Pleione 13(1): 19 - 31. 2019. ISSN: 0973-9467

Doi:10.26679/Pleione.13.1.2019.019-031

Tree biomass and carbon stock assessment of two forest areas of Assam in North East India

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[Received 06.05.2019; Revised 19.06.2019; Accepted 23.06.2019; Published 30.06.2019]

Abstract

The present study was carried out for assessment of tree above ground biomass and carbon stock of two forest areas of Assam *viz*. Poba Reserve Forest (PRF) and Nambor-Doigrung Wildlife Sanctuary (NDWS). Data were collected from ten random plots of 0.1 ha for both forests. In each plot, all tree species having diameter at breast height (dbh) more than or equal to10 cm were identified and their height as well as dbh were measured. Above ground biomass (AGB) was estimated by using allometric equations. The Diversity Indices were also calculated for each study site. AGB and above ground carbon (AGC) values were found to be highly variable across all plots, with the average values of 110.07 Mg ha^{-1} and 55.03 Mg C ha^{-1}, respectively for PRF and 91.04 Mg ha^{-1} and 45.52 Mg C ha^{-1} respectively for NDWS. There were 2396 stems ha^{-1}, belonging to 63 tropical species, 48 genera and 27 families in the PRF. In NDWS, there were 1666 stems ha^{-1}, belonging to 43 tropical species, 35 genera and 21 families. A positive and significant linear relationship among the tree growth variables was found for both the forests which facilitate insights into the role of biodiversity in maintaining carbon storage. The average soil carbon stock (SOC) in the upper, middle and lower layers was 50.07-73.63 kg m^{-2}, 37.25-66.01 kg m^{-2} and 36.60-57.42 kg m^{-2}, respectively in PRF and NDWS. However, compared to NDWS, a higher AGB and AGBC were found in PRF due to the presence of old growth matured forest with big and diverse tree species in PRF.

Key words: Above ground biomass, Biodiversity, Soil organic carbon, Tree diversity, Carbon stock

INTRODUCTION

Tree composition and structure of forests provide a vital instrument in assessment of sustainability of the forests, conservation of species and in management of the forest ecosystems. Again, in mitigating the effects of global warming, forests play an important role since it acts as one of the largest carbon pool (Sasaki & Kim 2009). The carbon stock potentiality of a forest can be determined by estimating its biomass. However, the above ground biomass (AGB) of most of the forests is directly affected by deforestation and forest degradation (Gibbs *et al*. 2007). Therefore, estimation of AGB is the most important aspect in the study of carbon stock of forest (Ketterings *et al*. 2001). Among different methods for quantifying AGB of a forest, non-destructive method is more preferable for its cost effectiveness, eco-friendly nature (Chave *et al.* 2005; Ravindranath & Ostwald 2008; Kunneke *et al.* 2014; Seifert & Seifert 2014; Magalhães, & Seifert 2015; Picard *et al.* 2015).

North East India – a gift of nature is having several different types of forest and is one of the mega biodiversity hot spot. The forests of this region are also not an exception regarding its lost in diversity, diminishing its areas and natural beauty due to anthropogenic activities. Shifting cultivation operation in NE India are most apparent causes of forests disturbances. The problem with shifting cultivation is that plants or ecosystem often do not get time to recover adequately as the human onslaught never stops (Singh 1998). Along with shifting cultivation, over exploitation, encroachment, flood, erosion, urbanization is the major threats for the normal growth and development of forests of this region. Apart from these, information related to nature of forest, AGB carbon stocks (AGBC) is rather inadequate in these forest habitats. In order to fill up this gap, it is necessary to assess representative forests in respect of characteristics and its role in maintaining the environment. In this study, species diversity, biomass and carbon stocks in two forest areas of Assam, i.e., the PRF and NDWS were assessed.

Study Area

The study was conducted in Poba Reserve Forest (PRF) and Nambor-Doigrung Wildlife Sanctuary (NDWS) of Assam. PRF is situated in Jonai Subdivision of Dhemaji district, Assam. The Reserved Forest (RF) was created in the year 1924 and covers an area of 10,221 hectares. The forest receives annual rainfall of 3600 mm to 4000 mm. The highest temperature recorded is 35^0 C in summer and lowest 7^0 C in winter. It is surrounded by Daying Ering Wildlife Sanctuary, NH-52 and foot-hills of Arunachal Pradesh in the North, Dibru-Saikhowa National Park and the Siang, Dibang and Lohit rivers in the East, Laly River in the South, and a few villages to the West. Boruah *et al.* (2003) from Assam Remote Sensing Application Centre, Guwahati on the basis of Satellite Remote Sensing Technique classified the vegetation cover of the RF into five types i.e. moist mixed semi-evergreen forest, moist mixed deciduous forest, degraded forest, tall grasses and small grasses. The NDWS occupies an area of 9,715 ha. The NDWS extends up to a foothill area of Karbi Anglong district is located in Golaghat district of Upper Assam. The mean annual temperature varies from 6° C to 36° C and rainfall from 2000 mm to 2300 mm. The plains are the floodplains of the Dhansiri River. The forest type is Tropical Semi-evergreen rainforest with of evergreen and marsh forest. The middle storey is dense and the undergrowth includes bamboo, other shrubs, and some deciduous tree species like *Tetrameles nudiflora* can be seen in the range. The geographical location of the two reserves has been presented in Table 1.

Table 1. Location (central coordinates) of the studied forests in Assam

Study Site name	Latitude	Longitude
Poba Reserve Forest (PRF)	27°50' N	95°17' E
Nambor-Doigrung Wildlife Sanctuary (NDWS)	26°25′N	93°43′ E

METHODOLOGY

For the present study a non-destructive sampling method was adopted to estimate above ground biomass (AGB) and carbon stocks of tree species. In each forest site, a plot of 250 m × 250 m size was taken. Four sample plots, each of 31.6 m × 31.6 m (0.1 ha) size were taken in the four corner of the plot according to the field manual for "vegetation carbon pool" assessment of India (Dadhwal *et al.* 2009). In each sample plot, girths of all the trees (e" 10 cm DBH) were measured at 1.37 m height from the ground by using metal measuring tape.

Vegetation composition was assessed by analysing the Frequency, Density, Abundance and Importance Value Index (IVI) according to Curtis and McIntosh (1951) and Mishra (1968). Species richness (at species, genera and family levels), stem density, Fisher's alpha and basal area m^2 ha^{-1} were assessed for each of the ten 0.1 ha plots. Fisher's alpha (a measure of diversity) which is fairly independent of plot size was used to assess species diversity (Condit *et al.* 1998; Fisher *et al.* 1943*).* The basal area of all trees in the sample plots were calculated using the formula:

$$BA = (\text{ë } D^2)/4$$

where, BA = Basal area (m^2), D = Diameter at breast height (cm) and ë = pie (3.142). The total BA for each plot was obtained by adding all trees BA in the plot. Shannon and Simpson diversity indices (Shannon & Weaver 1963; Simpson 1949) were calculated to determine the species abundance relationships in plant communities. Beta diversity (â) was calculated by Whittaker (1972) to designate the degree of species change along a given habitat as such it is a measure of between area diversity. Evenness was calculated by as given by Pielou (1966).

The volume of each tree was calculated by using the Newton's formula (Husch *et al.* 2003). Species-specific wood density was obtained from the global wood density database (Chave *et al*. 2009). Besides, for species that lacked species-level wood density values, genus-level averages were used. The AGB was estimated using the allometric model proposed by Chave *et al*. (2005) for moist forest stands as the mean annual precipitation of the selected sites is between 1500 and 3000 mm. The AGBC stock was calculated that by assuming that the carbon mass fraction of the dry wood is 50 % of the total AGB (Ravindranath *et al.* 1997).

The collected plant specimens were identified with the help of floras, books and literature including Kanjilal *et al*. (1934 – 1940); Barooah and Ahmed (2014); Balakrishnan (1983); Goswami and Barua (1996) and taxonomic keys available at http://www.efloras.org. For the updated nomenclature and family delimitation http://www.theplantlist.org/ was mostly consulted. Voucher specimens were deposited in herbarium of the CSIR NEIST, Jorhat, Assam.

Statistical analysis

Pearson Correlation Coefficient was used to examine the relationship among the growth variables. Student t-test was performed to determine significant difference between soil parameters at $p < 0.05$. All analyses were performed with SPSS 16.0.

RESULTS

The tree density of the present study is 138.83 – 205.66 trees ha^{-1}. Basal area ranged from 19.69 – 46.62 m^2 ha^{-1}. *Tectona grandis* was the dominant species in the PRF, with the IVI value 8.35. The Co-dominant species are *Vatica lanceifolia* and *Cinnamomum bejolghota* with IVI value 6.09 and 6.0 respectively. A total of 63 species are recorded from the PRF. 100 % frequency was reported by *Tectona grandis, Lagerstroemia speciosa, Canarium bengalense, Tetrameles nudiflora* and *Alstonia scholaris.* The minimum IVI value (3.51) was reported for *Mesua ferrea.* 75 % frequency was observed by the twenty-three species. The A/F ratio was in the range from 0.03 to 0.10. Density of 205.66 trees ha^{-1} was recorded in the PRF.

Table 2. Distribution analysis of tree species in Poba Reserve Forest (PRF).

Family	Botanical name	Local name	D	F	A	A/F	IVI
Lauraceae	*Litsea monopetala* (Roxb.) Pers.	*Sualu*	2.58	83	3.10	0.04	4.18
	Phoebe cooperiana P.C.Kanjilal & Das	*Mekahi*	3.17	92	3.45	0.04	4.98
	Phoebe goalparensis Hutch.	*Bonsum*	3.33	75	4.44	0.06	4.98
	Cinnamomum glanduliferum (Wall.) Meisn.	*Gansoroi*	3.50	67	5.25	0.08	5.05
	Cinnamomum bejolghota (Buch.-Ham.) Sweet	*Paihunda*	3.33	83	4.00	0.05	6.01
	Beilschmiedia assamica Meisn.	*Amchoi*	2.92	75	3.89	0.05	4.85
Lamiaceae	*Alseodaphne owdenii* R.Parker	*Jatisundi*	2.92	67	4.38	0.07	4.65
	Tectona grandis L.f.	*Shagun, Teak*	7.50	100	7.50	0.08	8.35
	Gmelina arborea Roxb.	*Gomari*	2.67	75	3.56	0.05	5.55
	Callicarpa arborea Roxb.	*Bonmola*	2.92	83	3.50	0.04	4.78
	Premna bengalensis C.B.Clarke	*Pakhirhar*	3.50	58	6.00	0.10	5.76
	Vitex peduncularis Wall. ex Schauer	*Akhoi*	3.08	83	3.70	0.04	5.21
Moraceae	*Ficus hispida* L.f.	*Dimoru*	3.50	75	4.67	0.06	4.44
	Artocarpus chama Buch.-Ham.	*Samgos*	2.42	75	3.22	0.04	4.89
	Artocarpus lacucha Buch.-Ham.	*Bohot*	2.92	75	3.89	0.05	4.61
	Artocarpus chaplasha Roxb.	*Sam*	2.83	75	3.78	0.05	4.43
	Morus macroura Miq.	*Bola*	2.83	67	4.25	0.06	4.58
	Ficus nervosa B.Heyne ex Roth	*Khari pati*	2.67	83	3.20	0.04	4.24
Malvaceae	*Bombax ceiba* L.	*Simolu*	4.42	75	5.89	0.08	5.53
	Pterospermum acerifolium (L.) Willd.	*Moragos*	2.83	67	4.25	0.06	5.14
	Kydia calycina Roxb.	*Pichola*	2.75	58	4.71	0.08	4.12
	Pterospermum lanceifolium Roxb.	-	3.25	75	4.33	0.06	4.50
	Sloanea sterculiacea var. *assamica* (Benth.) Coode	*Joba hingori*	2.75	67	4.13	0.06	4.21
	Pterygota alata (Roxb.) R.Br.	*Pahari*	3.42	75	4.56	0.06	4.86
	Sterculia villosa Roxb.	*Udal*	2.83	75	3.78	0.05	4.59
	Mansonia dipikae Purkayastha	*Badam*	3.67	75	4.89	0.07	4.59
Combretaceae	*Terminalia myriocarpa* Van Heurck & Müll.Arg	*Hoolokh*	2.50	83	3.00	0.04	4.54
	Terminalia arjuna (Roxb. ex DC.) Wight & Arn.	*Arjun*	2.17	75	2.89	0.04	4.70
	Terminalia chebula Retz.	*Hilika*	3.00	83	3.60	0.04	5.52
	Terminalia bellirica (Gaertn.) Roxb.	*Bauri*	2.83	75	3.78	0.05	4.31
Magnoliaceae	*Magnolia hodgsonii* (Hook.f. & Thomson) H.Keng	*Barhamthuri*	4.08	67	6.13	0.09	4.71
	Magnolia doltsopa (Buch.-Ham. ex DC.) Figlar		2.75	75	3.67	0.05	5.21
	Magnolia griffithii Hook.f. & Thomson	*Gahari sopa*	3.67	75	4.89	0.07	4.64
Meliaceae	*Aglaia spectabilis* (Miq.) S.S.Jain & S.Bennet	*Amari*	2.42	83	2.90	0.03	4.34
	Toona ciliate M.Roem.	*Poma*	3.42	67	5.13	0.08	5.47
	Dysoxylum gotadhora (Buch.-Ham.) Mabb.		2.67	75	3.56	0.05	5.60
Phyllanthaceae	*Bischofia javanica* Blume	*Urium*	3.83	83	4.60	0.06	5.03
	Antidesma acidum Retz.	*Abutenga*	2.50	83	3.00	0.04	4.38
Leguminosae	*Dalbergia sissoo* DC.	*Sissoo*	2.67	75	3.56	0.05	4.18
	Dalbergia assamica Benth.	*Sissoo*	2.75	75	3.67	0.05	4.25
	Albizia procera (Roxb.) Benth.	*Koroi*	3.00	67	4.50	0.07	4.88
	Albizia lebbeck (L.) Benth.	*Siris*	2.67	58	4.57	0.08	4.46
	Albizia lucida Benth.	*Potka Siris*	3.00	67	4.50	0.07	4.35
	Erythrina suberosa Roxb.	*Modar*	2.92	83	3.50	0.04	4.19
	Bauhinia purpurea L.	*Og-yok*	2.75	92	3.00	0.03	3.95
Lythraceae	*Duabanga grandiflora* (DC.) Walp.	*Bondorphulla*	2.92	75	3.89	0.05	4.78
	Lagerstroemia speciosa (L.) Pers.	*Ajar*	4.58	100	4.58	0.05	5.85
	Lagerstroemia parviflora Roxb.	*Ajar*	2.92	92	3.18	0.03	5.08
Euphorbiaceae	*Mallotus repandus* (Willd.) Müll.Arg.	*Bhelko*	3.00	83	3.60	0.04	4.53
	Mallotus philippensis (Lam.) Müll.Arg.	*Red Kamala*	2.33	92	2.55	0.03	4.56
Rubiaceae	*Pavetta indica* L.	-	4.33	75	5.78	0.08	5.26
Actinidiaceae	*Saurauia roxburghii* Wall.	*Bon posola*	3.67	83	4.40	0.05	3.85
Altingiaceae	*Altingia excelsa* Noronha	*Jutuli*	3.67	92	4.00	0.04	3.95
Burseraceae	*Canarium bengalense* Roxb.	*Dhuna*	4.42	100	4.42	0.04	5.03
Bignoniaceae	*Stereospermum chelonoides* (L.f.) DC.	*Paroli*	3.58	92	3.91	0.04	4.11
Calophyllaceae	*Mesua ferrea* L.	*Nahor*	2.67	75	3.56	0.05	3.51
Dilleniaceae	*Dillenia indica* L.	*Ou tenga*	3.50	83	4.20	0.05	4.04
Tetramelaceae	*Tetrameles nudiflora* R. Br.	*Bhelu*	7.08	100	7.08	0.07	5.83
Apocynaceae	*Alstonia scholaris* (L.) R. Br.	*Satiyana*	2.75	100	2.75	0.03	4.47
Dipterocarpaceae	*Vatica lanceifolia* (Roxb.) Blume	*Morhal*	4.50	92	4.91	0.05	6.10
Fagaceae	*Castanopsis indica* (Roxb. ex Lindl.) A.DC.	*Hingori*	2.75	92	3.00	0.03	4.92
Rutaceae	*Evodia meliifolia* (Hance ex Walp.) Benth.	*Maiphak*	4.42	92	4.82	0.05	5.78

The maximum IVI (12.04) was for the *Bombax ceiba, Gmelina arborea* and *Lagerstroemia speciosa* has the IVI value of 10.62 and 9.85 respectively. 100% frequency was recorded for the *Bombax ceiba, Gmelina arborea and Lagerstroemia speciosa*. 83 % frequency was observed for the sixteen species. A Density of 138.83 trees ha^{-1} was recorded in the NDWS. The A/F ratio was in the range from 0.03 to 0.09. The minimum IVI Value (4.78) was recorded for the *Pterygota alata* (Table 3).

Table 3. Distribution analysis of tree species in Nambor Doigrung Wildlife Sanctuary

Family	Botanical name	Local name	D	F	A	A/	IV
Leguminosae	*Albizia lebbeck* (L.) Benth.	*Siris*	2.17	92	2.36	0.0	6.2
	Albizia procera (Roxb.) Benth.	*Koroi*	3.92	83	4.70	0.0	7.7
	Albizia odoratissima (L.f.) Benth.	*Siris*	4.58	92	5.00	0.0	6.5
	Bauhinia purpurea L.	*Og-yok*	2.58	92	2.82	0.0	7.7
	Butea monosperma (Lam.) Taub.	Palash	3.67	92	4.00	0.0	8.4
	Dalbergia sissoo DC.	*Sissoo*	4.17	67	6.25	0.0	9.3
	Cassia fistula L.	*Shunaru*	2.42	75	3.22	0.0	5.5
Malvaceae	*Pterospermum acerifolium* (L.) Willd.	*Moragos*	3.00	92	3.27	0.0	6.1
	Pterygota alata (Roxb.) R.Br.	*Pahari*	1.67	67	2.50	0.0	4.7
	Sterculia villosa Roxb.	*Udal*	2.92	92	3.18	0.0	5.5
	Bombax ceiba L.	*Simolu*	7.75	10	0.00	0.0	12.
Clusiaceae	*Garcinia cowa* Roxb. ex DC.	*Kau thekera*	4.33	92	4.73	0.0	7.1
	Garcinia morella (Gaertn.) Desr.	*Kujithekera*	2.33	83	2.80	0.0	5.3
	Garcinia pedunculata Roxb. ex Buch.-Ham.	*Bar thekera*	3.58	75	4.78	0.0	5.4
Moraceae	*Streblus asper* Lour.	-	4.42	83	5.30	0.0	8.5
	Ficus semicordata Buch.Ham. ex Sm.	*Tokuk asing*	2.75	92	3.00	0.0	6.8
	Artocarpus heterophyllus Lam.	*Kothal*	2.33	75	3.11	0.0	7.2
Lauraceae	*Phoebe cooperiana* P.C.Kanjilal & Das	*Mekahi*	2.67	67	4.00	0.0	8.0
	Litsea monopetala (Roxb.) Pers.	*Soalu*	3.50	83	4.20	0.0	8.3
	Phoebe goalparensis Hutch.	*Bonsum*	2.83	58	4.86	0.0	5.0
Lamiaceae	*Gmelina arborea* Roxb.	*Gomari*	4.42	10	4.42	0.0	0.6
	Callicarpa arborea Roxb.	*Bonmola*	3.58	92	3.91	0.0	9.6
Apocynaceae	*Plumeria alba* L.	*Champa*	4.33	92	4.73	0.0	6.1
	Alstonia scholaris (L.) R. Br.	*Satiyana*	4.42	92	4.82	0.0	7.4
Lythraceae	*Duabanga grandiflora* (DC.) Walp.	*Bondorphulla*	2.25	83	2.70	0.0	5.5
	Lagerstroemia speciosa (L.) Pers.	*Ajar*	4.33	10	4.33	0.0	9.8
Magnoliaceae	*Magnolia globosa* Hook.f. & Thomson	-	1.75	75	2.33	0.0	5.9
	Magnolia hodgsonii (Hook.f. & Thomson) H.Keng	*Barhamthuri*	2.08	83	2.50	0.0	5.6
Phyllanthaceae	*Baccaurea ramiflora* Lour.	*Leteku*	2.08	83	2.50	0.0	5.8
	Bischofia javanica Blume	*Urium*	4.42	83	5.30	0.0	8.4
Meliaceae	*Azadirachta indica* A.Juss.	*Neem*	1.67	75	2.22	0.0	5.1
	Toona ciliata M.Roem.	*Poma Jatipoma*	2.42	75	3.22	0.0	4.9
Euphorbiaceae	*Mallotus nudiflorus* (L.) Kulju & Welzen	*Bhelko*	3.58	83	4.30	0.0	7.3
	Mallotus philippensis (Lam.) Müll.Arg.	*Red Kamala*	3.67	83	4.40	0.0	5.9
Rhamnaceae	*Ziziphus jujuba* Mill.	*Bogori*	3.08	92	3.36	0.0	5.7
	Ziziphus rugosa Lam.	*Bon bogori*	3.92	75	5.22	0.0	5.5
Altingiaceae	*Altingia excelsa* Noronha	*Jutuli*	3.00	83	3.60	0.0	5.1
Bixaceae	*Bixa orellana* L.	*Jolandhar*	2.92	92	3.18	0.0	5.6
Dilleniaceae	*Dillenia indica* L.	*Ou-tenga*	2.50	83	3.00	0.0	5.7
Moringaceae	*Moringa oleifera* Lam.	*Sajana*	2.33	83	2.80	0.0	4.9
Sapotaceae	*Mimusops elengi* L.	*Bakul*	2.75	83	3.30	0.0	5.8
Sapindaceae	*Sapindus mukorossi* Gaertn.	*Reetha*	2.33	83	2.80	0.0	7.7
Tetramelaceae	*Tetrameles nudiflora* R. Br.	*Bhelu*	3.42	83	4.10	0.0	8.4

α-diversity (Species Richness) was the maximum 63 for PRF. NDWS has reported 43 as its α-diversity. Beta Diversity 2.5 was recorded for NDWS. The highest Concentration of Dominance (Cd) (0.312) was recorded for PRF while NDWS showed 0.243 Concentration of Dominance (Cd). The highest H' (4.12) was recorded in the PRF while the lowest H' (3.7) was recorded in NDWS. The maximum value of Evenness (J) (0.73) was recorded in the PRF while the minimum (0.71) was recorded in the NDWS (Table 4).

Table 4. Diversity index of trees at PRF and NDWS

Indices	Poba Reserve Forest	Nambor Doigrung Wildlife Sanctuary
Richness (α)	63	43
Diversity (β)	2.33	2.5
Dominance (Cd)	0.312	0.243
Shannon(H')	4.12	3.7

The AGB of the present study ranged from 91.04 Mg ha^{-1} to 110.07 Mg ha^{-1}. Similarly, the values of AGBC stocks in this study ranged from 45.52 Mg ha^{-1} to 55.03 Mg ha^{-1}. Overall compared to the NDWS, AGB and AGBC stocks were recorded less than PRF. This result of higher AGB and AGBC stocks in PRF also substantiates the positive relationship of basal area with AGB to that of matured large tree composition and old growth managed reserve forest (Table 5).

Table 5. Above ground biomass and carbon stocks

Forest	Aboveground biomass (Mg ha^{-1})	Aboveground biomass carbon (Mg ha^{-1})
Poba Reserve Forest	110.07	55.03
Nambor-Doigrung Wildlife Sanctuary	**91.04**	**45.52**

In PRF, for height distribution the highest proportion of stems (1436 stems ha^{-1}) was recorded in the height class of 6-10 m, followed by the height class of 11-15 m (714 stems ha^{-1}) (Figure 1). The lowest proportion of stems (44 stems ha^{-1}) was recorded in the height class of Â 5 m. The majority of the trees (60 %) occupied the lower stratum where they form a close canopy (height between 6 - 10 m). Height class of 11-15 m occupies 30 % of middle and about 5% and 4% occupied the upper stratum (16 -20 m and 21-25 m respectively) (Figure 1). Similarly, in NDWS highest proportion of trees (1204 stems ha^{-1}) was found in 6-10 m, followed by 11-15 m height class with 355 stems ha^{-1}. Also the lowest proportion of stems (43 stems ha^{-1}) was recorded in the height class of Â 5 m. There was no tree species found in the 21-25 m height class. About 72 % of 6-10 m class occupied the lower stratum. 11-15 m height class occupied 21 % of middle stratum. Upper stratum in only occupied by 4 % of 16-20 m trees (Figure 1).

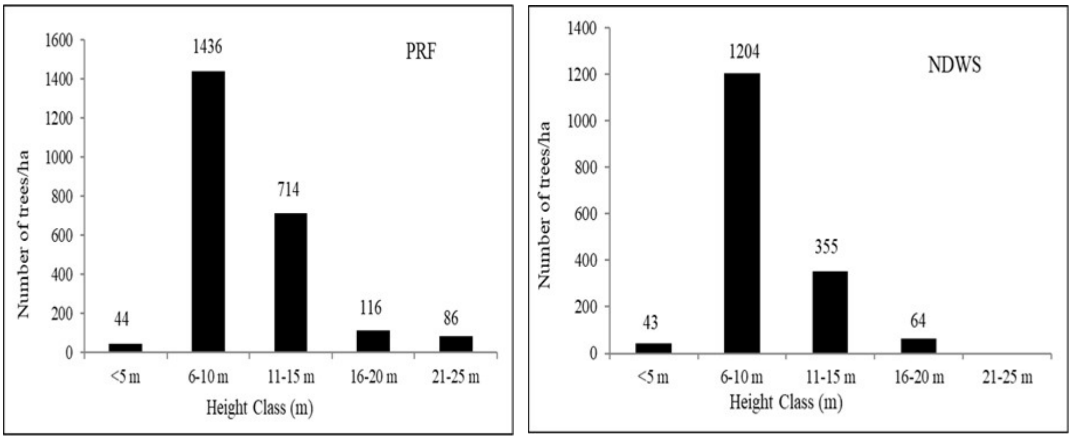

Figure 1. Number of stems ha^{-1} in each of the height classes of PRF and NDWS

There was a positive and significant linear relationship among the tree growth variables both at PRF and NDWS (Table 6). In PRF, the r-values ranged between 0.03 and 0.98. The highest correlation coefficient was obtained between the height and volume (0.98) followed by basal area and logarithm transformed basal area (0.94). Very weak correlation was observed between DBH and most of the other growth variables. The r-value between the height and basal area and also between heights with logarithm transformed basal area was

0.03. Similarly in NDWS, the r-values ranged between 0.21 and 0.97. The highest correlation coefficient was obtained between the basal area and logarithm transformed basal area (0.97). Very weak correlation was observed between height and other growth variables.

Table 6. Correlation matrix for tree growth variables of PRF and NDWS

PRF	DBH(cm)	Height (m)	BA (m^2)	Vol (m^3)	Ln Ba	Ln Vol
DBH(cm)	1.00					
Height (m)	0.21	1.00				
BA (m^2)	0.23	0.03	1.00			
Vol (m^3)	0.38	0.98	0.00	1.00		
Ln Ba	0.20	0.03	0.94	0.05	1.00	
Ln Vol	0.57	0.80	0.08	0.88	0.11	1.00
NDWS						
DBH(cm)	1.00					
Height (m)	0.28	1.00				
BA (m^2)	0.21	0.26	1.00			
Vol (m^3)	0.73	0.66	0.29	1.00		
Ln Ba	0.23	0.28	0.97	0.33	1.00	
Ln Vol	0.76	0.65	0.31	0.97	0.34	1.00

DBH= Diameter at breast height; BA= Basal area; Vol= Volume of the trees

DISCUSSION

In this study, the floristic diversity was found to be very similar to other tropical forests. Though there is little variation, in both the forests, species richness (63 & 43 species ha^{-1}respectively) and species diversity (4.12 & 3.7 respectively) were observed as higher which is in accordance with some other Indian forests such as tropical forests of Shervarayan hills (Kadavul & Parthasarathy 1999), Nelliampathy (Chandrasehkara & Ramakrishnan 1994), Mylodai forest of Courtallum (Parthasarathy & Karthikeyan 1997b). The higher number of species richness in the study area is attributed due to the presence of the riverine forest that contributes to the growth of many species. Species richness might be varied from forest to forest due to climatic factors, edaphic variability and anthropogenic activities and natural calamities. The number of species in NDWS is found less as compared to PRF which might be due to the factors such as over exploitation, wood smuggling, erosion, human encroachment, jhum cultivation as well as conversion of forest land into agricultural land etc. Whereas, the species richness value of PRF (63) indicates it as a mature tropical forest (Losose & Leigh 2004). The higher value of species richness in PRF might be due to the presence of less anthropogenic activity, lack of jhum cultivation and every year flash flood. Every year flash flood helps the forest from non-conversion into agricultural field.

In the present study, the tree density for both the forests (PRF and NDWS) were analysed and found as 138.83- 205.66 trees ha^{-1} respectively which is less than the reports of other study (245-1800 trees ha^{-1}) for several Indian tropical forests (Campbell *et al.* 1992; Visalakshi 1995; Ayyappan & Parthasarathy 1999). The tree density might be lees owing to natural calamities, anthropogenic activities and soil properties. Conversely, earlier study supports the present findings regarding number of tree families and number of trees (Lu *et. al*. 2010).

The most obvious variation in tree species and the proportion of dominant species in the two forests can directly be attributed to rainfall distribution. PRF with more rainfall is predominantly an evergreen forest which situated in the hilly regions along its northern boundary. The basal area of the two forests ranged between 19.69 and 46.62 m^2 ha^{-1} (Table 2). The values are in range between 3.73 - 59.33 m^2 ha^{-1} for North East (IIRS 2002). Basal area of PRF is greater than 25.5 m^2 ha^{-1} in Rio Xingu, Brazil (Campbell *et al.* 1992) and 27.4 m^2 ha^{-1} in Ecuador, Amazon (Valencia *et al.* 1994), but lower than 82.67 m^2 $ha^{-1}$of Reunion island

(Strasberg 1996), 55-94 m^2 ha^{-1} of Kalakad in Western Ghats (Ganesh *et al.* 1996) and 62.49-90.29 m^2 ha^{-1} of Kholahat reserve forest and Gibbon Wildlife Sanctuary of Assam (Borah *et al.* 2015). The basal area value of NDWS is closer to the values (18.9-19.58 m^2 ha^{-1}) reported by Jha and Singh (1990) for dry tropical forest of Vindhyan region of India. The lower basal area in the forests likely results from smaller numbers of larger individuals (Gonzalez & Zak 1996).

Importance value index (IVI) was found to range from 3.51- 8.35 and 4.79 -12.04 for both PRF and NDWS respectively (Tables 2 & 3). The IVI revealed that these two forests are dominated by relatively few species. The small values of IVI denote that these sites are under heavy disturbances.

The value of Shannon-Wiener index (H') for PRF and NDWS ranged between 4.12 and 3.7 respectively (Table 5). The larger the value of H', the greater the species diversity and *vice versa* (Parthasarathy & Karthikeyam 1997a). An ecosystem with H' value greater than 2 has been regarded as medium to high diverse in terms of species (Barbour *et al.* 1999). Higher H' value for PRF indicates the most complexity whereas lower value of H' for NDWS depicts simplest community in term of species composition and diversity. According to some other study the diversity index is generally higher in tropical forests [5.06 and 5.40 for young and old stand respectively (Knight (1975)], whereas for Indian forests it ranged between 0.83 to 4.1 (Parthasarathy *et al.* 1992; Singh *et al.,* 1984; Visalakshi 1995; Agni *et al.* 2000) which supports the present findings. The concentration of dominance (CD) of the present study sites ranged from 0.243 to 0.312 (Table 5). According to Whittaker and Niering (1975); Risser and Rice (1971); Singhal *et al.* (1986) and Pande *et al.* (1996), the value of concentration of dominance (CD) for temperate forests falls within the range of 0.10 to 0.99, however, for tropical forests the average value is 0.06 as reported by Knight (1975). The range of CD reported for tropical forest of India varies from 0.21 to 0.92 (Parthasarthy *et al.* 1992; Visalakshi 1995). The CD value reported in present study corresponds well with the reported range for tropical forest by several workers (Parthasarthy *et al.* 1992; Visalakshi 1995). The value of diversity index of the present study, therefore, lies within the range reported for tropical forests.

Tree stem volume at stand level is one of the most important parameters in forest management but its acquisition is very time consuming and expensive as it is normally obtained from field surveys (Tonolli *et al.* 2011). The estimated tree stem volume in this study is ranged from 53.92 to 130.15 m^3 ha^{-1} which is less than 391 m^3 ha^{-1} reported by Wittmann *et al.* (2008) and the 406 - 416 m^3 ha^{-1} reported by Tonolli *et al.* (2011) for multilayer forest areas in Italian Alps. The difference in this value might be due to the different methods adopted for volume computation. In this present study, an analytical formula, namely the Newton's volume estimation formula as suggested by Husch *et al*. (2003) was used. The variation in these values could also be attributed to factors like the sampling intensity, inter-location variations, soil properties and different climatic conditions.

Floristic diversity of forests plays an important role in storing carbon as the old growth and matured forest with big and diverse tree species contain more AGB and AGBC (Brown & Lugo 1982; Terakunpisut *et al.* 2007; Borah *et al.* 2015). The AGB of the present study ranged from 91.04 Mg ha^{-1} (NDWS) to 110.07 Mg ha^{-1} (PRF) which is less than the study made on Tropical forest of Thailand (275 Mg ha^{-1}, Terakunpisut *et al*. 2007); South Africa (358.1 Mg ha^{-1}, Mensah *et al.* 2016); Singapore (334.98- 209.04 Mg ha^{-1}, Ngo *et al.* 2013); Asia (225 Mg ha^{-1}, Brown *et al.* 1991) and some studies made in India (307 Mg ha^{-1}, Ramachandran *et al.* 2007) while being comparable with the findings of Borah *et al.* (2013) (32.47 to 261.64 Mg ha^{-1}); Haripriya (2000) (14 to 210 Mg ha^{-1}); and Larson (2002) (50-430

Mg ha^{-1}). Similarly, the values of AGBC stocks in this study ranged from 45.52 Mg ha^{-1} (NDWS) to 55.03 Mg ha^{-1} (PRF) which supports the other previous studies (Cairns *et al.* 2003; Sierra *et al.* 2007; Chaturvedi *et al.* 2011; Borah *et al.* 2013; Haripriya 2000; Larson 2002). Overall, compared to the PRF, the AGB and AGBC stocks were recorded less in NDWS.

CONCLUSION

In PRF, the forest area was moist mixed semi-evergreen forest, moist mixed deciduous forest, degraded forest, tall grasses and small grasses while in NDWS forest area was covered with Tropical Semi-evergreen rainforest with of evergreen and marsh forest. The species diversity and abundance compared are similar with other forest ecosystems. A total of 63 and 43 different tree species belong to 27 and 21 families was recorded in the PRF and NDWS, respectively. Compared to the PRF, a significantly less density of trees was recorded in the NDWS. Basal area also showed similar trend. Considerably higher AGB (110.07 Mg ha^{-1}) and AGBC (55.03 Mg C ha^{-1}) was recorded in the PRF compared to the NDWS. The highest correlation coefficient was obtained between the height and volume. A very weak correlation was observed between DBH and most of the other growth variables. From the findings it could be concluded that the higher AGB and AGBC in the PRF were due to diverse tree species while in the NDWS all the three parameters were lower due to reduced forest area as the Sanctuary faces large-scale encroachments by human populations (Sarma *et al.* 2008). Also in recent years, developmental activities such as establishment of the Numaligarh Refinery and increasing tea estates have influenced the species diversity.

Acknowledgements

The authors are thankful to Dr. D. Ramaiah, Director, CSIR-NEIST for his support and DST, Govt. of India for providing financial support.

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