristics it can effectively store carbon on its tree trunk for long duration. However, due to the rapid anthropogenic activities these forests are confined only in some particular patches in Barak Valley (Borah 2012).

This paper aims to quantify the aboveground and soil organic carbon stocks of *Dipterocarpus* forests of Karimganj district, Assam in northeast India. At the same time we analysis the stand characteristics and their contribution to the total carbon pool to understand the role of individual species.

## STUDY AREA

The study was conducted in four *Dipterocarpus turbinatus* dominant forest stands in Karimganj district of South Assam (Figure 1). Location and geographic coordinates of the four sites are given in Table 1. Among them Site I and Site II are plantation forests whereas Site III and Site IV are natural forests. The climate is warm humid with frequent rainfall. Meteorological data of last nine-year period (2004-2012) was collected from the Regional Agricultural Research Station (RARS), Akbarpur, Karimganj. The mean annual rainfall was 4250 mm $yr^{-1}$ of which 83% was received during the period May to October. The mean maximum temperature ranges from 27 °C (January) to 33 °C (August) and the minimum temperature from 9 °C (January) to 23 °C (July). Relative humidity ranges from 88.55 to 98.75 % (Figure 2).

## METHODS

### Vegetation Sampling

For the present study a non-destructive sampling method was adopted to estimate aboveground biomass (AGB)

Table 1. Site description of the Dipterocarpus forests in Karimganj district, Assam, northeast India

| Site name/ Location | Latitude | Longitude |
|---|---|---|
| Site I Shal kona, Chankhira | 24° 34' 24.9" | 92° 16' 36.7" |
| Site II Karikhai, Lowairpoa | 24° 26' 52.3" | 92° 18' 07.8" |
| Site III Garjantilla, Solgoi | 24° 28' 30.0" | 92° 21' 09.5" |
| Site IV South Raipur, Nivia | 24° 23' 23.6" | 92° 26' 45.0" |

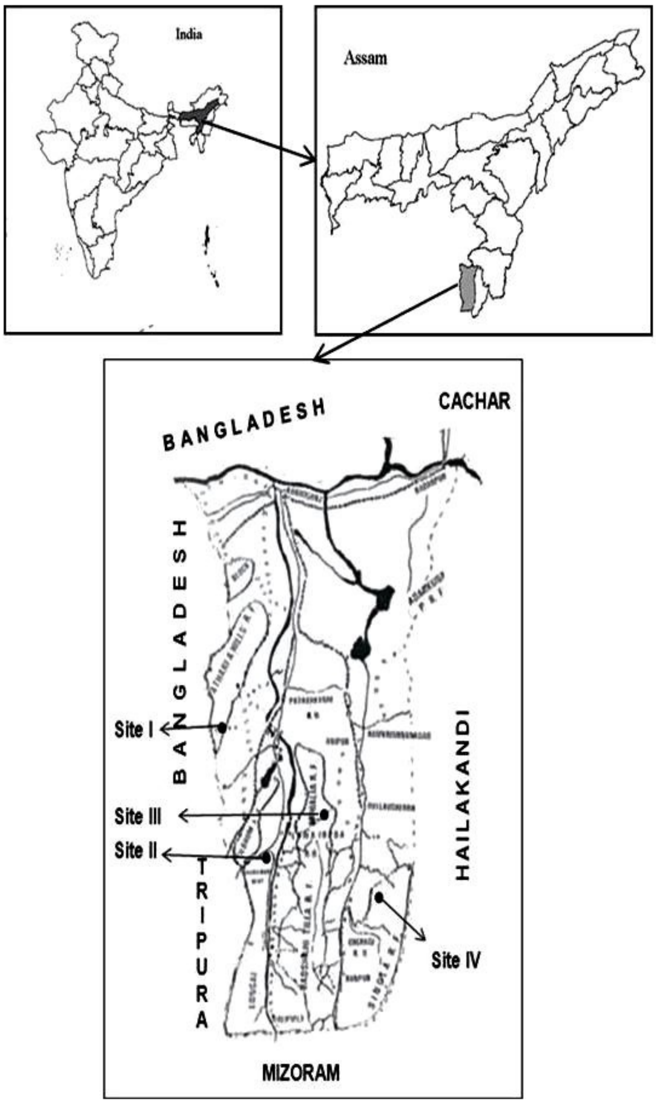


Figure 1. Location of the study area in Karimganj district, Assam, northeast India

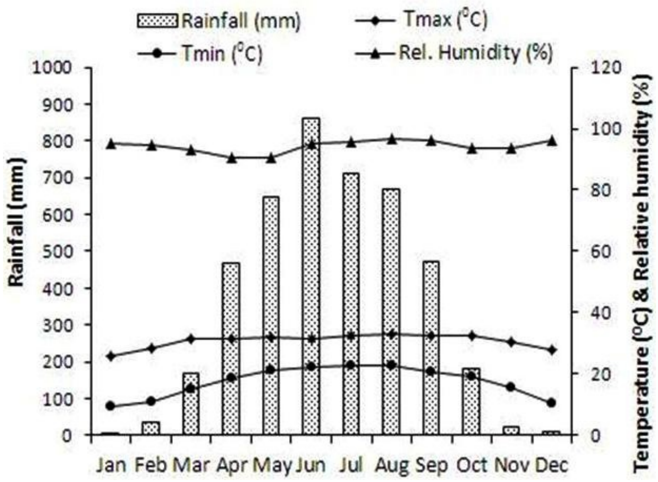


Figure 2. Average monthly rainfall and temperature data from the period 2004 to 2012 collected from the Regional Agricultural Research Station, Akbarpur, Karimganj district, Assam

and carbon stocks of tree species. In each forest site a super plot of 250 m × 250 m size was laid. Four sample plots, each of 31.6 m × 31.6 m (0.1 ha) size were laid in the four corner of the super plot according to the field manual for "vegetation carbon pool" assessment of India (Singh and Dadhwal 2009). In each sample plot, girths of all the trees (≥ 10 cm DBH) were measured at 1.37 m height from the ground by using metal measuring tape. Species were identified with the help of Botanical Survey of India, Shillong.

**Estimation of Aboveground Biomass (AGB) and Carbon Stock**

Species-specific volume equation and regional volume equation published by Forest Survey of India (FSI 1996) were used to estimate the tree volume taking DBH as an independent variable. For all other species, for which specific equations are not available, area-specific generalized volume equation developed by FSI was used. The aboveground biomass of each individual tree was calculated by using following equation-

Biomass = volume × wood specific gravity

Species wood specific specific-gravity data of each tree species in the present study region was collected from the Forest Research Institute (FRI 1996) and other related literatures. For the species for which species specific specific-gravity is not available, an area average specific gravity was used. The volume equations and species specific gravity used in the present study is listed in Appendix 1. Estimation of C-stock in each tree was done by multiplying the tree biomass with 0.5 as in many other similar studies (Brown and Lugo 1982, Montagnini and Porras 1998).

**Soil Organic Carbon (SOC)**

Soil samples were collected from three sides of soil pits excavated centrally in one of the four 0.1 ha plots, at 0-30 cm, 30-60 cm and 60-100 cm depth. Triplicate samples of each soil depth at a given site were analysed for bulk density, texture and organic carbon. The soil bulk density was estimated by Corer method (Brady and Weil 2008) while soil texture and soil organic carbon were estimated by Bouyoucos (1962) soil hydrometer method and Walkley and Black (1934) rapid titration method respectively. The Walkley and Black method measures average 76 % of total SOC (only oxidizable C). So, a correction factor of 1.32 was used for unrecovered organic C as suggested by Walkley and Black (1934). Soil carbon storage was estimated from the soil volume at each horizon, bulk density (g $cm^{-3}$) and organic carbon concentration (%), according to the method given by Joao Carlos et al. (2001).

**Statistical Analysis**

One-way analysis of variance (ANOVA) was used to test the differences between stem density, basal area and total C density. The Tukey post-hoc test was used to test differences among means in different parameter when the F-test was significant. Standard error was used (Mean ± SE) where mean value is signified. Statistical analysis was performed using SPSS-15 software.

RESULTS

**Stand Characteristics**

A total of 33 species representing 24 families were recorded from the present study sites. Highest 25 species from 18 families was recorded at Site IV although the density of the maximum species was very less and 13 species were represented by only one individual in 0.4 hectare studied. At Sites I, II and III, the species number was only 4, 4, and 7 respectively (Table 2).

The stem density ranged from 155 stem ha$^{-1}$ to 460 stem ha$^{-1}$ (Table 2). Highest stem density (460 stem ha$^{-1}$) was recorded in Site IV and lowest (155 stem ha$^{-1}$) both in Site I and Site III. The basal area ranged from 23.62 m$^2$ ha$^{-1}$ to 53.58 m$^2$ ha$^{-1}$. The maximum basal area was recorded in Site IV (53.58 m$^2$ ha$^{-1}$). The mean difference of density and basal area in different sites ($P < 0.05$) were found significant. The Tukey post-hoc test revealed that the differences in density were significant across the all sites except Site I and Site III. Similarly the mean difference of basal area was also found significant excluding Site I, Site II and Site IV (Table 2).

## Aboveground Biomass (AGB) and C Stocks

The AGB ranged from 161.44 Mg ha$^{-1}$ to 373.19 Mg ha$^{-1}$ and C stocks ranged from 75.88 Mg ha$^{-1}$ to 175.40 Mg ha$^{-1}$ (Table 2). Tukey post-hoc test was performed as the mean difference of AGB and AGC ($P = 0.007$, $P < 0.05$) was found significant in respect to the study sites. The LSD of Tukey post-hoc test revealed that Site III was significant with all the other sites. The highest AGB and C stocks were recorded at Site I and lowest at Site III. At Site II, the AGB and C stocks were 313.37 Mg ha$^{-1}$ and 147.28 Mg ha$^{-1}$, respectively and at Site IV, the values were 290.10 Mg ha$^{-1}$ and 136.35 Mg ha$^{-1}$, respectively.

Table 2. Cumulative results of the sampled inventory of Dipterocarpus forest sites in Karimganj district, Assam, northeast India

| Parameters | Site I | Site II | Site III | Site IV |
|---|---|---|---|---|
| Species number | 4 | 4 | 7 | 25 |
| Family number | 4 | 4 | 6 | 18 |
| Density (stem ha$^{-1}$) | 155±14.79$^{A}$ | 257.5±34.53$^{AB}$ | 155±10.31$^{B}$ | 460±26.69$^{AB}$ |
| Basal area (m$^2$ ha$^{-1}$) | 52.82±2.49$^{A}$ | 52.01±3.00$^{B}$ | 23.62±4.77$^{ABC}$ | 53.58±5.28$^{C}$ |
| AGB (Mg ha$^{-1}$) | 373.19±27.68$^{A}$ | 313.37±17.30$^{B}$ | 161.44±35.55$^{ABC}$ | 290.10±35.91$^{C}$ |
| AGC (Mg ha$^{-1}$) | 186.60±13.84$^{A}$ | 156.69±8.65$^{B}$ | 80.72±17.78$^{ABC}$ | 145.05±17.95$^{C}$ |
| SOC (Mg ha$^{-1}$) up to 1 m depth | 141.13 | 91.4 | 125.43 | 115.8 |

± SE of mean; Values followed by the same superscript alphabet(s) are significantly different at 0.05 level across the sites

### *Contribution of* Dipterocarpus turbinatus *to Total AG Carbon Stock*

*Dipterocarpus turbinatus* contributed 70.5 % to 94.3 % of total AGC stocks in different sites. In Site I, it contributed 94.3 % of total C stocks while at Site II, Site IV and Site III, this species contributed 93.5 %, 81.6 % and 70.5 % respectively (Figure 3). *Dipterocarpus turbinatus* is the single dominant contributor of total AGC around 80-95 % except at Site III where *Tectona grandis* contribute 26.65 % of total AGC.

## AGB and AGC in Different Girth Classes

At Site I, tree density increased with increase in the DBH up to 60-70 cm before gradually decreasing at greater DBH. Basal area and AGC showed a similar trend; increased up to 60-70 cm diameter and slightly decreased at 70-80 cm DBH, again increased in 80-90 cm diameter class and drastically decreased in highest DBH classes. Here the highest stem density (42.50 stem ha$^{-1}$), basal area (14.31 m$^2$ ha$^{-1}$) and AGC stocks (50.81 Mg ha$^{-1}$) were recorded in 60-70 cm DBH class (Figure 4). In Site II individuals are lacking in lowermost two and 80-90 DBH classes. Density (115 stem ha$^{-1}$) and basal area (18.31 m$^2$ ha$^{-1}$) recorded highest in 40-50 cm DBH class, while highest AGC (55.90 Mg ha$^{-1}$) was recorded in 60-70 DBH class. In Site III lowermost DBH class has the highest stem density (35 stem ha$^{-1}$) and it almost decrease with increase in the DBH class. Basal area and AGC increased with the increase of DBH class up to 50-60 DBH class and then it decrease. Drastic change of density, basal area and AGC in 60-70 DBH class in Site III may be due to the selective illegal tree felling of that girth size. At Site IV stem density showed the reverse “J” shaped curve indicating the good regeneration of the

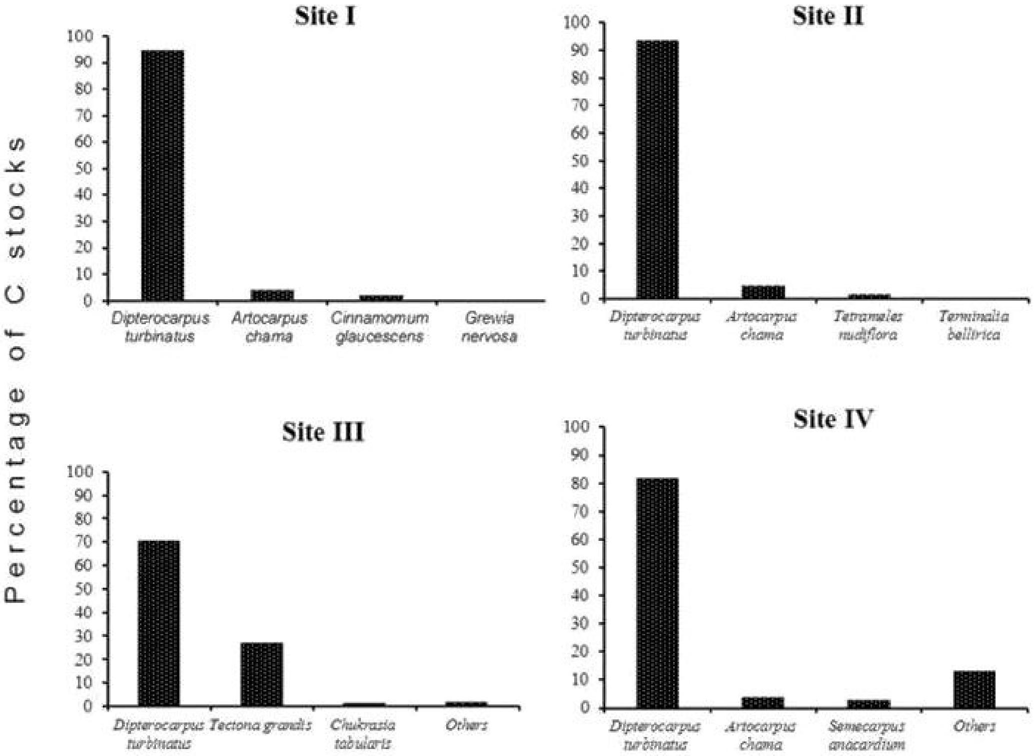


Figure 3. Contribution of AGC stocks by different tree species in Dipterocarpus forest sites

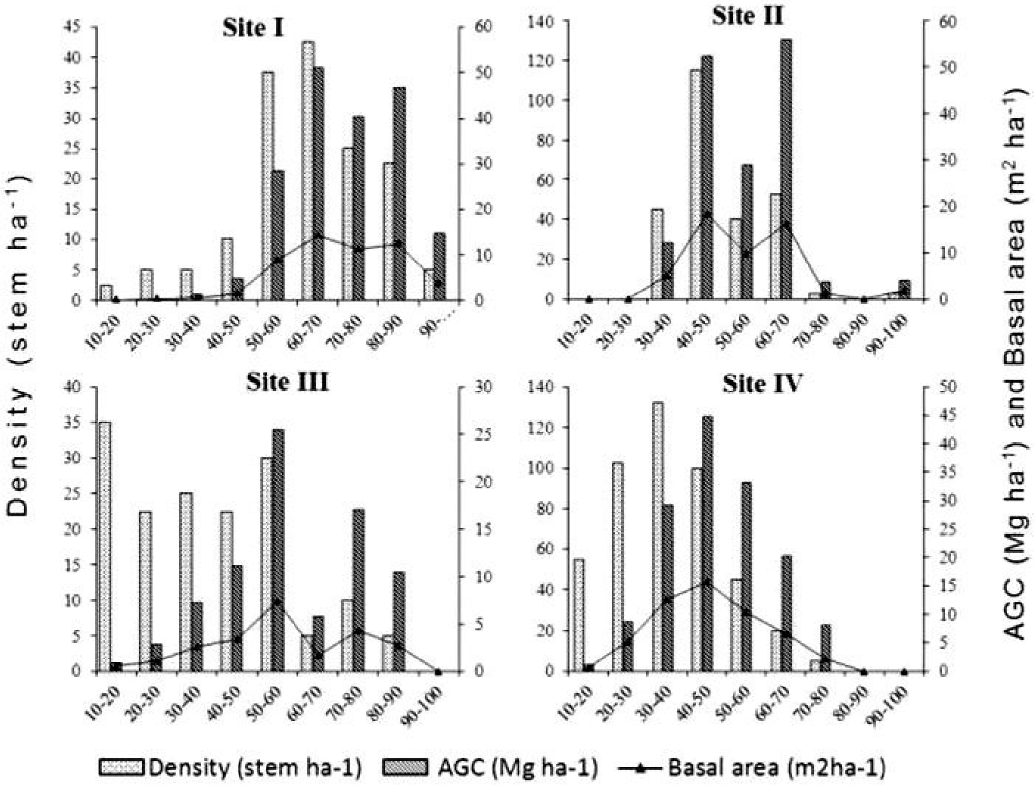


Figure 4. Distribution of Density, Basal area and AGC of tree species in different DBH classes

constituent species. Here, with the increase in DBH class, basal area and AGC also increased up to 40-50 cm DBH classes but gradually decreased later. The highest stem density (132.5 stem $ha^{-1}$) was recorded in 30-40 cm DBH class whereas maximum basal area (15.7 $m^2$ $ha^{-1}$) and AGC (44.8 Mg $ha^{-1}$) was found in 40-50 cm DBH class.

**Soil Properties and Soil Organic Carbon (SOC)**

Soil colour of the study sites were yellowish brown, reddish yellow, dark yellowish brown and strong brown at different depths and at different locations (Table 3). Soil texture of Site I and Site IV were sandy clay loam at all the three depths while Site III was characterized by silty clay loam at all the three depths (Table 3). In Site II, the top soil layer (0-30 cm depth) was characterized by silty clay loam followed by silty clay and clay at 30-60 cm and 60-100 cm depths respectively.

The carbon storage in the soil ranged from 91.40-141.13 Mg $ha^{-1}$ in top 1 meter depth. Highest soil organic carbon was recorded in Site I and lowest in Site II (Table 3). The SOC content ranged from 0.90% to 1.40%, 0.63% to 0.97% and 0.60% to 0.83% in surface (0-30 cm), middle (30-60 cm ) and bottom (60-100 cm) soil layers, respectively. In surface layer highest SOC was recorded at Site I (1.40%) and lowest (0.91%) at Site II. Soil organic carbon content (%) was high in the top layer and decreased significantly ($p = 0.01$, $p <0.05$) with increasing in soil depth. Soil bulk density (g $cm^{-3}$) showed no significant difference ($p = 0.07$, $p >0.05$) in respect of the soil depths.

DISCUSSION

Tropical forest store 37 % of the total 90 % of the world terrestrial carbon in its components (Houghton 1996). In the present study the mean average of AGB and AGC was recorded as 284.52 Mg $ha^{-1}$ and 142.27 Mg $ha^{-1}$. Comparing the AGB of similar forests dominated by *Dipterocarpus turbinatus* of this region, the present study found much higher than the secondary semi-evergreen tropical forest of Manipur (15.60- 15.84 Mg $ha^{-1}$ reported by Devi and Yadava 2009) and tropical forests of Bangladesh (96.13 Mg $ha^{-1}$ reported by Ullah and Al-Amin 2012). The observed AGB is also comparable with other forest types of India such as 32.47–261.80 Mg $ha^{-1}$ in the tropical forests of Cachar district of Assam (Borah et al. 2013), 324 Mg $ha^{-1}$ in humid tropical forest of Meghalaya (Baishya et al. 2009), 179.14–246.38 Mg $ha^{-1}$ in the sub-tropical broad leaved forests in Manipur (Thokchom and Yadava 2013), and 7.25-287.05 Mg $ha^{-1}$ in the tropical forests of Karnataka (Devagiri et al. 2013).

Dipterocarp forests are particularly dominant in tropical Asian forests. When compared to the other Dipterocarp forests in different Asian countries the result of the present study found fairly similar to the Dipterocarp forests of Philippines (265 Mg $ha^{-1}$ AGB, Kawahara et al. 1981), Malaysia (291–400 Mg $ha^{-1}$ AGB, Pinard and Putz 1996), Thailand (60-179 Mg $ha^{-1}$ AGC, Ogawa et al. 1965). The present value was found lower than the different part of Asian countries reported by several workers (Lasco et al. 2000, 2002, 2006; Murdiyarso and Wasrin 1996; van Noordwijk et al. 2000; Hairiah and Sitompul 2000; Slik et al. 2010). Biomass densities of old-growth forests of Philippines showed a range of 446 to 1126 Mg $ha^{-1}$ (Lasco et al. 2000, 2002) and in Indonesia it was 500-700 Mg $ha^{-1}$ (Murdiyarso and Wasrin 1996; van Noordwijk et al. 2000, Hairiah and Sitompul 2000). The upper value of the AGB (373.19) in the present study is comparable with Dipterocarp forest of Mindanao, Philippines (406 Mg $ha^{-1}$) reported by Lasco et al. (2006).

*Dipterocarpus turbinatus* contributed 70-90 % (mean 124.43 ± 1.14 Mg $ha^{-1}$) of the total aboveground carbon in the present study. The value is found much higher than the study carried out by Ullah and Al-Amin (2012) in a natural forest of Bangladesh where *Dipterocarpus turbinatus* contributed 70.80 Mg $ha^{-1}$ AGB and 39.48 Mg $ha^{-1}$ AGC. Alamgir and Al-Amin (2007) reported that the same species contributed 7.9 Mg $ha^{-1}$ AGB in a mixed Dipterocarp forest of Chittagong forest division, Bangladesh.

Comparing the AGC stocks among the studied forest, Site III contain comparatively less AGC stock than the other sites. It is due to the ongoing anthropogenic disturbances such as illegal felling, collection of fire-wood, cattle grazing etc which were evident during the study period. Extensive and frequent removal of the tree species lead to lower tree density and basal area, and it results low AGC in the forest site. Though the Site I reveals less tree density, the site has highest AGC stock. The presence of large *Dipterocarpus turbinatus* trees results in higher basal area than at the other sites. Slik et al. (2010) reported that the AGC is positively correlated only with basal area. In the present study also a positive and significant correlation ($r = 0.92$, $P < 0.01$) was recorded between AGC and basal area. The lower tree

Table 3. Physico-chemical properties of soil in different Dipterocarpus forest sites in Karimganj district, Assam, northeast India

| Location | Soil Depth (cm) | Soil Colour | Soil Texture Sand (%) | Silt (%) | Clay (%) | Textural Class | Bulk Density (g cm$^{-3}$) | SOC (%) | SOC (Mg ha$^{-1}$) | Total SOC (0-100 cm) (Mg ha$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|
| Site I | | | | | | | | | | |
| | 0-30 | Yellowish Brown | 55.23 | 17.37 | 27.40 | Sandy clay loam | 1.36 | 1.40 | 57.00 | 141.13 |
| | 30-60 | Yellowish Brown | 52.10 | 17.30 | 30.60 | Sandy clay loam | 1.32 | 0.97 | 38.40 | |
| | 60-100 | Yellowish Brown | 48.07 | 16.33 | 35.60 | Sandy clay loam | 1.38 | 0.83 | 45.73 | |
| Site II | | | | | | | | | | |
| | 0-30 | Brownish yellow | 20.43 | 46.70 | 32.87 | Silty clay loam | 1.3 | 0.91 | 35.67 | 91.40 |
| | 30-60 | Reddish yellow | 19.00 | 40.70 | 40.30 | Silty clay | 1.32 | 0.67 | 26.40 | |
| | 60-100 | Reddish yellow | 14.07 | 38.63 | 47.30 | Clay | 1.23 | 0.60 | 29.32 | |
| Site III | | | | | | | | | | |
| | 0-30 | Dark yellowish brown | 13.23 | 53.67 | 33.10 | Silty clay loam | 1.40 | 1.08 | 45.55 | 125.43 |
| | 30-60 | Yellowish Brown | 10.90 | 53.67 | 35.43 | Silty clay loam | 1.46 | 0.90 | 39.59 | |
| | 60-100 | Strong brown | 8.23 | 59.67 | 32.10 | Silty clay loam | 1.47 | 0.69 | 40.29 | |
| Site IV | | | | | | | | | | |
| | 0-30 | Yellowish Brown | 54.50 | 24.90 | 20.60 | Sandy clay loam | 1.52 | 1.10 | 49.96 | 115.80 |
| | 30-60 | Yellowish Brown | 46.87 | 23.23 | 29.90 | Sandy clay loam | 1.55 | 0.63 | 29.12 | |
| | 60-100 | Yellowish Brown | 51.87 | 24.43 | 23.70 | Sandy clay loam | 1.42 | 0.65 | 36.72 | |

density in this site is due to low regeneration potential of the forest or the removal of young trees by nearby local people for fire-wood. It was seen that numbers of seedling and saplings of tree species were tampered during fire-wood collection. At the other two sites also more or less similar types of anthropogenic disturbances were seen during the survey period.

Recurrent human intervention for the collection of fuel-wood, fodder, litter, and minor forest products as well as grazing, browsing and trampling can substantially degrade species habitats (Pandey and Shukla 1999). Dipterocarp forests are very sensitive to habitat degradation (Aguilar et al. 2006). According to Aguilar et al. (2006) and Kettle (2010) there are a number of ecological reasons why Dipterocarp forests may be especially sensitive to habitat degradation and fragmentation. Briefly, many species have lower density of reproductive adults; they are insect pollinated and have poor seed dispersal, and recalcitrant seeds, traits which are likely to reduce the resilience of Dipterocarp forests to fragmentation. So, it is very important to protect these forests from different anthropogenic disturbances to proper management and conservation of Dipterocarp forests. *Dipterocarpus turbinatus* is recently included in the IUCN Red Data Book in critically endangered category having some characteristics features which make it very effective in carbon storage. It has the high wood density value i.e. 0.655 and doesn't fall or get blown over, often die standing, gradually losing their branches until only the trunk remains unlike African and the Amazon forests (Hossain and Nath 2002). Distribution of AGC in different girth classes is an important parameter for studying vegetation C stocks (Baishya et al. 2009). Tree girth size determines the carbon storage of a tree (Brown 1997, Brown et al. 1989). Clark and Clark (1996) revealed that the large trees (> 70 cm DBH) play an important role in carbon storage. They account 2% of large stems contributed 27% of AGB in a Neotropical lowland rainforest in La Selva, Costa Rica. Paoli et al. (2008) found that stem density for large tree (DBH >70 cm) to be up to three times higher in Borneo than Neotropics. Slik et al. (2010) found significant positive correlation among percentage of Dipterocarp trees in >70 cm DBH class with AGB. In the present study large trees (> 70 cm DBH classes) account around 34%, 2%, 10% and 1% of total stems in Site I, Site II, Site III and Site IV respectively. Site I occupied the highest AGC as large stem (> 70 cm DBH) contributes 54.4 % of total AGC although Site IV account around two times higher density than Site I. In Site III, 10 % of large stems contribute 33 % of the total AGC. Higher stem density (57 % of total stems) of large trees (> 210 cm gbh ≈ 67 cm DBH) also reported from undisturbed tropical wet evergreen forest of Namdapha National Park, Arunachal Pradesh, Northeast India (Nath et al. 2005). In sub-tropical humid forest of Meghalaya large tree (> 65 cm DBH) account 2-3 % of total stems (Tripathi et al. 2010) whereas Lu et al. (2010) account 3 % of large trees (> 70 cm DBH) in tropical seasonal rain forest in Xishuangbanna, South West China. Higher AGC in large stems found consistent to the earlier works (Brown and Lugo 1992; Brown et al. 1995; Baishya et al. 2009) 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 the smaller trees contribute to most AGB in forest which has less than 300 Mg $ha^{-1}$ AGB. In Site IV small size stems belong to 10-20 cm to 40-50 cm DBH classes (84.78 % of total stems) contributed 57.54 % of total AGB. Borah et al. (2013) also reported 50 % of the AGB and C stock contributed by smaller to medium size stems from tropical forest of Cachar district, northeast India. Smaller trees had the greater potential to accumulate significant quantities of biomass and thus sequestering more atmospheric carbon than the larger tree (Brown et al. 1997). In Site II middle size stems belong to 40-50 cm to 60-70 cm DBH classes grasp the maximum (87%) carbon and density (80 %) signifying the win-win condition in carbon storage and carbon sequestration. Lower AGB in higher DBH class as found in Site IV indicates the anthropogenic disturbances in the past (Brown 1996).

Soil organic carbon estimated average 118.44 Mg $ha^{-1}$ ranged from 91.40-141.13 Mg $ha^{-1}$ in top 1 meter soil depth. The projected SOC (47.04 Mg $ha^{-1}$) in surface layer (0-30 cm) found likely to be similar with the other Dipterocarp forests (dominated by *Shorea robusta*) of India such as 47.29 Mg $ha^{-1}$ in Himachal Pradesh (Negi and Gupta 2010), 58.45 Mg $ha^{-1}$ in Uttarakhand (Negi et al. 2013), 60.07 Mg $ha^{-1}$ in Garhwal Himalayas (Gupta and Sharma 2011). Chhabra et al. (2003) nationwide estimated the mean soil organic carbon density for top 1 meter depth 138.9 Mg $ha^{-1}$ in tropical evergreen forests and 111.6 Mg $ha^{-1}$ in tropical moist deciduous forests. Jha et al. (2003) estimated soil organic carbon in total forest soils under 19 species spread over 27 States and Union Territories in India. They estimated *Dipterocarpus macrocarpus* forests have 0.82 million Mg SOC stored (120.59 Mg $ha^{-1}$) in 0.0068 Mha area. Recently Choudhury et al. (2013) estimated spatially 62.83 % soils of Assam had 1.0–1.5 % SOC content in surface layer (0-15 cm) and 65.31 % of geographic area content 20-30 Mg $ha^{-1}$ whereas in the present study percentage of SOC was found 0.90-1.40 % in top 0-30 cm soil layer. They estimated mean soil bulk density for Assam to be 1.24 g $cm^{-3}$ while in the present study it was 1.39 g $cm^{-3}$. Thapa et al. (2011) reported that the percentage of SOC from top 0-20 cm was 0.88 and 1.05 in natural and plantation forests of *Shorea robusta* (one of the dominant species of the family Dipterocarpaceae) respectively in tropical forests of Meghalaya. In the present study SOC contributed 36.84-60.84 % of total forest carbon similar with the study done by Lasco et al. (2006) in Dipterocarp forests of Philippines where SOC contributed 31–52 % of total carbon stock. Soil organic carbon was recorded high in the top layer and decreased with increasing depth in agreement to the other similar studies (Ullah and Al-Amin 2012, Dinakaran and Krishnayya 2010). In different soil depth SOC found non-significance ($p = 0.051$, $p > 0.05$) at 0.05 level displaying the importance of deeper layer. Higher soil organic carbon in top layer may be due to the rapid decomposition of forest litter in the favourable environment. Low SOC in Site II may be because of timber extraction, frequent forest fire and excessive cattle grazing. Shin et al. (2007) stated that due to the over-extraction of forest resources and forest land encroachment soil carbon reduces fast. Paul (1984) stated that soil texture plays an important role in carbon stock, increasing clay content generally decreases carbon outputs through its stabilizing effect on soil organic carbon which was reflected in the present study.

## CONCLUSIONS

It may be concluded that Dipterocarp forests dominated by *Dipterocarpus turbinatus*, can store good amount of carbon in its biomass and soil. But, these forests are under huge anthropogenic pressure. Conservation of these forests will help in maintaining the local as well as regional carbon cycle. In the present study, Site I is mainly carbon storing patch and Site IV has the highest potential to sequester carbon in the near future as these forests contain significant numbers of young trees. Conservation of the present study sites may be fruitful for mitigation of climate change as well as conservation of *Dipterocarpus turbinatus* - the critically endangered species. It is important to identify such Diperocarp forest stands for carbon conservation in northeast India and elsewhere in the Southeast Asia.

## ACKNOWLEDGEMENTS

We thank Botanical Survey of India, Shillong for species identification. We gratefully acknowledge the Regional Agricultural Research Station of Assam Agricultural University at Akbarpur, Karimganj district, Assam for providing the meteorological data. D. Rabha thanks the Ministry of Tribal Affairs, Govt of India, for financial assistance under the Rajiv Gandhi National Fellowship scheme to carry out the study. We are also thankful to the Indian Institute of Remote Sensing (IIRS), Dehradun, Indian Space Research Organisation (ISRO), Govt. of India for research grant and Senior Research Fellowship (SRF) to NB, and to the forest department of Karimganj district for permission and support during the field work.

## REFERENCES

Aguilar, R.; Ashworth, L.; Galetto, L. and Aizen, M.A. 2006. Plant reproductive and susceptibility to habitat fragmentation: review and synthesis through a meta-analysis. Ecological Letters 9: 968-980.

Alamgir, M. and Al-Amin, M. 2007. Organic carbon storage in trees within different Geopositions of Chittagong (South) forest division, Bangladesh. Journal of Forestry Research 18 (3): 174-180.

Baishya, R.; Barik, S.K. and Upadhaya, K. 2009. Distribution pattern of aboveground biomass in natural and plantation forests of humid tropics in Northeast India. Tropical Ecology 50 (2): 295-304.

Batjes, N.H. 1996. Total carbon and nitrogen in the soils of the world. European Journal of Soil Science 47: 151- 163.

Bawa, K.S. 1998. Conservation of genetic resources in the Dipterocarpaceae. Pages 45–56, In: Appanah, S. and Turnbull, J.M. (Editors), A Review of Dipterocarps, Taxonomy, Ecology and Silviculture. Bogor, Indonesia: CIFOR.

Birdsey, R.A. and Heath, L.S. 2001. Forest inventory data, models and assumption for monitoring carbon flux. Soil carbon sequestration and the greenhouse effects. SSSA special publication no 57. Soil Science Society of America. Madison, WI.

Borah, N.; Nath, A.J. and Das, A.K. 2013. Aboveground biomass and carbon stocks of tree species in tropical forests of Cachar district, Assam, Northeast India. International Journal of Ecology and Environmental Sciences 39 (2): 97-106.

Borah, N. 2012. Community structure, tree regeneration and utilization of forest resources in Cachar and Hailakandi districts of Assam, India. Ph.D. Thesis, Assam University, Silchar, Assam, India.

Bouyoucos, G.H. 1962. Hydrometer method improved for making particle size analyses of soils. Agronomy Journal 54: 464-465.

Brady, N.C. and Weil, R.R. 2008. The Nature and Properties of Soils. Pearson Education, New Jersey. 975 pages.

Brown, I.F.; Martinelli, L.A.; Thomas, W.W.; Moreira, M.Z.; Ferreira, C.A.C. and Victoria, R.A. 1995. Uncertainty in the biomass of Amazonian forests: an example from Rondonia, Brazil. Forest Ecology and Management 75: 175-189.

Brown, S. and Lugo, A.E. 1982. The storage and production of organic matter in tropical forests and their role in the global carbon cycle. Biotropica 14: 161-187.

Brown, S. and Lugo, A.E. 1992. Aboveground biomass estimates for tropical moist forests of the Brazilian Amazon. Interciencia 17: 8-18.

Brown, S.; Gillespie, A.J.R. and Lugo, A.E. 1989. Biomass estimation methods for tropical forests with applications to forest inventory data. Forest Science 35 (4): 881-902.

Brown, S.; Schroeder, P. and Birdsey, R. 1997. Aboveground biomass distribution of US eastern hardwood forests and the use of large trees as an indicator of forest development. Forest Ecology and Management 96: 37-47.

Brown, S. 1996. Tropical forests and the global carbon cycle: estimating state and change in biomass density. Pages 135-144, In: Apps, M.J. and Price, D.T. (Editors) Forest Ecosystems, Forest Management and the Global Carbon Cycle. NATO ASI Series, Springer-Verlag.

Brown, S. 1997. Estimating Biomass and Biomass Change of Tropical Forests: A Primer. FAO forestry paper 134, Food and Agriculture Organization, Rome. 55 pages.

Brown, S.L.; Schroeder, P. and Kern, J.S. 1999. Spatial distribution of biomass in forests of the eastern USA. Forest Ecology and Management 123: 81-90.

Champion, H.G. and Seth, S.K. 1968. A Revised Survey of the Forest Types of India. Govt. of India publications, New Delhi. 404 pages.

Chatterjee, S.; Saikia, A.; Dutta, P; Ghosh, D. and Worah, S. 2006. Review of Biodiversity in Northeast India. WWF-India, Delhi, India. 45 pages.

Chhabra, A.; Palria, S. and Dadhwal, V.K. 2003. Soil organic carbon pool in Indian forests. Forest Ecology and Management 173: 187-199.

Choudhury, B.U.; Mohapatra, K.P.; Das, A.; Das, P.T.; Nongkhlaw, L.; Fiyaz, R.A.; Ngachan, S.V.; Hazarika, S.; Rajkhowa, D.J. and Munda, G.C. 2013. Spatial variability in distribution of organic carbon stocks in the soils of North East India. Current Science 104 (5): 604-614.

Clark, D.B. and Clark, D.A. 1996. Abundance, growth and mortality of very large trees in Neotropical lowland rainforest. Forest Ecology and Management 80: 235–244.

Corlett, R. and Primack, R. 2005. Dipterocarps: Trees that dominate the Asian rainforest. Arnoldia 63: 2–7.

Devagiri, G.M.; Money, S.; Singh, S.; Dadhwal, V.K.; Patil, P.; Khaple, A.; Devakumr, A.S. and Hubballi, S. 2013. Assessment of above ground biomass and carbon pool in different vegetation types of south western part of Karnataka, India using spectral modeling. Tropical Ecology 54 (2): 149-165.

Devi, L.S. and Yadava, P.S. 2009. Aboveground biomass and net primary production of semi-evergreen tropical forest of Manipur, North-Eastern India. Journal of Forestry Research 20 (2): 151–155.

Dinakaran, J. and Krishnayya, N.S.R. 2010. Variations in soil organic carbon and litter decomposition across different tropical vegetation covers. Current Science 99 (8): 1051-1060.

FRI (Forest Research Institute). 1996. Indian Woods. Volume I-VI. Forest Research Institute, Ministry of Environment and Forests, Dehra Dun, India. 249 pages.

FSI (Forest Survey of India). 1996. Volume Equations for Forests of India, Nepal and Bhutan. Forest Survey of India, Ministry of Environment and Forests, Government of India, Dehradun.

Gupta, M.K. and Sharma, S.D. 2011. Sequestrated carbon: organic carbon pool in the soils under different forest covers and land uses in Garhwal Himalayan region of India. International Journal of Agriculture and Forestry 1 (1): 14-20.

Hairiah, K.M. and Sitompul, S.M. 2000. Assessment and simulation of above-ground and below-ground C stocks and dynamics. Science- Policy Workshop on Terrestrial Carbon Assessment for Possible Carbon Trading. Bogor, Indonesia.

Hossain, M.K. and Nath, T.K. 2002. *Dipterocarpus turbinatus* Gaertn. Pages 443-445, In: Tropical Tree Seed Manual, Part II-Species Description. Reforestatiom, Nurseries and Genetic Resources. (http://www.rngr.net/publications/ttsm/species).

Houghton, R.A. 1996. Terrestrial sources and sinks of carbon inferred from terrestrial data. Tellus 48: 420–432.

Hudson, J.M.; Gherini, S.A. and Goldstein, R.A. 1994. Modeling the global carbon cycle: nitrogen fertilization of the terrestrial biosphere and the "missing" $CO_2$ sink. Global Biogeochemical Cycles 8: 307-333.

IUCN (International Union for Conservation of Nature). 2013. IUCN 2013, IUCN Red List of Threatened Species. Version 2013.1. Available at: http://www.iucnredlist.org/.

Jha, M.N.; Gupta, M.K.; Saxena, A. and Kumar, R. 2003. Soil Organic Carbon Store in different forests of India. Indian Forester 129 (6): 714-724.

Joao Carlos de, M.S.; Carlos, C.C.; Warren, A.D.; Rattan, L.; Solismar, P.; Venske, F.; Marisa, C.P. and Brigitte, E.F. 2001. Organic matter dynamics and carbon sequestration rates for a tillage chronosequence in a Brazilian Oxisol. Soil Science Society of America Journal 65: 1486–1499.

Kawahara, T.; Kanazama, Y. and Sakurai, S. 1981. Biomass and net production of the man-made forests in Philippines. Journal of Japanese Forestry Society 63 (9): 320–327.

Ketterings, Q.M.; Coe, R.; van Noordwijk, M.; Ambagau, Y. and Palm, C.A. 2001. Reducing uncertainty in the use of allometric biomass equations for predicting above-ground tree biomass in mixed secondary forests. Forest Ecology and Management 146: 199-209.

Kettle, C.J. 2010. Ecological considerations for using dipterocarps for restoration of lowland rainforests in Southeast Asia. Biodiversity and Conservation 19: 1137-1151.

Lasco, R.D.; Macdicken, K.G.; Pulhin, F.B.; Guillermo, I.Q.; Sales, R.F. and Cruz, R.V.O. 2006. Carbon stocks assessment of a selectively logged dipterocarp forest and wood processing mill in the Philippines. Journal of Tropical Forest Science 18: 212–221.

Lasco, R.D.; Pulhin, F.B.; Visco, R.G.; Racelis, D.A.; Guillermo, I.Q. and Sales, R.F. 2000. Carbon stocks assessment of Philippine forest ecosystems. Science-Policy Workshop on Terrestrial Carbon Assessment for Possible Carbon Trading. Bogor, Indonesia.

Lasco, R.D. 2002. Forest carbon budgets in Southeast Asia following harvesting and land cover change. Science in China Series C: Life Science 45: 55–64.

Lu, X.T.; Yin, J.X. and Tang, J.W. 2010. Structure, tree species diversity and composition of tropical seasonal rainforests in Xishuangbanna, South-west China. Journal of Tropical Forest Science 22 (3): 260–270.

Montagnini, F. and Porras, C. 1998. Evaluating the role of plantations as carbon sink: an example of an integrative approach the humid tropics. Environmental Management 22 (3): 459-470.

Murdiyarso, D. and Wasrin, U.R. 1996. Estimating land use change and carbon release from tropical forests conversion using remote sensing technique. Journal of Biogeography 22: 715–721.

Nath, P.C.; Arunachalam, A.; Khan, M.L.; Arunachalam, K. and Barbhuiya, A.R. 2005. Vegetation analysis and tree population structure of tropical wet evergreen forests in and around Namdapha National Park, Northeast India. Biodiversity and Conservation 14: 2109-2136.

Negi, S.S. and Gupta, M.K. 2010. Soil organic carbon store under different land use systems in Giri catchment of Himachal Pradesh. Indian Forester 136 (9): 1147-1154.

Negi, S.S.; Gupta, M.K. and Sharma, S.D. 2013. Sequestered organic carbon pool in the forest soils of Uttarakhand State, India. International Journal of Science, Environment and Technology 2 (3): 510-520.

Ogawa, H.; Yoda, K.; Ogino, K. and Kira, T. 1965. Comparative ecological studies on three main types of forest vegetation in Thailand, II, Plant Biomass. Nature and Life in Southeast Asia 4: 49-80.

Pandey, S.K. and Shukla, R.P. 1999. Plant diversity and community patterns along the disturbance gradient in plantation forests of sal (*Shorea robusta* Gaertn.). Current Science 77 (6): 814-818.

Paoli, G.D.; Curran, L.M. and Slik, J.W.F. 2008. Soil nutrients affect spatial patterns of aboveground biomass and emergent tree density in southwestern Borneo. Oecologia 155: 287–299.

Paul, E.A. 1984. Dynamics of organic matter in soils. Plant and Soil 76:275-285.

Pinard, M.A. and Putz, F.E. 1996. Retaining forest biomass by reducing logging damage. Biotropica 28: 278-295.

RARS (Regional Agricultural Research Station). 2013. Agromet Advisory Service, Regional Agricultural Research Station. Akbarpur, Karimganj, Assam.

Ravindranath, N.H.; Somashekhar, B.S. and Gadgil, M. 1997. Carbon flow in Indian forests. Climate Change 35: 297-320.

Saatchi, S.S.; Harris, N.L.; Brown, S.; Lefsky, M.; Mitchard, E.T.A.; Salas, W.; Zutta, B.R.; Buermann, W.; Lewis, S.L.; Hagen, S.; Petrova, S.; White, L.; Silman, M. and More, A. 2011. Benchmark map of forest carbon stocks in tropical regions across three continents. Proceedings of the National Academy of Sciences, USA 108: 9899–9904.

Shin, M.Y.; Miah, M.D. and Lee, K.H. 2007. Potential contribution of the forestry sector in Bangladesh to carbon sequestration. Journal of Environmental Management 82: 260–276.

Singh, S. and Dadhwal, V.K. 2009. Manual on Spatial Assessment of Vegetation Carbon Pool of India. Indian Institute of Remote

Sensing, ISRO, Department of Spage, Govt. of India, Dehradun. 32 Pages.

Slik, J.W.F.; Aiba, S.I.; Brearley, F.Q.; Cannon, C.H.; Forshed, O.; Kitayama, K.; Nagamasu, H.; Nilus, R.; Payne, J.; Paoli, G.; Poulsen, A.D.; Raes, N.; Sheil, D.; Sidiyasa, K.; Suzuki, E. and van Valkenburg, J.L.C.H. 2010. Environmental correlates of tree biomass, basal area, wood specific gravity and stem density gradients in Borneo's tropical forests. Global Ecology and Biogeography 19: 50–60.

Thapa, N.; Upadhaya, K.; Baishya, R. and Barik, S.K. 2011. Effect of plantation on plant diversity and soil status of tropical ecosystems in Meghalaya, Northeast India. International Journal of Ecology and Environmental Sciences 37 (1): 61-73.

Thokchom, A. and Yadava, P.S. 2013. Biomass and carbon stock assessment in the sub-tropical forests of Manipur, North East India. International Journal of Ecology and Environmental Sciences 39 (2): 107-113.

Tripathi, O.P.; Upadhaya, K.; Tripathi, R.S. and Pandey, H.N. 2010. Diversity, dominance and population structure of tree species along fragment- size gradient of a subtropical humid forest of North East India. Research Journal of Environmental and Earth Sciences 2 (2): 97-105.

Ullah, M.R. and Al-Amin, M. 2012. Above- and below-ground carbon stock estimation in a natural forest of Bangladesh. Journal of Forest Science 58 (8): 372–379.

van Noordwijk, M.; Hairiah, K.M. and Sitompul, S.M. 2000. Reducing uncertainties in the assessment at national scale of C stock impacts of land use change. Pages 150-163, In: Magcale-Macandog, D.B. (Editor) Proceedings of the IGES/NIES Workshop on GHG Inventories for Asia-Pacific Region. IGES, Hayama, Japan.

Walkley, A. and Black, I.A. 1934. An examination of Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science 37: 29–38.

Wani, N.; Velmurugan, A. and Dadhwal, V.K. 2010. Assessment of agricultural crop and soil carbon pools in Madhya Pradesh, India. Tropical Ecology 51: 11-19.

*Received 4 February 2014;*
*Accepted 22 March 2014*

Appendix 1. Volume equations and specific gravity used in the present study (FSI, 1996)

| Species Name | Volume equation | Specific gravity |
|---|---|---|
| *Artocarpus chama* Buch.-Ham. | $V=1.65081-4.57531\sqrt{D}+11.62114D^2$ | 0.447 |
| *Bombax ceiba* L. | $V= 0.0589+0.000956D^2$ (dia. In cm.) | 0.329 |
| *Callicarpa arborea* Roxb. | $\sqrt{V}=-0.04506+2.233446D$ | 0.557 |
| *Carallia branchiata* (Lour.) Merr. | $V=0.11079-1.81103D+11.4132D^2+0.38528D^3$ | 0.624 |
| *Caryota urena* L. | $V=0.11079-1.81103D+11.4132D^2+0.38528D^3$ | 0.557 |
| *Chukrasia tabularis* A. Juss | $V=-0.07559+9.23051D^2$ | 0.560 |
| *Cinnamomum glaucescens* (Nees) Hand-Mazz. | $V=0.14885-1.62875D+5.93114D^2+11.73286D^3$ | 0.444 |
| *Cordia dichotoma* Forst. F. | $V=-0.49388+7.56417D- 31.45373D^2 + 50.93877D^3$ | 0.733 |
| *Dillenia indica* L. | $\sqrt{V}=0.05376+3.73731D-0.79622\sqrt{D}$ | 0.531 |
| *Dipterocarpus turbinatus* Gaertn. | $\sqrt{V}=-0.4464+3.6062D$ | 0.655* |
| *Dysoxylum binectariferum* (Roxb.) Hook.f. | $V=-0.04752+0.50667D+1.88433D^2+11.30632D^3$ | 0.581 |
| *Elaeagnus* sp | $V=0.11079-1.81103D+11.4132D^2+0.38528D^3$ | 0.557 |
| *Ficus racemosa* L. | $\sqrt{v}V= 0.03629+3.95389D-0.84421\sqrt{D}$ | 0.385 |
| *Grewia nervosa* (Lour.) Panigr. | $V=-0.44075+7.49221D-36.099962D^2+71.91238D^3$ | 0.675 |
| *Litsea monopetala* (Roxb.) Pers. | $V=0.11079-1.81103D+11.4132D^2+0.38528D^3$ | 0.557 |
| *Mesua ferrea* L. | $V=0.09252-1.95124D+13.51055D^2$ | 0.809 |
| *Mesua floribunda* Forst. f. | $V=0.11079-1.81103D+11.4132D^2+0.38528D^3$ | 0.665 |
| *Michelia champaca* L. | $\sqrt{V}=0.37142+5.64184D-2.27448 \sqrt{D}$ | 0.442 |
| *Mitragyna rotundifolia* (Roxb.) O.Kuntze | $V=0.11079-1.81103D+11.4132D^2+0.38528D^3$ | 0.581 |
| *Schima wallichii* (DC) Kuntze | $V=0.27609-3.68443D+15.86687D^2$ | 0.539 |
| *Semecarpus anacardium* L. | $\sqrt{V}=1.67477+14.83747D-9.43386\sqrt{D}$ | 0.557 |
| *Spondias pinnata* (L.f.)Kurz | $\sqrt{V}= 0.49487+6.18662D-2.95076\sqrt{D}$ | 0.368 |
| *Sterculia villosa* Roxb. | $V= 0.27909-3.26515D+13.46829D^2$ | 0.428 |
| *Stereospermum personatum* (Hassk) Chatterjee | $V=1.38791-12.52739D+30.51466D^2-9.65242D^3$ | 0.637 |
| *Syzygium syzygioides* (Miq.) Merr. | $V=-0.13284+1.88944D-4.96385D^2+21.41051D^3$ | 0.678 |
| *Tectona grandis* L. f. | $V=0.19112-3.25372D+17.9194 D^2-1.66117D^3$ | 0.568 |
| *Terminalia bellirica* (Gatertn.) Roxb. | $V=0.26454-3.05249D+12.35740D^2$ | 0.605 |
| *Tetrameles nudiflora* R.Br. | $V/D^2= 0.12914/D2-2.50478/D+15.25108$ | 0.289 |
| *Vitex peduncularis* Wall. ex Schauer. | $V=-0.16386+2.23116D-7.00969D^2+22.13099D^3$ | 0.771 |
| *Vitex altissima* L.f. | V=-0.16386+2.23116D-7.00969D2+22.13099D3 | 0.771 |

D = diameter at breast height in m where not mentioned, * (Hossain and Nath 2002)