BIOMASS AND BIOENERGY 78 (2015) 25–35

Available online at www.sciencedirect.com

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Tree species composition, biomass and carbon stocks in two tropical forest of Assam

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ARTICLE INFO

Article history:
Received 16 May 2014
Received in revised form
4 April 2015
Accepted 8 April 2015
Available online

Keywords:
Forest
Habitats
Diversity index
Allometric equation
Biomass
Carbon

ABSTRACT

Tropical forests store higher above ground biomass (AGB) and AGB carbon (AGBC) than any other forest ecosystems. In the present study the tree composition, diversity, dominance and carbon stocks in the AGB and soil of tropical forests *viz.*, the Gibbon wildlife sanctuary (GWS) and the Kholahat reserve forest (KRF) of Assam, India were assessed. Soil sampling, tree survey, girth above 1.3 m height of plants >10 cm girth of plants were assessed in 1000 m^2 quadrate. Allometric model for moist forest stands was used to determine AGB and AGBC. A total of 71 and 108 different tree species belong to 32 and 42 families were found in the GWS and KRF, respectively. In the GWF, the Shannon diversity index (1.22) and the Simpson index (0.085) were significant, while for the KRF these indices were insignificant. The basal area, AGB and AGBC in the GWS and KRF were 62.49–90.29 $m^2\ ha^{-1}$, 135.30–146.42 Mg ha^{-1}, and 67.64–73.21 Mg ha^{-1}, respectively. The average soil carbon stock (SOC) in the upper, middle and lower layers was 57.74–78.44 kg m^{-2}, 39.22–64.93 kg m^{-2} and 30.32–42.86 kg m^{-2}, respectively, in the GWS and KRF. However, compared to GWS, a higher AGB and AGBC were found in KRF. This finding reveals that the higher AGB, AGBC and SOC in the KRF were due to old growth matured forest with big and diverse tree species.

1. Introduction

Forest ecosystems and their soils are major sinks of atmospheric carbon [1–4] and thus influence of forest in the global carbon cycle is now well recognized [5–7]. Forest vegetation captures atmospheric CO_2 through photosynthesis and stores it in their above and below ground biomass and in soil [8,9]. It has also been reported that the world's forest ecosystems are estimated to store more carbon than the entire atmosphere [5]. Interestingly, out of the various forest habitats, tropical forests store an estimated 350 Pg of carbon in their AGB that is more than any other biome [3]. As a result, there have been increased and continued efforts in the past to estimate carbon stocks in forest ecosystems and related anthropogenic activities that influence the alteration of the carbon cycle [5,6,10,11]. Studies also report that tropical forest carbon stocks are currently declining with losses due to deforestation and habitat degradation [11]. In addition, carbon stocks in intact old growth forests may be increasingly effected due to

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http://dx.doi.org/10.1016/j.biombioe.2015.04.007

global environmental changes [12,13]. Thus, an accurate characterization of AGBC in tropical forest is utmost importance to estimate their contribution to global carbon stocks.

Although, carbon monitoring techniques have been improved recently in several aspects, including the development of generalized tree allometry theory [14] and the assembly of global wood density databases [15], uncertainty remains regarding their quantitative contribution to the global carbon cycle. One approach to quantifying carbon biomass stores consists of inferring changes from long-term forest inventory plots for which regression models are used to convert inventory data into an estimate of AGB [14]. The most common method for estimating tree biomass is through the use of regression analysis. Equations are developed by weighing entire trees or their components and relating the weight to easily measured tree dimensions, such as the diameter at breast height (dbh) and height [15]. Similar to AGBC, soil carbon is also an important determinant for its role in maintaining soil physical and chemical properties. Moreover, soil stores 2–3 times more carbon than the atmosphere in the form of CO_2 and 2.5–3.0 times more than terrestrial plants [16]. It has also been predicted that the majority of carbon in the terrestrial pool is stored below ground in soils and that the total global carbon in soils constitutes between 1.5 Eg and 2.0 Eg. However, due to the myriad human pressures on tropical forest ecosystems, the assessment AGB and SOC has gained importance. Moreover, the degradation of tropical forest in developing countries is enormous and base line data is yet to be established which show uncertainty regarding the contribution of large amount of carbon to the global carbon cycle.

Assam, in the northeastern (NE) part of India, is a part of the Indo-Burma mega biodiversity hotspot [17]. The forest types occurring in the state are tropical wet evergreen, tropical semi-evergreen, tropical moist deciduous, subtropical broadleaf hill, subtropical pine, littoral and swamp forests and grasslands and savanna [18]. Though there are a few referred publications on forest areas of Assam [19–23] however, information related to nature of forest, AGBC and SOC stocks are scanty under different forest habitats. In order to fill up this gap, it is necessary to assess representative forests in respect of characteristics and role in maintaining the environment. In this study, comparative tree diversity, basal area and carbon stocks in two forest areas of Assam, *i.e.*, the GWS and KRF including their nature were assessed.

2. Materials and methods

2.1. Study area

The GWS under the Jorhat district and the KRF under the Nagaon district of Assam, India were selected for the study. The GWS, formerly known as the Hollongapar Reserve Forest, is an isolated and protected area of evergreen forest patches located in eastern Assam and Created in 1881, the GWS was officially named in 1997. Previously, the sanctuary was named after Hollong (*Dipterocarpus macrocarpus*), a species of trees found abundantly in the reserve, but was renamed in 1997 as the GWS. In the early 20th century, a well-stocked secondary forest was developed that resulted in rich biodiversity at the site. The GWS lies between 26°40′-26°45′ N latitude and 94°20′-94°25′ E longitude at an elevation of 100–120 m above msl. The KRF lies between 26°07′-24°6′ N latitude and 92°26′20.3–94°25′ E longitude at an elevation of 250–270 m above msl. The climate of the region can be divided into four seasons: pre-monsoon (March–April), monsoon (May to September), retreating monsoon (October to November) and winter (December to February) [24]. The average temperature and humidity in both the place were within 18.95 °C–27.9 °C and 64.5% and 94.5%, respectively.

2.2. Survey of the tree species

Vegetation classification of the study area has been prepared from Cloud free IRS 1D LISS III imagery of December, 2008. Visual interpretation techniques were employed to delineate various land cover and vegetation features from the False Colour Composite (FCC) of band 2, 3 and 4 combinations of the satellite data. Geographic Information System (GIS) using Arc GIS 9.3 software was used for forest classification, based on which an inventory of the trees was prepared along transects oriented in a north-south direction and measured by a handheld GPS unit with accuracy of 10 m (GPSMAP 60 CSx, Garmin, USA). Based on the forest habitats determined from GIS, tree inventory were done in 0.1-ha plots quadrates in each habitat. In each plot, trees of >10 cm in diameter at breast height (breast height = 1.3 m) was measured, identified to the species level, and their diameters were measured to the nearest centimetre (using dbh tapes) for further analysis. When a bole irregularity was observed at 1.3 m, the measurement was taken 10 cm above the irregularity. To avoid edge effects, the quadrate was established 30 m inside of the plot. Entire survey was done during 2010 and 2011 in winter season and ten quadrates were taken into consideration.

2.3. Determination of plant diversity

Shannon Weaver diversity [25] was calculated as follows:

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

where, p_i is the proportion of individuals of ith species out of all of the individuals.

The concentration of dominance was calculated following Simpson [26] as follows:

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

where, p_i is the proportion of individuals of ith species out of all the individuals.

2.4. Determination of tree basal area

Eq. (3) was used to determine tree basal area.

$$\text{Basal Area (dbh in cm)} = 0.00007854 \times \text{dbh}^2 \quad (3)$$

2.5. Wood density estimation

Species-specific wood density was obtained from the global wood density database [27]. Furthermore, for species that lacked species-level wood density values, genus-level averages were used instead.

2.6. Determination of aboveground biomass

Allometric model proposed by Chave et al. [14] was used for estimation of AGB for moist forest stands because the mean annual precipitation of the selected sites is between 1500 and 3000 mm.

$$AGB = 0.0509 * \rho * D^2 * H \quad (4)$$

where dbh is diameter at breast height, H is the total height, and ρ is the density of the tree species.

2.7. Determination of aboveground biomass carbon

The AGBC stock was calculated that by assuming that the carbon mass fraction of the dry wood is 50% of the total AGB [28].

3. Soil organic carbon

SOC was estimated from each location by placing three quardrates tree quadrates were placed [13]. Soil core samples were taken from both the forests. In each plot, three 1-m deep soil pits were excavated, each located 10 m away from the middle of the plot. Soil cores (100 cm^3) were inserted horizontally down to 1 m depth, and sub-samples were taken from 3 different layers (0–30, 30–60, and 60–100 cm) using standard soil corers (n = 270). Three replicates of each layer in each plot were pooled for subsequent soil analyses to account for site variability. Damp soil samples were laid out to dry in trays inside a well-ventilated room to dry until the sample weight became constant (taking approximately 5 days to 1 week depending on the initial conditions of the samples). Rocks were separated from each sample, and their weight and volume was determined using the water displacement method for rocks. Bulk density was derived from the following equation:

$$BD = (MS - MR)/(VS - VR) \quad (5)$$

where, BD is bulk density (kg m^{-3}), MS is the mass of the dry soil (g), MR is the mass of rocks (g), VS is the volume of dry soil (cm^3) and VR is the volume of rocks (cm^3). Samples were further ground in a porcelain mortar and pestle to pass through a 2.0 mm sieve. Carbon content was determined by a wet chemical analysis method described by Walkley-Black [29]. Total soil organic carbon stocks in each layer were determined by Eq. 5 [30], where C is organic carbon concentration, T is the layer thickness (m), BD is the bulk density (kg m^{-3}), CF is a coefficient to discount coarse fragments (applicable for stony soil samples; not the case of the samples in this study, hence CF = 1) and 10 kg m^2.

$$SOC = C \times T \times BD \times CF \times 10 \quad (6)$$

4. Statistical analysis

All the data were normalized for conducting parametric tests. It was hypothesised that AGB has positive relationship with the basal area and diversity as per Pearson correlation coefficient Student t-test was performed to determine significant difference between soil parameters at $p < 0.05$. All analyses were performed with SPSS 13.0.

5. Results and discussion

The GWS occupies an area of 2072.6 ha with six forest types while KRF occupies an area of 17855.2 ha with 15 forest habitats (Table 1). In the GWS, 38% area was occupied by open evergreen/semi-evergreen dense forest, 29.8% by evergreen/semi-evergreen open forest while only 0.2% was occupied by wetlands. Most of the vegetation within the GWS is evergreen in nature and composed of several canopy layers. The upper canopy of the forest is dominated by the Hollong tree (*Dipterocarpus macrocarpus*), growing up to 12–30 m of height with straight trunks, while the Nahor (*Mesua ferrea*) dominates the middle canopy. The lower canopy consists of evergreen shrubs and herbs. It receives >2940 mm average rainfall per year. In the KRF, 38% of total area is occupied by Forest-Deciduous (Moist)-Dense/Closed, 31.8% agricultural land followed by 16.1% with open evergreen/semi-evergreen dense forest, 29.8% evergreen/semi-evergreen open forest while only 0.2% was of wetlands. KRF receives >1530 mm average rainfall per year, and the predominant vegetation type is deciduous, moist forest.

Descriptions of various plant species which belong to different families, BA and DBH is described in Table 2. In the case of the GWS, of the 71 recorded tree species, 12% tree species belong to the Moraceae and this family was dominant followed by Anacardiaceae (9%), Euphorbiaceae (7%), Magnoliaceae (6%), Clusiaceae, Dipterocarpaceae and Meliaceae (5%), and rest were <5%. Similarly, in the KRF, out of 108 recorded tree species, Lauraceae was 9% followed by Fabaceae (7%), Malvaceae and Meliaceae (6%), Moraceae and Bursearaceae (5%) while others occupy < 5%. A summary of number of tree, diversity in the GWS and in the KRF of Assam is described in Table 4. The tree density in the present study (286.92 − 416.25 trees ha^{-1}) is less than that reported study for several tropical forests (550–1800 trees ha^{-1}) [31,32]. Instead, the presence of 24–53 families, 20–467 numbers of trees were reported earlier for different tropical forest support the present findings [33]. Overall, a significantly ($p < 0.05$) higher aerial tree density (416.25 tree ha^{-1}) but lower basal area (62.49 m^2 ha^{-1}) were recorded in KRF compared to that in the GWS. Basal cover measured at the KRF (62.49 m^2 ha^{-1}) is similar to that of the lower montane forest (62 m^2 ha^{-1}) in Costa Rica [34]. In contrast to tree

Table 1 – Forest types and area covered by each forest habitats found in the Gibbon wild life sanctuary and Kholahat reserve forest of Assam.

Sl. No.	Forest habitat type	Area covered in each forest (ha)	
		Gibbon	Kholahat
1	Forest (Evergreen/Semi Evergreen - Open)	618.5	1225.8
2	Forest (Degraded)	509.3	–
3	Agricultural land (Kharif)	40.7	5557.6
4	Forest (Evergreen/Semi Evergreen - Dense)	788.2	–
5	Built-up Area (Rural)	110.5	–
6	Wetlands (Inland Natural)	5.3	7.9
7	Tree Clad Area-Open	–	1832.7
8	Wastelands-Scrub land-Dense scrub	–	11.8
9	Forest-Deciduous (Moist)-Open	–	359.0
10	Forest–Evergreen/Semi Evergreen-Dense/Closed	–	1968.5
11	Forest–Forest Plantation	–	104.9
12	Forest-Deciduous (Moist)-Dense/Closed	–	2889.6
13	Wastelands-Scrub land-Open scrub	–	1.3
14	Forest-Scrub Forest	–	123.9
15	Agricultural Land-Plantation-Horticulture Plant	–	11.9
16	Forest–Forest Blank	–	151.5
17	Tree Clad Area-Closed	–	3455.9
18	Agricultural Land-Plantation-Agriculture Plantation	–	152.9

densities, tree basal cover found in the GWS is close to that of an evergreen forest (55–94 m^2 ha^{-1}) of Kalakad in Western Ghats [35].

Compared to KRF though there was appreciably higher Simpson index of concentration of dominance (0.085) and Shannon diversity index 1.22 in the GWS it was not significant (Table 3). The higher Simpson and Shanon diversity index in GWS might be due to different plant species in a comparatively small area. The Shannon diversity index in the present study is comparable to the findings of Parthasarathy et al. [36] who reported a Shannon diversity index of 0.83–4.10 for different Indian forests.

5.1. *Relationship of AGB with basal area, density and diversity indices*

The relationship of AGB with basal area, density and diversity indices are shown in Table 4. In the present study, basal area, tree density and Shanon index of the GWS showed a positive significant ($p < 0.001$) correlation ($r = 0.606$) with AGB. However, the Simpson index of the concentration of dominance showed negative significant correlation with AGB. In the KRF, basal area was positively and significantly correlated with AGB ($p < 0.01$) while tree density, Shanon and Simpson diversity index were insignificantly correlated. According to Caspersen and Pacala [37], there is a positive relationship between diversity and productivity. In the present study irrespective of number of trees in an area, basal area showed positive correlation with AGB.

The Shannon diversity index showed a positive relationship with AGB, while the Simpson index of the concentration of dominance showed a negative correlation with AGB, which contradicts the findings of Kirby and Potvin [38]. The positive relationship between AGB and basal area in a forest stand may be due to architectural control and growth by the lower part of the tree trunk.

5.2. *Aboveground biomass and carbon stocks*

The comparison of the AGB and AGBC stocks of tree species in the GWS and the KRF of Assam and their comparison with a previously studied forest are described in Tables 5 and 6.

The AGB of the present study ranged from 135.29 Mg ha^{-1} to 146.42 Mg ha^{-1}, which is less than the study made on Tropical forest in Sri Lanka, Brazil and some studies made in India (23, 39–41) while being comparable with the findings of Lasco [42], Borah et al. [22], Ngo et al. [43] and comparatively higher to few other studies [28,44]. Similarly, the values of AGBC stocks in this study ranged from 67.65 Mg ha^{-1} to 73.21 Mg ha^{-1}, which supports the other previous studies [23,45,46]. Overall, compared to the KRF in the GWS, AGB and AGBC stocks were recorded less. This result of higher AGB and AGBC stocks in KRF also substantiates the positive relationship of basal area with AGB to that of matured large tree composition and old growth managed reserve forest. According to some ecologists, mature tropical forests with high AGB contain a large proportion of their AGB in large trees [39]. It was observed that Anacardiaceae, Euphorbiaceae, Magnoliaceae, Clusiaceae, Dipterocarpaceae and Meliaceae, etc. in the GWS and Lauraceae, Fabaceae, Malvaceae and Meliaceae, Moraceae and Bursearaceae, etc. in the KRF are the important contributors to AGB and AGBC stock. Thus, the potential effects on overall AGB and C stock from the removal or conservation of these species of different families are considered to be significant.

5.3. *Soil organic carbon*

The soil particle size analysis, pH, SOC and bulk density of the soil samples collected from the two forests are summarized in Table 7. Both soil samples collected from the KRF (53.5%) and the GWS (86.2%) were found to be clayey. Soil pH was higher in the KRF (6.59, 6.07, and 5.54) than in the GWS (4.19, 3.66, and

Table 2 – Basal area (BA) and diameter at breast height (DBH) of individual tree species found in Gibbon Wildlife Sanctuary and Kholahat forest of Assam, India.								
Name of the family	Name of the species	Local name	BA ($m^2\ ha^{-1}$)		BA (%)		DBH (cm)	
			Gibbon	Kholahat	Gibbon	Kholahat	Gibbon	Kholahat
Moraceae	*Artocarpus integrifolia*	Kothal	0.64	0.54	0.7	0.87	92.8	90.45
	A. chama	Cham kothal	1.14		1.26		115.5	
	A. lakoocha	Dewasam	2.44		2.7		171.1	
	A. chaplasha	Sam		0.5		0.8		87.45
	A. slakoocha	Bahat		0.63		1.01		94.9
	Ficus fistulosa	Mou-dimoru	0.36		0.4		66.6	
	F. nerifolia	Kotiadimaru	0.57		0.63		82.8	
	F. urophylla	Khongal bar	0.95		1.05		107.6	
	F. hispida	Jyagyadimaru	1.13		1.25		118	
	F. nervosa	Kharipatidimaru		0.5		0.79		86.5
	F. rumphii	Pakhri	1.29		1.43		124.2	
	F. benjamina	Jori	3.82		4.23		202.1	
	F. bengalensis	Borgash	0.41		0.45		265	
	Morus laevigata	Bhola	1.33	0.67	1.47	1.07	70.9	99.9
Anacardiaceae	*M. sylvatica*	Bon aam	3.83	0.51	4.24	0.81	223	113.05
	M. indica	Aam	2.63		2.91		162.6	
	Rhus semialata	Naga tenga	2.95		3.27		84	
	Spondias pinnata	Amara	0.96		1.06		114	
	S. axillaries	Tileka	1.13		1.25		111.7	
	S. mangifera	Amora		0.05		0.08		52.05
	Drymicarpus racemosus	Aamsia	1.78		1.97		94.4	
	Semecarpus anacardium	Bhela	3.73		4.13		126.8	
	Lannea grandis	Jia		0.37		0.59		86
Euphorbiaceae	*Sapium baccatum*	Seleng	1.46	0.45	1.62	0.71	112.6	81.35
	S. eugeniaefolium	Korha	0.95		1.06		104.4	
	Glochidion hirsutum	–	0.54		0.6		94.7	
	Emblica officinalis	Amalokhi	1.55		1.72		95.6	
	Trewia nudiflora	Bhelkar	1.29	0.54	1.43	0.87	113.1	89.75
	Baccaurea sapida	Leteku	0.31		0.35		71.4	
	Endospermum chinense	Phulgamari		0.26		0.41		50.1
	Aporosa roxburghii	Garokhuta		0.33		0.52		71.75
	Cyclostemon assamicus (Dryptes assamica)	Dukoha		0.56		0.89		93.15
Magnoliaceae	*Michelia oblonga*	Borsopa	0.84		0.94		113.4	
	M. doltsopa	Sopa	2.09	0.54	2.32	0.86	238	92.2
	M. champaca	Titasopa		0.54		0.86		92.2
	Magnolia hodgsonii	Borhamthuri	2.33		2.58		149.9	
	Manglietia hookeri	Pansopa	3.81		4.22		172.9	
	Talauma phellocarpa	Kharikasopa		0.43		0.69		85.7

(continued on next page)

Table 2 – (*continued*)

Name of the family	Name of the species	Local name	BA (m^2 ha^{-1})		BA (%)		DBH (cm)	
			Gibbon	Kholahat	Gibbon	Kholahat	Gibbon	Kholahat
Clusiaceae	*Garcinia cowa*	Kauri thekera	0.32		0.35		74.55	
	Garcinia kydia	Thekera	0.24		0.27		72.4	
	Mesua assamica	Nahar	3.09		3.42		208.5	
	M. ferrea	Nahar		0.51		0.82		91.6
	Kayea floribunda	Karol		0.58		0.92		97.45
	K. assamica	Sianahar		0.5		0.8		89.5
	Callophyllum polyanthum	Telo		0.51		0.81		89.3
Meliaceae	*Aglaia spectabilis*	Amari	5.66	0.23	6.27	0.37	180.4	49
	Amoora wallichii	Amari		0.25		0.4		69.55
	Cedrela toona	Jatipoma		0.38		0.6		62.8
	Dysoxylum hamiltonii	Gendhelipoma		0.45		0.72		69
	Melia azedarach	Ghoranim		0.32		0.51		55.1
	Dysoxylum binectariferum	Bandordima	0.44	0.21	0.49	0.34	81.8	50.25
	Chukrasia tabularis	Bogipoma	0.95	0.48	1.05	0.77	97.6	67.3
Lauraceae	*Cinnamomum glanduliferum*	Gansoroi	1.5		1.66		128.5	
	C. obtusifolium	Patihunda		0.25		0.4		44.55
	C. fragrantisima	Mahidal		0.3		0.48		68.7
	Cinnamomum cecicodaphne	Gonsorai		0.46		0.74		82.6
	Litsea khasiana	–	0.43		0.48		79.2	
	L. panamonja	Barichapa		0.42		0.67		66.3
	Machilus globosus	Som	0.03	0.19	0.04	0.31	97.7	39.75
	Alseodaphne owdenii	Jatisundi		0.73		1.16		89.45
	Beilschmiedia assamica	Amchoi		0.41		0.65		63.65
	Cryptocarya amygdalina	Banhoalu		0.52		0.82		72.05
	Phoebe goalparensis	Bonsum		0.63		1.01		92.45
	P. attenuata	Mekahi		0.43		0.69		79.65
	P. cooperiana	Mekahi		0.66		1.06		97.65
Burseraceae	*Canarium bengalensis*	Dhuna	0.75	0.43	0.84	0.69	104.2	91.25
	Garuga pinnata	Paniamora	0.95	0.57	1.05	0.92	77.6	94
Caesalpinaceae	*Cassia fistula*	Sonaru	1.13		1.25		88.3	
	Bauhinia purpurea	Kanchan	0.48		0.53		84.9	
Combretaceae	*Terminalia chebula*	Hilikha	0.51	0.25	0.56	0.41	104.9	66.5
	T. myriocarpa	Halakh	3.05	0.87	3.38	1.4	151	127.65
	T.tomentosa	Sain		1.21		1.93		130.2
	T. belerica	Bhomora		0.89		1.42		112.25
Dipterocarpaceae	*Vatica lanceaefolia*	Morsal	1.15		1.27		101.2	
	Dipterocarpus macrocarpus	Holong	0.49	0.53	0.55	0.85	128	91.9
	D. turbinatus	Gurjan		0.46		0.74		85.9
	Shorea robusta	Sal		0.53		0.85		93.95
	S. assamica	Mekai		1.08		1.73		132.3
Elaeocarpaceae	*Elaeocarpus ganitrus*	Rudrakshya	0.96		1.07		119.7	
	Elaeocarpus floribundus	Jalpai	0.05		0.06		58	

Lythraceae	*Lagerstroemia parviflora*	Ajar	2.49	0.04	2.76	0.07	187.8	34.75
	L. flos-reginae	Sida		0.17		0.26		66.05
	Duabanga sonnertioides	Khakan		0.74		1.19		107.75
	Lawsonia inermis	Jetuka	0.75		0.84		66.1	
Verbenaceae	*Gmelina arborea*	Gomari	0.54		0.6		95.6	
	Premna bengalensis			0.46		0.74		107.6
	P. milleflora	Hillgomari		0.05		0.08		57.7
Lamiaceae	*Vitex glabrata*	Paniamara	0.22		0.24		60.3	
	V. peduncularis	Ahoi		1.29		2.07		138.25
	Gmelina arborea	Gomari		0.89		1.42		120.45
	Tectona grandis	Shagun,		0.67		1.07		99.25
Sterculiaceae	*Pterospermum acerifolium*	Hatipiola	0.36		0.4		73.9	
	Sterculia villosa	Udal	0.82	0.38	0.91	0.61	110.6	79.6
	Mansonia dipikae	Badam		0.25		0.4		64.9
Altingeaceae	*Altingia excelsa*	Jutuli	0.58	0.41	0.65	0.66	91.7	68.15
Annonaceae	*Polyalthia jenkinsii*	Koliori	0.54		0.6		88.9	
Apocynaceae	*Alstonia scholaris*	Chotiana	0.49	1.6	0.54	2.57	87.7	126.15
Aquifoliaceae	*Ilex godjam*	Hatikerepa	0.63		0.69		92.2	
Bignoniaceae	*Streospermum personatum*	Paroli	2.12	0.78	2.35	1.25	173.1	90.55
Bombacaceae	*Bombax ceiba*	Simulu	1.14		1.27		108.5	
Dilleniaceae	*Dillenia indica*	Ou-tenga	0.85	0.43	0.94	0.69	99.9	110.9
Fabaceae	*Dalbergia assamica*		0.76		0.84		102.2	
	D. sissoo	Sissoo		0.68		1.09		99.7
	Acacia catechu	Khoir		0.76		1.21		105.5
	Acrocarpus fraxinifolius	Mandhani		0.57		0.91		92
	Parkia roxburghii	Manipuriurohi		0.82		1.32		92.5
	A. lebbck	Siris		1.14		1.82		99.75
	Al. odoratissima	Hiharu		0.95		1.53		98.2
	A.procera	Korai		1.11		1.78		105
	Cassia fistula	Sonaru		0.86		1.37		95.1
Fagaceae	*Castonopsis indica*	Hingori	0.71	1.6	0.79	2.56	100.9	125.5
Flacourtiaceae	*Hydnocarpus kurzii*	Chalmugra	0.56		0.62		91.5	
Mimosaceae	*Albizzia lebbeck*		0.73		0.81		85.8	
	A. lucida	Moj		0.67		1.07		95.75
	A. stipulata	Sau		0.53		0.85		90.45
Myrtaceae	*Syzygium obalata*	Jamuk	0.56		0.62		75.2	
	Eugenia jambolana	Jamuk		0.38		0.6		83.75
	E. wallichii	Bogijamuk		0.27		0.43		75.8
	E. operculata	Gocha jam		0.17		0.26		66.25
Papilionaceae	*Erythrinasu berosa*	Modar	0.55		0.61		94.1	
Phyllanthaceae	*Bischofia javanica*	Urium	2.34	0.14	2.59	0.22	128.95	63.85
	Bridelia retusa	Kuhir		0.42		0.68		80.6
Rubiaceae	*Anthocephalus chinensis*	Kadam	1.77		1.96		143.8	
	Adina cordifolia	Haldu		0.5		0.79		85.35
	A. cordiafolia	Haldusopa		0.54		0.86		94.95
Rutaceae	*Euodia meliaefolia*	Maiphak	1.42		1.57		119	
	Zanthoxylum budrunga	Bajrang		0.58		0.93		74.7

(continued on next page)

Table 2 – (continued)

Name of the family	Name of the species	Local name	BA (m² ha⁻¹)		BA (%)		DBH (cm)	
			Gibbon	Kholahat	Gibbon	Kholahat	Gibbon	Kholahat
Sapotaceae	*Chrysophyllum roxburghii*	Gandhsoroi	0.84		0.93		94.3	
	Palaquium polyanthum	Kurta		0.41		0.66		63.55
Simaroubaceae	*Ailanthus integrifolia*	Borpat	0.05	0.38	0.05	0.6	39.1	73.75
Malvaceae	*Pterospermum acerifolium*	Hatipoila		0.35		0.55		59.95
	Sterculi aalata	Pahari		0.31		0.49		75.5
	Bombax insigne	Dhumboil		0.42		0.67		82.55
	Bombax ceiba	Simolu		0.04		0.07		45.55
	Kydia calycina	Pichola		0.56		0.89		93.45
	Pterospermum lanceaefolium		0.32		0.51		77.9	
	Echinocarpus assamicus	Jobahingori		0.26		0.41		67.8
	Heritiera acuminata	Baroi		1.06		1.7		101.3
	Hibiscus macrophyllus	Pohuudal		0.42		0.66		82
Rosaceae	*Crypteronia paniculata*	Gorumora		0.25		0.41		45.95
Ulmaceae	*Ulmus lancifolia*	Manuk		0.22		0.35		71.05
	Gironniera sp.	Dudhchampa		0.41		0.66		84.8
Cannabaceae	*Celtis tetrandra*	Mouhita		0.57		0.92		63.8
Rhizophoraceae	*Carallia integerrima/lucida*	Mahithekera		0.47		0.76		52.55
Betulaceae	*Betula alnoides*	Bhojpotra		1.51		2.41		128.45
Leguminosae	*Cynometra polyandra*	Ping		0.79		1.26		89.15
Cornaceae	*Nyssa sessiliflora*	Gahorichopa		1.5		2.4		118.95
Theaceae	*Schima wallichii*	Makrisal		0.64		1.03		84.55
Podocarpaceae	*Podocarpus neriifolia*	Jinari		0.6		0.96		77.7
Pinaceae	*Pinus khasya*	Ppine		0.7		1.13		89.2
Tetramelaceae	*Tetrameles nudiflora*	Bhelu		0.46		0.74		67.9
Celastraceae	*Lophopetalum fimbriatum*	Sutrong		0.52		0.83		64.85

Table 3 – Summary of tree diversity in the Gibbon wild life sanctuary and Kholahat reserve forest of Assam.

Study sites	Gibbon	Kholahat
Number of families	32	42
Number of tree species	71	108
Density (trees ha^{-1})	286.92	416.25
Basal area (m^2 ha^{-1})	90.29	62.49
Simpson index of diversity	0.085 ns	0.043
Shannon diversity index	1.22 ns	1.16

Table 4 – Correlation between aboveground biomass (AGB), basal area, density and tree species diversity.

Parameters	r	P	Significance level
Gibbon wild life sanctuary			
Basal area	0.606	0.000	**
Density	0.333	0.004	**
Shannon diversity index	0.373	0.001	**
Simpson's index	−0.331	0.003	**
Kholahat reserve forest			
Basal area	0.361	0.000	**
Density	0.171	0.077	NS
Shannon diversity index	−0.028	0.777	NS
Simpson's index	0.065	0.507	NS

**significant at p = 0.01, NS- Not significant, Pearson Correlation coefficient (r), P value and significance level are given.

3.48) for the upper, middle and lower layers, respectively. A difference was observed between the bulk density of the soils from the upper (1.22 kg m^{-3} and 1.28 kg m^{-3}) and lower (1.38 kg m^{-3} and 0.89 kg m^{-3}) layers of the GWS and the KRF, respectively which was found to be non-significant. The bulk density was higher for the upper layer (0–30 cm) in both forests. A significantly different SOC, greater in the upper layers in the KRF (2.04%) than in the GWS (1.36%) was observed. Middle and lower layers also showed a similar trend. Other studies have shown that in natural tropical forests, SOC is 2.58% and 1.99% in multispecies tree plantations, while in teak forest it is 1.69% [47] which supports the findings of the present study. Overall, higher SOC was found in the upper 0–30 cm of soil. SOC from the upper 20 cm to the deeper layers varied from 29% to 57% [16]. Although, the higher SOC in the upper layers was due to higher organic matter content, in the KRF, more organic carbon in the soil was due to large amounts of decomposed plant material in the top layer. This higher SOC in the KRF than GWS also support the dominance of mature large trees. Overall, significant differences ($p < 0.05$) in organic carbon between forests was found at all depths. SOC stocks were higher in the KRF (78.4 kg m^{-2}) than in the GWS (57.7 kg m^{-2}) in the upper layer. The GWS showed the higher stocks in the upper layer (57.74 kg m^{-2}), followed by the middle layer (39.22 kg m^{-2}) and lowest by the lower layer (30.32 kg m^{-2}).

Table 5 – Above ground biomass (AGB) and C stock of tree species in Gibbon wild life sanctuary and Kholahat reserve forest of Assam.

Forest	Aboveground biomass (Mg ha^{-1})	Aboveground biomass carbon (Mg ha^{-1})
Gibbon	135.30	67.65
Kholahat	146.42	73.21

Table 6 – Comparison of aboveground biomass (AGB) and AGB-C stocks of tropical forests in different tropical countries.

Forest type and location	AGB (Mg ha^{-1})	AGBC stock (Mg ha^{-1})	Reference
Tropical dry deciduous forest, Mexico	–	113	[48]
Tropical forest, Brazil	217	–	[49]
Tropical evergreen forest, Colombia	–	112	[50]
Tropical forests in Asia	50–360	100–200	[40]
South and Southeast Asia	35.0–116.0	17.5–58.0	[51]
Southeast Asia, including India, Cambodia, Malaysia and Indonesia	–	17.0–350.0	[46]
Tropical forest, Singapore	104.5–167.5	–	[43]
Tropical forest, Thailand	–	60.0–179.0	[45]
		138.0–182.0	[52]
Tropical forest, Sri Lanka	154	77	[39]
India	126	–	[28]
India	67.4	–	[44]
Tropical forest, India	324	162	[23]
	372	186	[41]
Tropical dry deciduous forest, India	–	87	[53]
Tropical forest of Cachar, Assam, India	32.47–261.64	16.24–130.82	[22]
Our study			
Gibbon	135.30	67.65	Present study
Kholahat	146.42	73.21	Present study

6. Conclusion

A total of six and fifteen different habitats were found in the GWS and KRF of Assam, India, respectively. In the GWS, 38% forest area was occupied by open evergreen/semi-evergreen dense forest while in KRF, forest area was covered with deciduous (Moist)-dense/closed forest and a lowest area (0.2%) was covered with wet lands. The GWS is the patch vegetation with diverse trees in a small area while the KRF is a matured forest with large trees. A total of 71 and 108 different tree species belong to 32 and 42 families was recorded in the GWS and KRF, respectively. Compared to the KRF, a significantly less density of trees was recorded in the GWS; however, it was reverse in basal area. Overall significant ($p < 0.01$) relation was observed for basal area with the accumulation AGB. Appreciably higher AGB (146.2 Mg ha^{-1}) and AGBC (73.21 Mg ha^{-1}) was recorded in the GWS compared to the KRF. In could be inferred that in the two studied forests neither higher nor less

Table 7 – Soil pH, organic carbon, bulk density and particle size distribution of soil sampled from Gibbon wild life sanctuary and Kholahat reserve forest of Assam.

Name of the forest	Soil depth (cm)	pH	Org. carbon (%)	Bulk density (G/cm^{-3})	Composition of soil particle (%)			Soil carbon stock (kg m^{-2})
					Clay	Silt	Sand	
Gibbon wild life sanctuary	00.0–30.0	4.2 ± 0.1a	1.4 ± 0.2a	1.2 ± 0.1a	86.2 ± 0.1a	13.5 ± 0.1b	0.2 ± 0.01a	54.7 ± 2.8a
	30.0–60.0	3.7 ± 0.1b	0.8 ± 0.2b	1.1 ± 0.2a	85.9 ± 0.1a	14.2 ± 0.2 ab	0.20 ± 01a	39.2 ± 7.3b
	60.0–100.0	3.5 ± 0.1c	0.4 ± 0.3c	1.4 ± 0.3a	84.1 ± 0.2b	15.7 ± 0.2a	0.20 ± 01a	30.3 ± 4.2c
Kholahat Reserve forest	00.0–30.0	6.6 ± 0.1a	2.0 ± 0.1a	1.3 ± 0.1a	53.5 ± 0.2a	40.0 ± 0.1b	6.7 ± 0.2 ab	78.4 ± 9.6a
	30.0–60.0	6.1 ± 0.2b	1.4 ± 0.1b	1.1 ± 0.2a	54.8 ± 0.1a	38.6 ± 0.2c	6.6 ± 0.2b	64.9 ± 9.4b
	60.0–100.0	5.5 ± 0.1c	1.2 ± 0.3c	0.9 ± 0.1a	50.0 ± 0.3b	42.5 ± 0.2a	7.5 ± 0.3a	42.9 ± 6.6c

n = 10 with three repetition in each location; ±0.1 = Standard error means of observed values; SE followed by similar letter in each column were not significantly different for the respective sites.

AGB and AGBC were recorded. From the findings it could be concluded that the higher AGB, AGBC and SOC in the KRF were due to old growth, matured forest with big and diverse tree species while in the GWS all the three parameters were lower due to its patch vegetation of secondary forests.

Acknowledgement

The authors are thankful to Dr. D. Ramaiah, Director, CSIR-NEIST, Jorhat, for his support and to DST, Govt. of India and CSIR, New Delhi for providing financial support. Authors are also thankful to unanimous reviewer for their suggestions in improving this MS.

REFERENCES

[1] Parresol BR. Assessing tree and stand biomass: a review with examples and critical comparisons. For Sci 1999;45(4):573–93.
[2] FAO. Global Forest resources assessment 2005 FAO. 2006. Rome.
[3] Fischlin A, Midgley GF, Price JT, Leemans R, Gopal B, Turley C, et al. Ecosystems, their properties, goods, and services. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE, editors. Climate change 2007: impacts, adaptation and vulnerability. Contribution of working group II to the forth assessment report of the intergovernmental panel on climate change. Cambridge UK: Cambridge University Press; 2007. p. 211–72.
[4] Schimel DS, House JI, Hibbard KA, Bousquet P, Ciais P, Peylin P, et al. Recent patterns and mechanisms of carbon exchange by terrestrial ecosystems. Nat Lond 2001 Nov 8;14:16972.
[5] Basu P. A green investment. If growing forest in India can generate lucrative carbon credits, then why isn't everyone planting trees. Nat Lond 2009 January 7:455–546.
[6] Bonan GB. Forests and climate change: forcing, feedbacks, and the climate benefits of forests. Science 2008;320:1444–9.
[7] Houghton RA. Aboveground forest biomass and the global carbon balance. Glob Change Biol 2005;11:945–58.
[8] Dixon RK, Brown S, Houghton RA, Solomon AM, Trexler MC, Wisniewski J. Carbon pools and flux of global forest ecosystems. Science 1994;263:185–90.
[9] Fang J, Wang G, Liu G, Xu S. Forest biomass of China: an estimate based on the biomass-volume relationship. Ecol Appl 1998;8:1084–91.
[10] Parthasarathy N, Kinbal V, Kumar LP. Plant species diversity and human impact in tropical wet evergreen forest of southern western ghats. Indo-French workshop on tropical forest ecosystem. Pondicherry: Natural Functioning and Anthropogenic Impact. French Institute; Nov. 1992.
[11] Laurance WF, Habitat destruction: death by a thousand cuts. Conservation biology for all, pp 73–87; Oxford Univ. Press.
[12] Davidson EA, Janssens IA. Temperature sensitivity of soil carbon decomposition and feedbacks to climate change. Nat Lond 2006 March 9;440:165–73.
[13] Phillips OL, Malhi Y, Higuchi N, Laurance WF, Nunez PV, Vasquez RM, et al. Changes in the carbon balance of tropical forests: evidence from long-term plots. Science 1998;282:439–42.
[14] Chave J, Andalo C, Brown S, Cairns MA, Chambers JQ, Eamus D, et al. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia 2005;145:87–9.
[15] Montes N, Gauquelin T, Badri W, Bertaudiere V, Zaoui EH. A non-destructive method for estimating above-ground forest biomass in threatened woodlands. For Ecol Manage 2000;130:37–46.
[16] Jobbagy EG, Jackson RB. The vertical distribution of soil organic carbon and its relation to climate and vegetation. Ecol Appl 2000;102:423–36.
[17] Myers N, Mittermeier RA, Mittermeier CG, da Fonseca GAB, Kent J. Biodiversity hotspots for conservation priorities. Nat Lond 2000 February 24;403:853–8.
[18] Champion HG, Seth SK. Eneral silviculture for India. Delhi: Publication Division, Government of India; 1968.
[19] Nath AJ, Das AK. Carbon pool and sequestration potential of village bamboos in the agroforestry system of northeast India. Trop Ecol 2012;53(3):287–93.
[20] Athokpam FD, Garkoti SC, Borah N. Periodicity of leaf growth and leafy dry mass changes in the evergreen and deciduous species of Southern Assam, India. Ecol Res 2014;(29):153–65.
[21] Nath AJ, Das G, Das AK. Above ground standing biomass and carbon storage in village bamboos in North East India. Biomass Bioenergy 2009;33:1188–96.
[22] Borah N, Nath AJ, Das AK. Aboveground biomass and carbon stocks of tree species in tropical forests of Cachar District, Assam, northeast India. Int J Ecol Environ Sci 2013;39(2):97–106.
[23] Baishya R, Barik SK, Upadhaya K. Distribution pattern of aboveground biomass in natural and plantation forests of humid tropics in northeast India. Trop Ecol 2009;50(2):295–304.
[24] Barhauh A, Roy Choudhury SB. In: Gazette of India Assam state, vol. I. Guwahati: District Gazettes, Govt. of Assam; 1999.
[25] Shannon CE, Weaver W. The mathematical theory of communication. Urbana (IL): Univ. Illinois Press; 1963.

[26] Simpson EH. Measurement of diversity. Nat Lond 1949 Apr 30;163:688.
[27] Chave J, Coomes D, Jansen S, Lewis SL, Swenson NG, Zanne AE. Towards a worldwide wood economics spectrum. Ecol Lett 2009;12:351–66.
[28] Ravindranath NH, Somashekhar BS, Gadgil M. Carbon flow in Indian forests. Clim Change 1997;35:297–320.
[29] Walkley A, Black IA. An examination of Degtjareff method for determining organic carbon in soils: effect of variations in digestion conditions and of inorganic soil constituents. Soil Sci 1934;63:251–63.
[30] Cienciala E, Exnerova Z, Macku J, Henzlik V. Forest topsoil organic carbon content in Southwest Bohemia region. J For Sci 2006;9:387–98.
[31] Visalakshi N. Vegetation analysis of two tropical dry evergreen forests in southern India. Trop Ecol 1995;36:117–42.
[32] Ayyappan N, Parthasarathy N. Biodiversity inventory of trees in a large scale permanent plot of tropical evergreen forest at Varagaliar. Anamalais, Western Ghats, India. Biodivers Conservation 1999;81:1513–51.
[33] Lu XT, Yin JX, Tang JW. Structure, tree species diversity and composition of tropical seasonal rainforests in Xishuangbanna, South-west China. J Trop For Sci 2010;22(3):260–70.
[34] Nadkarni NM, Matelson TJ, Haber WA. Structural characteristics and floristic composition of a neotropical cloud forest, Monteverde, Costa Rica. J Trop Ecol 1995;11(04):481–95.
[35] Ganesh T, Ganesan R, Soubadradevy M, Davidar P, Bawa KS. Assessment of plant biodiversity at a mid-elevation evergreen forest of Kalakad-Mundanthurai Tiger Reserve, Western Ghats, India. Curr Sci 1996;71:379–92.
[36] Parthasarathy N, Karthikeyam R. Plant biodiversity inventory and conservation of two tropical dry evergreen forests on coromandal coast, South India. Biodivers Conservation 1997;6:1063–83.
[37] Caspersen JP, Pacala SW. Successional diversity and forest ecosystem function. Ecol Res 2001;16:895–903.
[38] Kirby KR, Potvin C. Variation in carbon storage among tree species: implication for management of small scale carbon sink project. For Eco Manage 2007;246:208–21.
[39] Brown S, Lugo AE. The storage and production of organic matter in tropical forests and their role in the global carbon cycle. Biotropica 1982;14:161–87.
[40] Lasco RD. Forest carbon budgets in Southeast 505 Asia following harvesting and land cover change. Sci China 2002;45:45–64.
[41] Mohanraj R, Saravanan J, Dhankumar S. Carbon stock in Kolli forests, Eastern Ghats (India) with emphasis on aboveground biomass, litters, woody debris and soil. Forest-Biogeosciences For 2011;4:61–5.
[42] Lasco RD. Forest carbon budgets in Southeast Asia following harvesting and land cover change. Sci China 2002;45:45–54.
[43] Ngo KM, Turner BL, Muller-Landau HC, Davies SJ, Larjavaara M, Hassan NFBN, et al. Carbon stocks in primary and secondary tropical forests in Singapore. For Ecol Manag 2013;296:81–9.
[44] Haripriya GS. Estimates of biomass in Indian forests. Biomass Bioenergy 2000;19:245–58.
[45] Ogawa H, Yoda K, Ogino K, Kira T. Comparative ecological studies on three main types of forest vegetation in Thailand II. Plant biomass. Nat Life South East Asia 1965;4:49.
[46] Flint PE, Richards JF. Trends in carbon content of vegetation in South and Southeast Asia associated with change in land use. In: Dale VH, editor. Effects of land-use change on atmospheric CO_2 concentrations, South and Southeast Asia as a case study. Berlin: Springer-Verlag; 1996. p. 201–300.
[47] Yao MK, Angui PKK, Konate S, Tondoh JE, Tano Y, Abbadie L, et al. Effects of land use types on soils organic carbon and nitrogen dynamics in Mid-West Cote d'lvoire. Eur J Sci Res 2010;40:211–22.
[48] Cairns MA, Olmsted I, Granadas J, Argaez J. Composition and aboveground tree biomass of a dry semi evergreen forest on Mexico's Yucatan Peninsula. For Ecol Manag 2003;186:125–32.
[49] Malhi Y, Baldocchi DD, Jarvis PG. The carbon balance of tropical, temperate and boreal forests. Plant, Cell Environ 1999;22:715–40.
[50] Sierra CA, Del Valle JI, Orrego SA, Moreno FH, Harmon ME, Zapata M, et al. Total carbon stocks in a tropical forest landscape of Porce region, Colombia. For Ecol Manag 2007;243:299–309.
[51] Hall CAS, Uhling J. Refining estimates of carbon released from tropical land use change. Can J For Res 1991;21(1):118–31.
[52] Boonpragob K. Estimation of greenhouse gas emission and sequestration from land use change and forestry in Thailand. In: Moya TB, editor. Greenhouse gas emission, aerosols, land use and cover changes in Southeast Asia. Bangkok, Thailand: Southeast Asia Regional Committee; 1998. p. 18–25.
[53] Chaturvedi RK, Raghubanshi AS, Singh JS. Carbon density and accumulation in woody species of tropical dry forest in India. For Ecol Manag 2011;262:1576–88.