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Assessment of Biomass and Carbon Stock in Sal (*Shorea robusta* Gaertn.) Forests under Two Management Regimes in Tripura, Northeast India

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Abstract

We investigated tree composition, stand characteristics, biomass allocation pattern and carbon storage variability in Sal forests (*Shorea robusta* Garten.) under two forest management regimes (Sal forest and Sal plantation) in Tripura, Northeast India. The results revealed higher species richness (29 species), stand density of 1060.00±11.12 stems ha^{-1} and diversity index (1.90±0.08) in Sal forest. and lower species richness (4 species), stand density of 230.00±37.22 stems ha^{-1} and diversity index (0.38±0.15) in Sal plantation. The total basal cover (33.02±4.87 m^2 ha^{-1}) and dominance (0.76±0.08) were found higher in Sal plantation than the Sal forest (22.53±0.38 m^2 ha^{-1} and 0.23±0.02 respectively). The total vegetation carbon density was recorded higher in Sal plantation (219.68±19.65 Mg ha^{-1}) than the Sal forest (167.64±16.73 Mg ha^{-1}). The carbon density estimates acquired in this study suggest that Sal plantation in Tripura has the potentiality to store a large amount of atmospheric carbon inspite of a very low species diversity. However, Sal forests has also an impending sink of carbon due to presence of large number of young trees.

Key Words: biomass, carbon sink, diversity, management regimes, soil

Introduction

Forest ecosystems act as natural carbon sinks and play the most significant role by producing large carbon pools stored as vegetation biomass including storage of carbon in the soil (Brown and Lugo 1992). The carbon acquired from the atmosphere is fixed to form organic compounds through photosynthesis (Alexandrov 2007). Thus atmospheric carbon becomes the part of the plant body and stored for a long period in different parts of the plant. The growing danger of increased environmental degradation and tangible economic services for human civilization, has resulted in primary old growth forest being replaced with planted forest, as a result biological diversity is lost due to the mismanagement of natural resources. The roles of natural as well as planted forests are being increasingly felt for diverse intangible services rather than tangible economic goods. Forest ecosystems are uniquely placed in the global scenario of climate change as they are acting as storehouse of biodiversity and carbon sink (Dixon et al. 1994; Dirzo and Raven 2003; Gibbs et al. 2007; Fahey et al. 2010). Once the plant dies or the plant material decomposes the carbon is released to the soil. This carbon content can be released in the form of CO_2 through decomposition of plant biomass and respiration, especially respiration of plant roots and the soil microbes. The amount of soil respiration that occurs in an ecosystem is largely controlled by factors like temperature, moisture, nutrient content and oxygen level.

It was reported that globally, biodiversity is changing at an unprecedented rate as a complex response to natural

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and human-induced changes (Vitousek 1997; FAO 2006). As per FAO (2012), the global forest area has decreased by 4.1 and 6.4 million ha year−1 and 3% of the world's forest are disturbed annually by logging, fire, pests, or weather. It has been reported that more than 60% of the world's forest are recovering from a past disturbance (FAO 2006). The role of tropical forest in mitigating climate change and potential effects on climate as result of deforestation have been extensively studied globally (Dixon et al. 1994; Houghton 1995; Masera et al. 1995; Fang et al. 1998; De Jong et al. 1999, 2000; Cairns et al. 2000; Grace et al. 2006). There is uncertainty in the magnitude of carbon flux due to tropical forest deforestation (Brown and Lugo 1984). In India, large areas of primary tropical forests are degraded at to a varying extent and converted to other land uses (Behera and Misra, 2006; Barik and Mishra 2008). About two-thirds of terrestrial C stored in terrestrial carbon pools like rocks and sediments and also sequestered in the standing forests, forest understory plants, leaf and forest debris, and in forest soils (Sedjo et al. 1998). Out of total carbon stored in an ecosystem, 89 % of losses are due to loss of living biomass (Keith et al. 2014).

In India Sal is spread over an estimated area of 13 million hectares and primary *Sal forest* is gradually replaced by secondary regenerated *Sal forest* due to over-exploitation, deforestation, encroachment and alteration in land use and land cover (Deka et al. 2012). Species composition of forests depends on potential regenerative status of tree species within a forest stand (Ayyapan and Parthsarthy 1999) and forest biomass is drastically modified by the level of exploitation, successional levels, and management practices. Absence of all negative factors and good management practices including model plantations of Sal would contribute further in high biomass values. The protection of existing forests, regeneration of degraded forests and raising of forest plantations in India have been contributing at large extent to enhanced productivity and carbon stock (Ravindranath et al. 2008).

Researches on carbon accumulation pattern and storage in forest ecosystem as well as plantation forest have gained momentum. Forests cover 4.03 billion hectares globally, approximately 30% of the Earth's total land area (FAO 2010). Natural forests possess high species diversity when compared with the plantation forests they are increasingly recognized for their capacity to sequester atmospheric carbon (Baishya and Barik 2011). It has been suggested that atmospheric carbon sequestration through increasing the volume of plantation forest lands on the planet is an effective measure for mitigating atmospheric carbon dioxide (Peichl and Arain 2006; Taylor et al. 2007). Plantations represent a reservoir of biomass carbon similar to natural forest since stand age is the dominant factor influencing the total plantation ecosystem carbon pool (Justine et al. 2015).

Tropical plantation forests have a slight competitive advantage over the natural forests when sequestering atmospheric C because of adoption of improved silvicultural practices (Baishya et al. 2009). Other studies estimated tree biomass and carbon (C) stock in different natural and plantation forests and yielded variable results (Young et al. 2005; Devagiri et al. 2013). The replacement of unproductive natural forests with plantations could be considered as a measure to enhance carbon sequestration. Biomass and carbon density varies with climatic zones and different management regimes within land-use types (Upadhaya et al. 2015). The sequestration potential also varies with different age classes and species level density change that lead to stratification of different carbon pools (Baishya and Barik, 2011). More emphasis is placed estimating aboveground biomass as it represents the 60% of total phytomass (Baishya et al. 2009) and considered as an important aspect while studying vegetation carbon pool (Ketterings et al. 2001). Furthermore assessment of other biomass components viz. belowground biomass, dead wood biomass and litter biomass is essential to account for the total carbon sequestered by the vegetation over a specific time and would be the key determinant of land use change and deforestation influence the net carbon fluxes. In terms of carbon benefit the present study has been conducted on *Sal plantation* and moist deciduous *Sal forest* in Tripura, Northeast India.

Therefore, the present study aims to assess stand characteristics, tree species composition, tree biomass and carbon stock (above and below ground) *Shorea robusta* Gaertn. dominated two management regimes (*Sal forest* and *Sal plantation*) of Tripura, Northeast India. It was also undertaken to understand the uncertainties and inconsistency of biomass and carbon stock variability in two management regimes.

Materials and Methods

Study area

The State Tripura has a tropical climate and receives adequate rainfall during the monsoons. The local flora and fauna bear a close affinity and resemblance with Indo-Malayan and Indo-Chinese sub-regions (http://www.forest.tripura.gov.in). The State is located in the bio-geographic zone of 9B-North-East hills (Champion and Seth, 1968) and possesses an extremely rich bio-diversity. The state lies between 22°56' to 24°32' N latitude and 90°09' to 92°20' E longitude. The state experiences three different climates of tropical savanna, tropical monsoon and humid subtropical climatic condition (https://www.en.climate-data). The temperature in the state ranges from 21°C to 38°C in summer, whereas it fluctuates from 13°C to 27°C in the winter season. The annual rainfall ranges from 1922 mm to 2855 mm. As per the report of the Forest Survey of India (FSI 2015) total forest and tree cover in the state is 8,044 km^2 i.e., 76.71 % of the total State's geographical area.

The forests of Tripura are divided into two major forest groups viz. - i) Semi Evergreen Forests and ii) Moist Deciduous Forests (FSI 2011). The Moist Deciduous Forests are further divided into Moist Deciduous *Sal Forest*s and Moist Deciduous Mixed Forests, the former beingt found in Belonia, Udaipur, Sonamura and Sadar Sub-Divisions of the state. *Shorea robusta* Gaertn. (commonly called as 'Sal') is the most dominant tree species in the Moist Deciduous *Sal Forest* occupying more than 60% top canopy (http://tspcb.tripura.gov.in). This type of forest is also found in southern and northern low hills extending up to the border of Bangladesh. However, due to expansion of agriculture coupled with other landuse change in recent years, *Sal forest*s have undergone significant changes in some areas of the state. Most frequently the native moist deciduous *Sal forest* found in Belonia, Udaipur, Sonamura and Sadar Sub-Divisions of the state. The major changes in this types of forest due anthropogenic pressure in terms of over exploitation of timber, fuelwood, extension of rubber plantation and other factors intensified the alteration of such forest cover into secondary degraded vegetation even in some PF and RF. However, as a management practices, several types of plantation program with native species had been carried out by Forest Department for rehabilitation of degraded forest for last few decades (Chakraborty 1985). In case of native Moist deciduous *Sal forest* potential silvicultural conditions prevail for forest production maintain by forest department. The present study area covered some extent of such forest types which comes under the jurisdiction of Sadar Fo rest Division, Udaipur Forest Division and Teliamura Forest Division comprising Reserve forest (23°28'41.80"N Lat. and 91°28'49.00"E Long.; 23°33'5.83"N Lat. and 91°25'10.54"E Long.; 23°30'20.40"N Lat. and 91°26'42.00"E Long.; 23°48'12.6"N Lat. and 91°38'36.8"E Long.), monoculture plantation (23°53'07.8" N Lat. and 91°17'21.2"E Long.). Among the studies one RF was secondary regenerated *Sal forest* due to the past disturbances and gradual shift from primary forest.

Sample plot design and measurements

Assessment of terrestrial vegetation biomass in the five different sites of Tripura was carried out using ground sampling. The selection of representative sites in different forests divisions was made on the basis of type of forest stand (Moist deciduous *Sal forest*, Secondary *Sal forest* and Sal monoculture plantation) and magnitude of stem distribution in terms of homogeneity in girth class and height classes thereby reduction in sampling area. A permanent plot of 250 x 250 m size was established during field investigation at each site. Four sample plots, each of 31.6 m x 31.6 m (0.1 ha) size in all the four directions i.e. NE, NW, SW and SE, respectively (Fig. 1.) were laid in each super plot for detail record such as forest type, species composition, girth at breast height (gbh of $\geq$ 10 cm) and height measurement. Tree population structure were analyzed using eight girth classes i.e., 10-30, 31-60, 61-90, 91-120, 121-150, 151-180, 181-210, 211-240. Overall 8 quadrats for Moist Deciduous *Sal Forest* (SF) and 12 quadrats for *Sal Plantation* (SP) were considered for girth measurement. All woody individuals at $\geq$10 cm girth over bark at 1.37 m height were measured which is a useful starting point for estimating tree volume. Height of all the trees present in the plot was measured using Clinometers. Basal area (m^2) was calculated using the following equation adapted from the simple formula for the area of a circle (area = πr^2). Stand density of the tree species within the selected areas were assessed as the number of trees per unit area and expressed per hectare basis.

Analytical features of the plant community (abundance, density and frequency) were calculated from field data for abundance, density and frequency following Curtis and McIntosh (1950). The relative frequency, relative density, relative basal area and Importance Value Index (IVI) was calculated following Mueller–Dombois and Ellenberg (1974). Tree species diversity, dominance index of the stand and evenness of the stand of both the selected forest types were calculated following Shannon and Weiner 1963, Simpson (1949) and Pielou (1966) respectively.

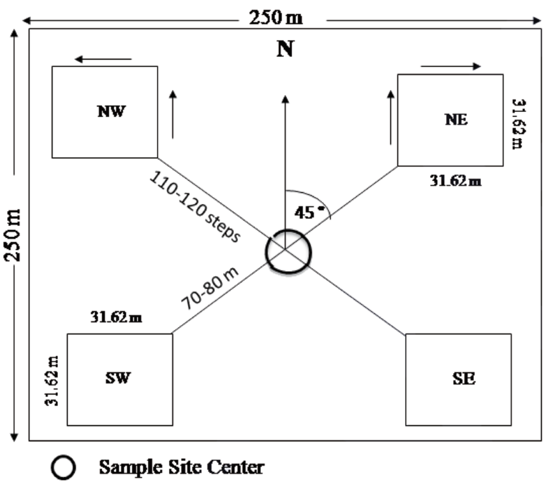

Fig. 1. Cluster sample plot design for enumerating trees species (Dadhwal et al. 2009).

Estimation of biomass & carbon density

Selection of methodological approaches before conducting any vegetation study is quite crucial when a large number of methods already had been practiced. There are a number of practical approaches to determine the stand volume by selecting and measuring the volume of an average tree, then inflate this value for the stand volume. The above ground biomass (AGB) of the tree species of forest stand and plantation stand was calculated by the existing volume equations. Species specific volume equation developed by Forest Survey of India (FSI 1996) and Biomass Conversion and Expansion Factor (0.8) for conversion of stem volume to above-ground Biomass (IPCC 2006), followed by Sahu et al. (2015) was considered under present study. In case of non-availability of species specific volume equation allometric biomass equation i.e. Above Ground Biomass (AGB) = exp[-0.37+0.33*ln(DBH)+0.933*ln(DBH)2-0.122*ln(DBH)3] developed by Chambers et al. (2001) where AGB was calculated per tree in kg and diameter at breast height (DBH) in cm. The allometric equation which was used for Moist deciduous Sal dominated mixed forest that have been suggested for vegetation carbon inventory (Chave et al. 2005) followed by many researchers of the North-eastern region (Baishya and Barik 2011; Upadhya et al. 2015). This is a very conventional method followed in several studies from the same eco-region of the North-East India and also in other states of the Indian territory (Salunkhe et al. 2016; Devagiri et al. 2013; Dadhwal et al. 2009) and has been suitable for biomass estimation by Non-destructive method (Table 1). The estimated volume was converted into biomass by using wood specific gravity of selected tree species developed by Forest Research Institute (FSI 1996). Below groundbiomass (BGB), dead wood biomass carbon (DWB C) of trees was determined by indirect method followed by Sahu et al. (2015). The estimation of forest floor litter biomass, the amount of per unit area was calculated as per Subedi et al. (2010).

For carbon stock assessment in all the study sites, IPCC (2006) suggested carbon fraction of 0.50 was used (Bhat and Ravindranath 2011; Mandal and Joshi 2014). Total vegetation carbon stock of the selected stand was estimated by adding all the values of AGB C, BGB C, DWB C and LB C and converted as Mg C ha^{-1}.

Soil carbon stock density

Soil samples were collected from four different corners from each of the quadrat maintaining 3 layers of the soil strata with the help of soil auger from 0-15, 15-30, 30-45 cm respectively. In total 60 samples (12 samples from each layer total of 36 samples from *Sal plantation* and 24 samples from *Sal forest*) were collected from each depth class. Collected soil samples were brought to the laboratory and air-dried. Samples were passed through a 2 mm sieve to remove stones, roots and large organic residues before conducting analyses of physical and chemical characteristics. Bulk density was determined by the core method. Soil organic Carbon (SOC %) was determined by Walkley-Black

Table 1. Volume equations and wood specific gravity used in the present study

Species	Volume equation	Type	Species specific gravity
Albizia lebbeck (L.) Benth.	V/D2H = −0.00858/D2H+0.0000316	G (North Cachar Hills)	0.760
Albizia procera (Roxb.) Benth.	√V = −0.23861+3.22483D	L (Tripura Survey)	0.579
Alstonia scholaris (L.) R. Br.			0.440
Anogeissus acuminata (Roxb. ex DC.) Wall. ex Guillem. & Perr.	V = 0.099−1.119D+8.2D2	L (MP, Andhra P and Orissa)	0.880
Artocarpus chama Buch.–Ham.	√V = −0.15154+2.79983D	L (Tripura)	0.450
Bombax ceiba L.	√V = −0.24276+2.95525D	L (Tripura Survey)	0.329
Callicarpa arborea Roxb.	√V=0.04506+2.33446D	L (Assam Survey)	0.410
Dillenia pentagyna Roxb.	√V = −0.18641+2.87919D	L (Tripura Survey)	0.579
Ficus hispida L.f.	√V = 0.03629+3.95389D−0.84421 √D		0.390
Grewia nervosa (Lour.) Panigrahi	V = −0.44075+7.49221D−36.09962D2+71.91238D3	L (Assam Survey)	0.703
Holarrhena pubescens Wall. ex G.Don	V = 0.17994−2.78776D+14.44961D2	L (Assam Survey)	0.640
Lannea coromandelica (Houtt.) Merr.	√V = −0.21972+2.86603D	L (Tripura Survey)	0.513
Phyllanthus emblica L.	V = 0.13734−2.49039D+15.59566D2−11.06205D3	L (Assam Survey)	0.619
Schima wallichii Choisy	√V = −0.11242+2.54133D	L (Tripura Survey)	0.550
Shorea robusta Gaertn.	√V = −0.22388+3.29474D	L (Tripura Survey)	0.700
Sterculia villosa Roxb.	V = 0.27909−3.26515D+13.46829D2	L (Assam Survey)	0.543
Tectona grandis L.f.	V =0.19112−3.25372D+17.9194D2−1.66117D3	L (Assam Survey)	0.720
Terminalia bellirica (Gaertn.) Roxb.	√V = −0.00598+2.28626D	L (Tripura Survey)	0.628
Vitex peduncularis Wall. ex Schauer	√V = −0.26502+3.01933D	L (Tripura Survey)	0.300

Source: (FSI 1996).

Note: V= Volume (m^3), D= DBH (cm), H= height (m), L=Local volume equation, G=General volume equation.

Method (1934) and carbon stock density of soil was estimated by following Pearson et al. (2007).

Statistical analysis

The variation in tree density, basal area, biomass and carbon stock due to differences in vegetation type were statistically analyzed using one-way analysis of variance (ANOVA). Comparison was also made between two land use types (*Sal forest* to *Sal plantation*) across different biomass and soil parameters. Data were analyzed using M.S. Excel 2007 (12.0.4518.1014).

Results

Stand structure and characteristics

The *Sal forest*s differed in their structure and community characteristics (Table 2). Maximum number of species (29 tree species) with a mean stem density of 1060.00±11.12 stem ha^{-1} and mean basal cover of 22.53±0.38 m^2 ha^{-1} was recorded for moist deciduous *Sal forest*. On the other hand low species richness (4 tree species) with a mean stem density of 230.00±37.22 stem ha^{-1} and mean basal cover of 33.02±4.87 m^2 ha^{-1} was recorded for *Sal plantation* (Table 3). The result of ANOVA showed significant variation in stand characteristics. Stand density and basal cover of tree species were significantly different in all the selected stands ($F=11.05$, $df=4,15$; $P<0.001$ and $F=7.23$, $df=4,15$; $P<0.05$, respectively). Furthermore, results of the t-test also suggested that stem density ($t=4.86$, $df=7$; $p<0.05$) was significantly higher in *Sal forest* than *Sal plantation*. Thoughbasal cover ($t=5.65$, $df=7$; $p<0.05$) was significantly higher in *Sal plantation* than *Sal forest*. The number of family and observed species in both the management regimes showed different trend of distribution. Mean Shannon's index value was higher in *Sal forest* (1.90±0.08) than in *Sal plantation* (0.38±0.15) and Simpson's index value also varied from site to site and was significantly ($p<0.05$) higher in *Sal plantation* (0.76±0.08) due to homogeneity of the stand in tree species composition than *Sal forest* (0.23±0.02). Species were evenly distributed in all the studied sites except in *Sal plantation* compared to *Sal forest*. In each stand type distribution of density and basal area in different gbh classes were shown in Fig. 2.A-D. In Sal planation maximum density was recorded in 121-150 cm gbh class followed by 61-

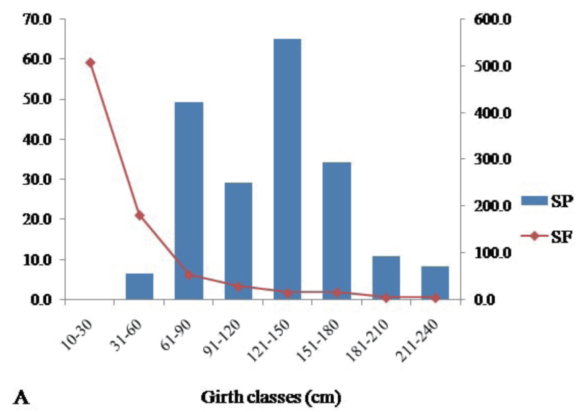

Fig. 2A. Girth class distribution of tree density.

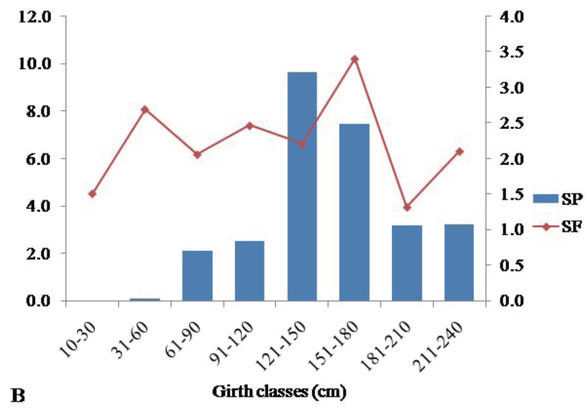

Fig. 2B. Tree basal area cover (BA).

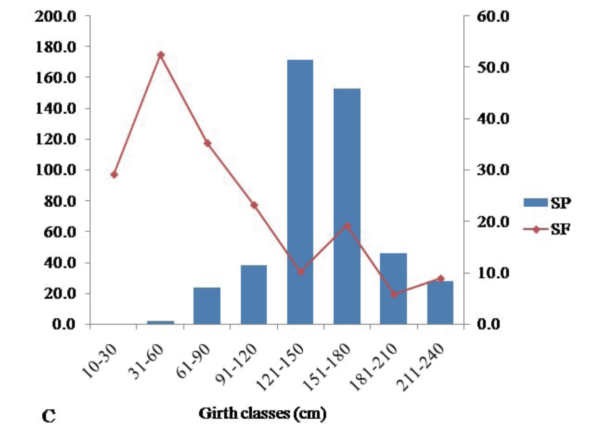

Fig. 2C. Above ground tree biomass (ABG) in Sal plantation (SP) and Sal frest ecosystem.

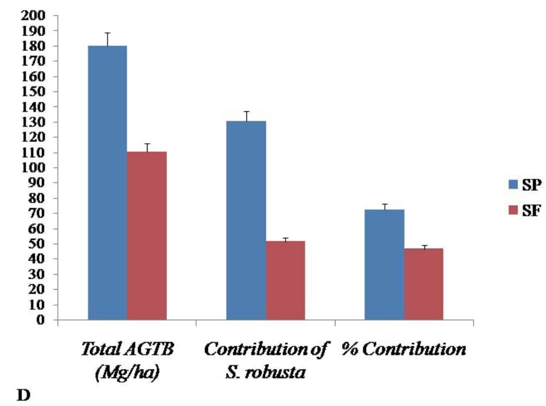

Fig. 2D. Above ground biomass attribute of tree species (AGTB) and the contribution of *Shorea robusta* as the greatest degree of biomass potential.

Table 2. Phyto-sociological attributes of tree species in Sal forests under two management regimes in Tripura, Northeast India

Species Name	Family	Relative Frequency		Mean Density Stem ha^{-1}		Relative Abundance		BA m^2 ha^{-1}		IVI	
		SP	SF	SP	SF	SP	SF	SP	SF	SP	SF
Albizia lebbeck (L.) Benth.	Leguminosae	_	2.08	_	5.00	_	1.17	_	0.03	_	2.82
Albizia procera (Roxb.) Benth.	Leguminosae	_	3.70	_	10.00	_	1.61	_	1.94	_	13.47
Alstonia scholaris (L.) R. Br.	Apocynaceae	_	2.08	_	7.50	_	1.75	_	0.06	_	3.34
Anogeissus acuminata (Roxb. ex DC.) Wall. ex Guillem. & Perr.	Combretaceae	_	6.02	_	50.00	_	2.70	_	0.91	_	17.76
Aporosa octandra (Buch.-Ham. ex D.Don) Vickery	Phyllanthaceae	_	2.08	_	5.00	_	1.17	_	0.01	_	2.66
Artocarpus chama Buch.-Ham.	Moraceae	32.50	14.81	50.00	10.00	27.69	1.61	8.23	4.21	86.54	34.16
Bauhinia acuminata L.	Leguminosae	_	4.17	_	20.00	_	2.33	_	0.30	_	8.76
Bombax ceiba L.	Malvaceae	_	3.70	_	10.00	_	1.61	_	0.02	_	5.40
Bridelia retusa (L.) A.Juss.	Phyllanthaceae	_	6.25	_	7.50	_	0.58	_	0.01	_	7.13
Callicarpa arborea Roxb.	Lamiaceae	_	8.33	_	35.00	_	2.04	_	0.18	_	13.44
Careya arborea Roxb.	Lecythidaceae	_	6.60	_	66.25	_	10.78	_	0.33	_	18.67
Cassia fistula L.	Leguminosae	_	6.25	_	60.00	_	4.67	_	0.34	_	15.23
Dillenia pentagyna Roxb.	Dilleniaceae	_	7.41	_	20.00	_	3.23	_	0.10	_	11.07
Ficus hispida L.f.	Moraceae	_	2.08	_	5.00	_	1.17	_	0.03	_	2.85
Grewia nervosa (Lour.) Panigrahi	Malvaceae	_	6.02	_	73.75	_	4.82	_	0.44	_	17.50
Holarrhena pubescens Wall. ex G.Don	Apocynaceae	_	4.17	_	47.50	_	5.54	_	0.33	_	11.75
Lannea coromandelica (Houtt.) Merr.	Anacardiaceae	_	2.08	_	5.00	_	1.17	_	0.21	_	4.33
Mitragyna rotundifolia (Roxb.) Kuntze	Rubiaceae	_	2.08	_	5.00	_	0.58	_	0.01	_	2.68
Phyllanthus emblica L.	Phyllanthaceae	_	2.89	_	6.25	_	1.10	_	0.03	_	4.02
Schima wallichii Choisy	Theaceae	20.00	8.68	10.00	28.75	10.00	2.65	2.53	0.67	33.90	16.97
Shorea robusta Gaertn.	Dipterocarpaceae	63.33	11.57	165.00	311.25	76.92	40.33	21.97	10.54	221.69	104.00
Spondias pinnata (L. f.) Kurz	Anacardiaceae	_	3.70	_	20.00	_	3.23	_	0.07	_	7.24
Sterculia villosa Roxb.	Malvaceae	_	4.17	_	5.00	_	0.58	_	0.08	_	5.33
Suregada multiflora (A.Juss.) Baill.	Euphorbiaceae	_	4.17	_	10.00	_	1.17	_	0.06	_	5.71
Syzygium cumini (L.) Skeels	Myrtaceae	25.00	6.25	5.00	25.00	3.85	1.94	0.29	0.14	28.18	10.00
Tectona grandis L.f.	Lamiaceae	_	4.17	_	32.50	_	3.79	_	0.88	_	14.96
Terminalia bellirica (Gaertn.) Roxb.	Combretaceae	_	7.41	_	130.00	_	20.97	_	0.47	_	30.36
Vitex peduncularis Wall. ex Schauer	Lamiaceae	_	5.79	_	38.75	_	5.86	_	0.08	_	12.01
Ziziphus oenopolia (L.) Mill.	Rhamnaceae	_	3.70	_	10.00	_	1.61	_	0.04	_	5.48

Note: SP - Sal plantation and SF - Sal forest.

90 gbh class. Overall, 87.3% density was recorded between 61 and 180 cm gbh in *Sal plantation* while 84.8% density was recorded between 10-60 cm gbh in *Sal forest* indicating good occurrence of juvenile and adult tree species and marked reduction of species of higher-diameter classes.

Biomass and carbon stock

The biomass allocation in different pools viz. above ground biomass (AGB), below ground biomass (BGB), dead wood biomass (DWB) and litter biomass (LB) in five different sites categorized into two vegetation type varied from *Sal plantation* to *Sal forest*. *Sal plantation* possessed maximum AGB (179.88±29.43 Mg ha^{-1}) in girth class 121-150 cm followed by 110.53±1.82 Mg ha^{-1} in girth class 31-60 cm recorded in *Sal forest* (Fig. 2C.). Among different sites, maximum contribution was made by *Shorea robusta* in *Sal plantation* (72.5%) and *Sal forest* (46.5%) (Fig. 2D.). The AGB and BGB biomass when pooled together registered higher biomass in *Sal plantation* (226.65 Mg ha^{-1}) than in *Sal forest* (139.27 Mg ha^{-1}) (Table 4). Total carbon estimated in all pools in *Sal plantation* was 219.68±19.65 Mg ha^{-1} while the corresponding value for *Sal forest* was 167.64±16.73 Mg ha^{-1}. In both the systems, the contribution of SOC was maximal to the total carbon stock; however, the relative contribution of SOC to the total carbon was conspicuously higher in *Sal forest* than *Sal plantation*. In terms of biomass productivity above ground biomass varies significantly from site to site (F=21.97, df=4,15; P<0.05) and significantly higher in *Sal plantation* than *Sal forest* (t=9.08, df=7, P<0.05). *Sal forest* showed significantly lower biomass density than *Sal plantation* since these sites accounted higher species density and considered to be as disturbed forest. Due to the irregular felling of trees and comparatively lesser number of mature trees formation of secondary forest though natural regeneration was found be very high (Table 4).

ANOVA showed significant variation in organic carbon accumulation within all sites (F=6.42, df=4,15; P<0.05) whereas t-test showed comparatively greater (t=38.64, df=7, P<0.001) mean soil organic carbon stock in *Sal plantation* than the mean value recorded for *Sal forest* however mean percent organic carbon content was higher in *Sal forest* (1.67±0.27) with mean bulk density of 1.78±0.04 than *Sal plantation* (1.59±0.35) with mean bulk density 1.95±0.04 and it can be assumed that due to high degree of compactness, porosity and bulky nature of the soil may lead to the uplift of organic matter deposition in various soil depth.

Correlation matrix (Table 5) highlighted a positive relation between bulk SOC stocks which is depended on bulk density (62% variation in SOC can be explained by bulk density). A strong and significantly positive correlation (0.83) was found between aboveground tree biomass and evenness index and it can be presumed that homogeneity in species composition along with their diameter class distribution is the key determinant of enhanced productivity. A positive correlation was found between aboveground biomass and basal cover by tree species. However, above ground biomass was not correlated with stem density.

Discussion

Stand structure and characteristics

Large and relatively low cost mitigation opportunities through biomass accumulation on the pick of global carbon issues likely to be attained by extensive studies. The results of this study revealed that the magnitude of biomass storage is comparatively higher in *Sal plantation* than *Sal forest* may be attributed to the adoption of proper silvicultural management practices including timber harvesting, fire management, adequate regeneration of suitable species. Moreover information on the species composition of a forest is essential for its sustainable management in terms of economic value, regeneration potential and ultimately may be leading to conservation of biological diversity. The observed tree species density was higher in Sal forest than *Sal plantation* and was comparable with the other studies reported from India. Jha and Singh (1990) reported 294–559 tree ha^{-1} in *Sal forest* from Central India and 408 trees ha^{-1} was reported in Gorakhpur, India by Pandey and Shukla (2003). In moist *Sal forest*s of West Bengal, India (Kushwaha and Nandy 2012) and in Doboka reserve forest, Assam, NE India (Dutta and Devi 2013) the reported tree densities were 438 tree ha^{-1} and 422 tree ha^{-1} respectively. However, Nag and Gupta (2014) reported much higher stem densities (1441 to 2233 stem ha^{-1}) with basal area cover between 12.89 m^2 ha^{-1} and 13.89 in Dry Deciduous *Shorea robusta* forests of West Bengal. The higher stem density recorded in their study was attributed

Table 3. Species diversity, dominance and structural variables in Sal forests under two management regimes in Tripura, Northeast India

Parameters	Stand Type	
	SP	SF
Number of species	4	29
Number of genera	4	28
Number of family	4	17
Density (stem ha^{-1})	230.00±37.22	1060.00±11.12
Basal area (m^2 ha^{-1})	33.02±4.87	22.53±0.38
Dominance Index	0.76±0.08	0.23±0.02
Diversity Index	0.38±0.15	1.90±0.08
Evenness Index	0.92±0.08	0.53±0.04

SP-Sal plantation, SF-Sal forest, ± SEM, n=8

Table 4. Biomass stock, carbon allocation and soil attributes (0-45 cm depth) of Sal forest under two management regimes in Tripura, Northeast India

Major pools	Stand Type	
	SP	SF
AGB (Mg ha^{-1})	179.88±29.43	110.53±1.82
AGB C (Mg C ha^{-1})	89.94±14.72	55.27±0.91
BGB (Mg ha^{-1})	46.77±7.65	28.74±0.47
BGB C (Mg C ha^{-1})	23.38±3.83	14.37±0.24
DWB C Mg ha^{-1}	12.47±2.04	7.66±0.13
LB C Mg ha^{-1}	1.25±0.01	1.49±0.12
SOC (%)	1.59±0.35	1.67±0.27
SOC Mg ha^{-1}	92.64±2.53	88.85±4.07
Total C Mg ha^{-1}	219.68±19.65	167.64±16.73
Soil Temperature	28.73±0.26	28.55±0.75
Soil Moisture Content	16.06±0.35	18.92±0.94
Bulk Density	1.95±0.04	1.78±0.04
pH	5.00±0.14	5.46±0.12
OM (%)	3.55±0.05	3.73±0.06

SP-Sal plantation, SF-Sal forest, ± SEM, n=8

Table 5. Correlation matrix between stand structural variables (stem density and basal area); diversity indices (Dominance index, Shannon index and Evenness index), above ground carbon pool (above ground tree biomass, aboveground biomass carbon) and soil characteristics (bulk density, soil organic carbon percent, soil organic carbon stock) among two different management regimes

	Stem Density ha^{-1}	Basal Area (m^2 ha^{-1})	Dominance_D	Shannon_H	Evenness_e^H/S	AGTB (Mg ha^{-1})	AGB C (Mg ha^{-1})	Bulk Density (g cm^{-3})	SOC (%)	SOC (Mg ha^{-1})
Stem Density ha^{-1}	-									
Basal Area (m^2 ha^{-1})	-0.99ns	-								
Dominance_D	-0.72ns	0.61*	-							
Shannon_H	0.83*	-0.74ns	-0.97ns	-						
Evenness (H´/log(S))	-0.87ns	0.81*	0.83*	-0.93ns	-					
AGTB (Mg ha^{-1})	-0.78ns	0.75*	0.83*	-0.83ns	0.83*	-				
AGB C (Mg ha^{-1})	-0.78ns	0.75*	0.83*	-0.83ns	0.83*	-	-			
Bulk Density (g cm^{-3})	-0.89ns	0.91*	0.62*	-0.66ns	0.60*	0.75*	0.75*	-		
SOC (%)	0.60*	-0.59ns	-0.74ns	0.66*	-0.56ns	-0.92ns	-0.92ns	-0.76ns	-	
SOC (Mg ha^{-1})	-0.63ns	0.68*	0.06	-0.22ns	0.25	0.05	0.05	0.62*	0.04	-

* significance $p< 0.05$, ns- not significant.

to higher regeneration *Sal forest* owing to increased anthropogenic disturbances. The present study recorded low species richness (4) in plantation and comparatively higher species richness (29) in forest and such estimates was also comparable with Rabha (2014a) who reported 3 species in disturbed *Sal forest*s and 18 species in undisturbed *Sal forest*s in Goalpara, Assam, Northeast India and also comparable with the other studies reported from different part of Northeast India (Deka et al. 2012; Dutta and Devi 2013). Rabha (201b) reported mean stem density and basal area of 830±33.6 tree ha^{-1} and 26.29±1.0 m^2 ha^{-1} respectively of an undisturbed *Sal forest*. and stand density of the six stands ranged between 560 and 846 trees ha^{-1} with a mean value of 673±40 ha^{-1} in Meghalay, Northet India was reported by Upadhaya et al. (2015). Whereas basal cover distribution did not show any similarity with the present findings. The observed Shannon diversity index (0.4-1.9) of the present study was within the range (0.83 to 4.1) for different Indian forests reported by Visalakshi (1995) and Mishra et al. (2000). Kent and Coker (1992) reported diversity index value which varies from 1.5 to 3.5 and rarely cross the value of 4.5 whereas Parthasarathy et al. (1992) and Visalakshi (1995) reported this index value varies from 0.83 to 4.1 for Indian forests. Present synthesis on structural and compositional attributes of plantation forest and natural forest land would play a vital role in future to understand about prioritization of plantation activity and the role of dominant species in terms of ecosystem services.

Biomass and carbon stock

Biomass allocation pattern and carbon stock density of the tree layer showed overall higher biomass and carbon storage in planted *sal forest* than naturally grown *sal forest*. The present estimates of above ground tree biomass (AGB) in *Sal plantation* is lower than the estimates of similar studies conducted in tropical semi-evergreen forest and Sal plantation forest of of Nongkhyllem wildlife sanctuary in Meghalaya, Northeast India (Baishya et al. 2009). However, it was in the range of the earlier estimate of AGB in a recovering tropical *Sal forest* of Eastern Ghats, India, (ranged 12.68-231.91 Mg ha^{-1}) along with AGB (261.08 Mg ha^{-1}) for 10-year-old Sal stand (Behera and Misra 2006) and also close to the reported value of ABG ranged 149-389 Mg ha^{-1} with a mean value of 254 Mg ha^{-1} for Community Managed Hill *Sal Forest*s of Central Nepal (Thapa-Magar and Shrestha 2015). The observed AGB was also comparable with the findings of Rabha (2014b) who estimated AGB of 239.45 Mg ha^{-1} for an undisturbed regenerating *Sal forest* of Assam, North-East India. Chaturvedi and Raghubanshi (2015) reported biomass carbon of 176 Mg C ha^{-1} for the mono-specific (Sal) category on determination of carbon density (Kg-C ha^{-1}) of a tropical dry region in India which was less than the present above ground biomass carbon value of 167.64 Mg C ha^{-1} in *Sal forest*. Forest inventory study during 2002-2008 by Forest Survey of India (FSI), estimated carbon stocks in different pools viz. above ground, below ground, deadwood, litter biomass and soil organic matter of very dense tropical moist deciduous forests, moderate dense tropical moist deciduous forests and open tropical moist deciduous forests as 124.98 Mg ha-1, 95.38 Mg ha^{-1} and 65.25 Mg ha^{-1} respectively which was comparable and slightly higher than the present value (93.72 Mg ha^{-1}) as per forest types. However, present value was quite low compared to that of Shrestha et al. (2000), who reported above ground tree biomass in the range of 337–698 Mg ha^{-1} in Sal regenerating forests of Central Nepal. AGB estimated for plantation and forest in the present study was very less than the reported value ranged 255.96-259.8 Mg $ha^{-1}$and ranged 204.15- 272.83 Mg ha^{-1} in *Sal plantation* and mixed sal natural forest repectively of Meghalaya, North-East India (Upadhaya et al. 2015). The value of AGB (110.53 Mg ha^{-1}) obtained in the *Sal forest*s is within the range (27.5-205.50 t ha^{-1}) reported by Pande and Patra, (2010); also within the range (32.4-261.61 Mg.ha^{-1}) reported by Borah et al. (2013) from tropical moist evergreen and tropical semi-evergreen forests and much higher than the value of AGB (42.26 Mg ha^{-1}) reported from tropical moist deciduous *Sal forest* (Majumdar et al. 2016). The present study implies that the remarkable less trend in biomass storage potential of the *Sal forest* of the State. The AGB of *Sal forest* in most of cases contrasts the findings of earlier workers from different region of India. Baishya et al. (2009) reported that the tropical plantation forests had an edge over the natural forests in terms of carbon storage because of adoption of improved forestry practices. Forest stand having mixed species can sequester CO_2 rapidly due to different photosynthetic rate by species (Montagnini and Porras 1998). In spite of the best protection efforts, most natural tropical forests are now under threat due to various human activities (Chaturvedi et al. 2011). It is an undisputed fact that natural forests harbour high diversity, plantation forests are increasingly recognized for their capacity to sequester atmospheric carbon. However, studies attempting to estimate tree biomass and carbon stock in different natural and plantation forests yielded variable results (Chen et al. 2005; Young et al. 2005; Devagiri et al. 2013).

The variability observed in two different management regimes in terms of carbon storage potential may be attributed to the stand structure adopted management practices. The biomass and C stocks are primarily determined by the diameter distribution of trees and species composition (Clark and Clark 2000). With the agreement of earlier workers (Brown and Lugo 1992; Brown et al. 1995; Brown 1996; Clark and Clark 1996; Terakunpisut et al. 2007; Baishya et al 2009; Upadhyaya et al. 2015) it was quite clear that in terms of carbon storage large trees (>70 cm dbh) generally contribute maximum storage potential but does not undermine the role of small trees with lower dbh classes (<60 cm dbh) which would enhance the future carbon stock because of their high carbon sequestration potential. In this concern it was also suggested to forest managers to fill the blanks inside the forest by target species to enhance tree productivity and this will also helpful to maintain the tree composition of the forest (Pande 2002). In natural forests, there is a net addition to standing biomass leading to carbon storage if most trees are yet to be matured. However, Plantation forests with higher annual productivity were reported to be ideal for carbon storage and sequestration. In the contrary with the other results our results has reflected such variation in terms of carbon allocation pattern and it can be concluded that the *Sal forest*s of Tripura were exposed to different intensities of anthropogenic disturbances in the past and differential management practices adopted in *Sal plantation* seem to be one of the most important determinants of tree density-diameter distribution that has affected the AGB, BGB and C stock of the forest stands.

Due to being inconsistent and lacking a harmonious uniformity, generalization of the role of plantation forests contrast to natural plantation in stocking carbon at global level has been barred and it has been also given the evidence against the replacement of natural forests by the plantations as a measure to enhance carbon sequestration (Liao et al. 2010). *Shorea robusta* Gaertn. also possess good natural regeneration capacity and fast growing ability. Therefore, this species came out as significant carbon sequester in this region and long term monitoring of carbon dynamics. However, lower plant diversity in *Sal plantation* could potentially decline the ability of long lived carbon pools of terrestrial ecosystems to continue to act as carbon sinks of atmospheric CO_2 (Fan et al. 1998; Pacala et al. 2001). A result from other mixed species plantations suggests that the identity of the dominant tree species plays an important role in determining carbon gained by the trees (Redondo-Brenes 2007). It was reported by Baishya et al. (2009) that large trees which represents maximum diameter range in a forest stand contribute 49% to the total AGB in natural forest. In contrast, the contribution of the smaller trees to total AGB in the plantation forest was higher (76%) than the larger trees. However present study recorded 72.46 % of total AGB production by a single dominant tree species in *Sal plantation*. It was reported that the contribution of large trees to AGB in natural forest is considerably higher (Brown and Lugo 1992; Brown 1996; Clark and Clark 1996). Analyses have shown that forests with reduced biomass either had their large trees removed by past human disturbance or represent regenerating secondary forests which do not yet have large trees. The distribution of biomass in large trees, therefore, could be an indicator of the presence or absence of past anthropogenic disturbance (Brown 1996).

In natural ecosystem, soil plays a very important role in regulating the environment. Soil nutrient level is a key attribute which influence soil's capacity to support ecosystem services. The differences in soil organic carbon (SOC) stock is mainly influenced by land use types. This suggests that differential use of forest land have fundamental difference in net primary productivity and carbon cycling processes. The observed SOC% of the present study revealed higher value of SOC% in *Sal forest* than *Sal plantation* which was similar to the findings of Chauhan et al. (2010) who reported SOC% value of 2.2 and 1.5 in natural *Sal forest* and planted forest. The present value was quite higher than the findings of Thapa et al. (2011) who reported SOC% value of 0.88 and 1.05 in *Sal plantation* and Sal natural forest respectively.. The decrese in SOC% in

Sal plantation may be attributed to the less number of tree species, removal of top soil through erosion and increased soil compactness resulting into increased soil bulk density (Mills and Cowling 2010). However, present study did not follows any definite pattern of soil organic carbon stock (SOC stock) distribution. Shin et al. (2007) reported over exploitation of forest resources and forest land encroachment reduces soil carbon faster. However present study is comparable with the findings of Singh et al. (1991) in tropical moist deciduous forest of Mizoram who reported SOC stock value ranged 82.1-134.1 Mg C ha^{-1} and also comparable with the reported SOC stock value ranged 31.0 – 62.90 Mg ha^{-1} in the top 30 cm depth depending upon the tree density and age of the stand tree (Negi and Chauhan 2002). As the forest ages the organic matter deposition as a result of litter fall and along with the reduced soil disturbance the soil switches from losing carbon to beginning to sequester carbon (Mao et al. 2010).

Conclusion

The estimated high C stocks in *Sal plantation* than the *Sal forest* in the present study suggest that the former is more productive in terms of carbon storage than the later owing to its less species diversity, uniform age and structure. The study further suggests that greater carbon stock may not always be associated with higher diversity. The *Sal forest*, on the other hand had higher species diversity implying a better role in carbon sequestration in long run if suitable management are undertaken.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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