Tropical Ecology **56**(2): 257-268, 2015
ISSN 0564-3295

www.tropecol.com

Tree diversity and biomass of tropical forests under two management regimes in Garo hills of north-eastern India

KRISHNA UPADHAYA[1], NAMITA THAPA[2] & SAROJ KANTA BARIK[2*]

[1]*Division of Environmental Sciences, Department of Basic Sciences and Social Sciences, North-Eastern Hill University, Shillong 793022, India*
[2]*Centre for Advanced Studies in Botany, North-Eastern Hill University, Shillong 793022, India*

Abstract: Tree diversity and biomass (above-and below-ground) were studied under two forest management regimes viz. Wildlife sanctuary (WLS) and Reserved forest (RF). The study was conducted in the undisturbed tropical primary forest (PF) at Siju, a WLS, and five RFs *viz.* Dambu and Darugiri (MSF1: Sal plantation forest) and Songsak, Rongrengiri and Baghmara (MSF2: Mixed sal-natural forest) of Garo hills, which remained undisturbed during the past 50 - 60 years. Tree species richness was highest in the WLS (67 species) followed by RFs (MSF2: 49 - 61 and MSF1: 33 - 35). Tree density was greater in WLS (846 trees ha^{-1}) than RFs (570 - 690). Tree biomass (above-and below-ground) in WLS (382 Mg ha^{-1}) was also greater than the RFs (250 - 332 Mg ha^{-1}). Variations in species composition, density, diameter distribution pattern, biomass and C stock in the WLS and RFs were attributed to two different forest management practices adopted.

Resumen: La diversidad y la biomasa (aérea y subterránea) arbóreas fueron estudiadas bajo dos regímenes de manejo forestal: Santuario de Vida Silvestre (WLS) y Bosque Reservado (RF; ambas siglas en inglés). Elestudiose realizóen el bosque tropical primario no perturbado (PF) en Siju, un WLS, y cinco RFs: Dambuy Darugiri (MSF1: plantación de sal), y Songsak, Rongrengiriy Baghmara (MSF2: mezcla de bosque natural y plantación de sal) de las colinas Garo, los cuales han permanecido inalterados durante los últimos 50 - 60 años. La riqueza de especies arbóreas más alta se registró en el WLS (67 especies), seguido de RFs (MSF2: 49 - 61 y MSF1: 33 - 35). La densidad de árboles fue más alta en WLS (846 árboles ha^{-1}) que en RFs (570 - 690). Asimismo, la biomasa (aérea y subterránea) en WLS (382 Mg ha^{-1}) fue mayor que en RFs (250 - 332 Mg ha^{-1}). Las variaciones en la composición de especies, la densidad, el patrón de distribución de diámetros, la biomasay el almacén de C en el WLS y los RFs fueron atribuidos a las dos diferentes prácticas de manejo forestal adoptadas.

Resumo: Estudaram-se a diversidade arbórea e a biomassa (acima e abaixo do solo) sob dois regimes de gestão florestal viz. Santuário de Vida Selvagem (WLS) e Reserva Florestal (RF). O estudo foi conduzido na floresta tropical primária não perturbada (PF) em Siju, um WSLe em cinco RFs viz. Dambue Darugiri (MSF1: plantação florestal de meranti) e Songsak, Rongrengiri e Baghmara (MSF2: floresta natural mistade meranti) nas colinas Garo, as quais se mantiveram imperturbáveis durante os últimos 50 - 60 anos. A riqueza de espécies arbóreas foi maior no WLS (67 espécies), seguida pela FR (MSF2: 49 - 61 e MSF1: 33 - 35). A densidade de árvores foi maior no WLS (846 árvores ha^{-1}) do que na FR (570 - 690). A biomassa das árvores (acima e abaixo do solo) em WLS (382 Mg ha^{-1}) também foi maior do que na FR (250 - 332 Mg ha^{-1}). As variações na composição de espécies, densidade, o padrão de distribuição dos

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

diâmetros, a biomassa e o estoque de C em WLS e FRs foram atribuídas às duas práticas de gestão florestal diferentes adotadas.

Key words: Above ground biomass, carbon stock, diversity, reserved forest, wildlife sanctuary.

Introduction

The broad strategy of forest management in the contemporary world is either to conserve the habitats, species and ecosystems, or to commercially exploit forest resources following principles of sustainable yield. While establishment of protected areas such as Biosphere Reserves (BR), National Park (NP) and Wildlife sanctuary (WLS), where felling of any kind is not permitted meets the conservation objective; the reserved forests (RF) where forests are managed following silvicultural principles meet the commercial objective. While most protected areas are natural forests, the reserved forests are largely man-made or modified plantation forests. In spite of the best protection efforts, most natural tropical forests are now under threat due to various human activities (Chaturvedi *et al.* 2011). While it is an undisputed fact that natural forests harbour high diversity, plantation forests are increasingly recognized for their capacity to sequester atmospheric carbon (Baishya & Barik 2011; Winjum & Schroeder 1997). However, studies attempting to estimate tree biomass and carbon (C) stock in different natural and plantation forests yield variable results (Chen *et al.* 2005; Devagiri *et al.* 2013; Young *et al.* 2005). Because of this inconsistency, generalization of the role of plantation forests in stocking C at global level has been precluded (Liao *et al.* 2010). Liao *et al.* (2010) argued against the replacement of natural forests by the plantations as a measure to enhance carbon sequestration. Baishya *et al.* (2009) reported that the tropical plantation forests had an edge over the natural forests in terms of C storage because of adoption of improved silvicultural practices. Management and cultural operations in a forest are the most important factors that influence the species diversity and C content of a forest. However, our understanding of plant diversity, biomass and C content of tropical forests under various management regimes is limited. Therefore, the present study was undertaken to assess species diversity, tree biomass and C content in the tropical forests of Garo hills, Meghalaya in north-eastern India under two different forest management regimes viz., WLS and RF.

The Garo hills have a geographical area of 8,167 km^2, of which 6,898 km^2 is under forest cover. This accounts for 41 % of the total forest cover of the state of Meghalaya. However, only 7.8 % of the total recorded forest of Garo hills is under the control of government in the form of NP (267.48 km^2), WLS (5.21 km^2) and RF (288.13 km^2). The remaining forests belong to the individual families, clans, village councils and traditional community bodies i.e. *Nokmas* (Barik & Mishra 2008). The natural forests of Garo hills represent one of the most diverse and luxuriant tropical vegetation of the world (Kumar *et al.* 2006). Many of these forests are now affected by one or the other form of human influences (Barik & Mishra 2008) resulting in the formation of diverse vegetation types that include primary forests, secondary forests, and sal (*Shorea robusta* Gaertn.) plantation forests. The primary forests are found in remote, inaccessible areas as remnant patches and in the form of NP and WLS. Secondary forests are common in the areas affected by shifting cultivation, and sal forests are found in the form of managed RFs. The availability of these diverse forest types under different management practices in Garo hills provided an ideal condition to explore the relationship between tree species diversity, biomass, C stock and management regimes.

Materials and methods

Study site

The study was carried out in Dambu (90° 49' 42.383" E and 25° 41' 8.265" N), Darugiri (90° 45' 16.218" E and 25° 37' 4.448" N), Songsak (90° 37' 8.234" E and 25° 40' 15.106" N), Rongrengiri (90° 34' 13.008" E and 25° 33' 11.98" N) and Baghmara (90° 40' 28.236" E and 25° 12' 009" N) RFs and Siju WLS (90° 41' 33.769" E and 25° 19' 57.721" N) in Garo hills (Table 1, Fig. 1). The cli-

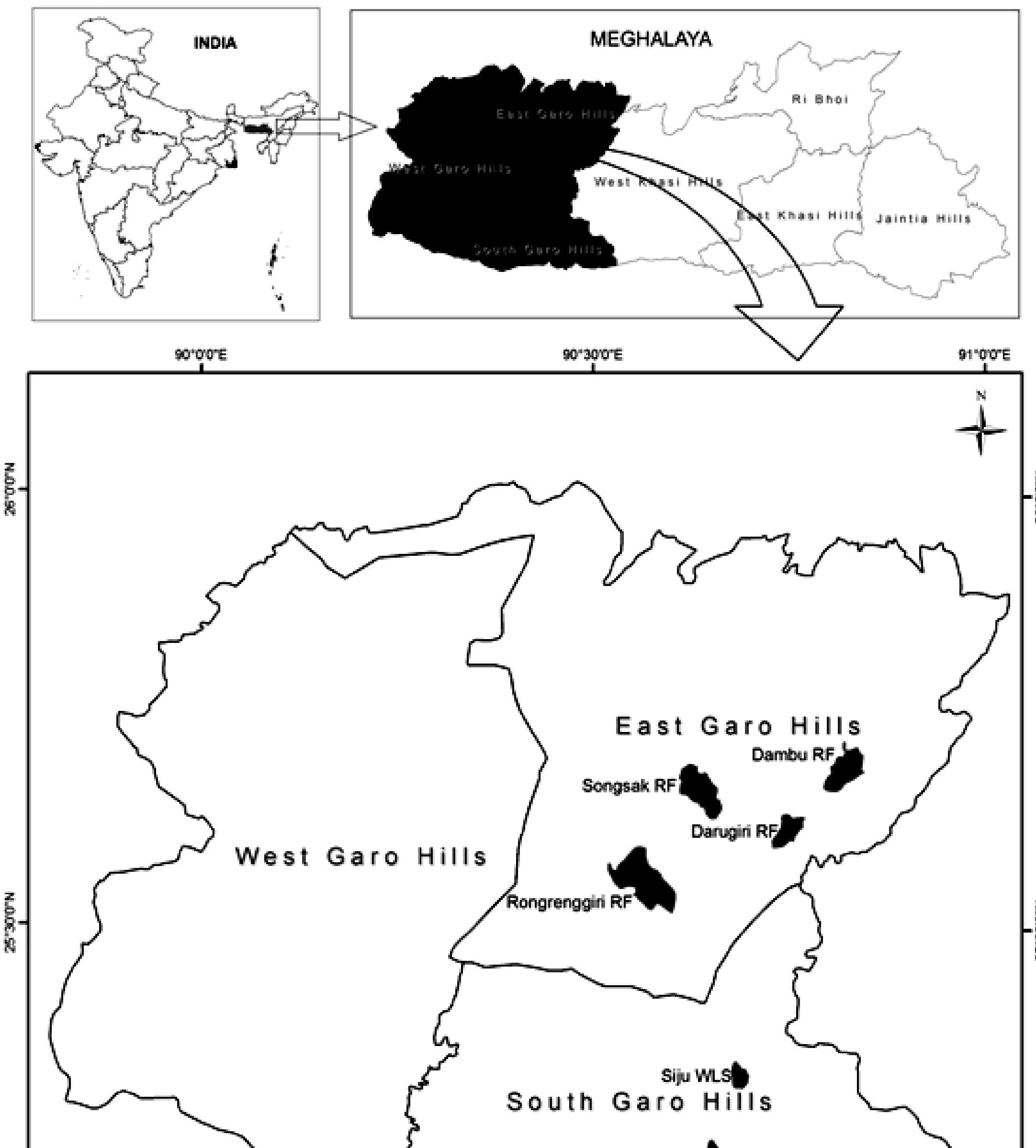

Fig. 1. Map showing the location of study sites in Meghalaya north east India.

mate of the area is monsoonic with a distinct wet and dry season. The wet season extends from May and continues up to October whereas the dry season extends from November to March. The annual mean rainfall (2003 - 2010) is 2630 mm. The mean annual maximum and minimum temperatures are 25 °C and 18 °C, respectively.

The scientific management of forests in Meghalaya was initiated as early as 1880, when some of the land under government ownership was converted to RF. Since then these lands are being managed by the successive state forest departments. The main objective of forest management in the RF was exploitation of timber trees. This RF

Table 1. Site characteristics of wildlife sanctuary (WLS) and reserved forests (RFs) in Garo hills of Meghalaya, northeast India.

Management regime	Forest stand	Altitude (m asl)	Area (ha)	Forest type	Disturbance level and history	Year of notification
Reserved forest (Notified under Indian Forest Act)	Dambu	391	1813	Sal plantation forest	After clear felling of natural forest in 1887, sal was planted. The last disturbance was about 60 years back when trees were felled and re-planted as a part of approved silvicultural plan. Since then no biomass extraction was made.	No. 22 of 12/03/1880
	Darugiri	380	1036	Sal plantation forest	Same as Dambu RF	No. 28 of 19/06/1883
	Songsak	302	2331	Mixed sal-natural forest	Since 1887, gaps were being filled with sal, retaining the existing species in the closed canopy forest areas. No biomass extraction for the past 50 years.	No. 29 of 01/10/1885
	Rongrengiri	280	3626	Mixed sal-natural forest	Same as Songsak forest with much less proportion of sal. No product extraction for the past 50 years.	No.28 of 19/06/1883
	Baghmara	250	4429	Mixed sal-natural forest	Same as Songsak forest with much less proportion of sal. No product extraction for the past 50 years.	No. 12 of 24/02/1887
Wildlife sanctuary [Notified under Wildlife (Protection) Act, 1972]	Siju	235	518	Primary natural forest	Undisturbed	No. MGF 66/4 of 30/03/1979

model of forest management was the only forest management strategy in India until 1972, the year in which Wildlife (Protection) Act was enacted. Following this legislation, protection of wildlife and their conservation through declaring the forests as WLS and NP, became an additional forest management strategy. In all the RFs, systematic management was initiated during 1880 - 1887. In Dambu and Darugiri RFs large-scale sal plantation was undertaken after clear-felling the previous vegetation, while in the other RFs plantation of sal was done only in patches retaining most of the native vegetation. These two categories of RF were abbreviated as MSF1 (Dambu and Darugiri), and MSF2 (Songsak, Rongrengiri and Baghmara). The wildlife sanctuary (WLS) at Siju was a natural primary forest, where no management intervention such as thinning or tree felling was undertaken.

Species diversity and aboveground biomass

In each forest, a plot of 5 ha (500 m x 100 m) was demarcated for detailed study. Two transects, 10 m wide and 500 m long, were laid 80 m apart within each plot. Each transect was further divided into 50 quadrats of 10 m x 10 m size. All tree species within these quadrats were enumerated and the dbh was measured at 1.37 m height from the ground level for the individuals with dbh ≥ 5 cm. The specimens were identified with the help of regional floras (Balakrishnan 1981-1983; Haridasan & Rao 1985-1987; Joseph

1982 & Kanjilal *et al.* 1934 - 1940). The herbaria at Botanical Survey of India, North-Eastern Circle, Shillong and North-Eastern Hill University were also consulted for correct identification. Community parameters such as frequency, density, basal area and importance value index of species were determined according to Misra (1968). To analyze tree population structure, the individuals were categorized into seven diameter classes i.e., 5-15, 16-25, 26-35, 36-45, 46-55, 56-65, and > 65 cm. Shannon-Wiener index of diversity, Pielou's evenness index and Simpson's dominance index were calculated to analyze species diversity and dominance in the community following the formulae:

Shannon-Wiener index of diversity (Shannon & Weaver 1963):

$H' = - \sum p_i \ln p_i$, where, H' is the measure of diversity and p_i is the proportion of the total sample belonging to the *i*th species.

Simpson's dominance index (Simpson 1949):

$D = \sum p_i^2$, where, D is the Simpson index of dominance and p_i is the proportional individuals of species *i* in the community.

Pielou's evenness index (Pielou 1969):

$E = H'/\ln S$, where, E is Pielou's evenness index, H' is the Shannon-Wiener index of diversity and S is the number of species in the community.

The above ground biomass (AGB) of trees was estimated using the allometric equation developed by Chambers *et al.* (2001) for mixed forests:

$$Y = \exp [- 0.37 + 0.33 \ln (D) + 0.933 \ln (D)^2 - 0.122 \ln (D)^3]$$

where, Y is biomass per tree in kg and D is diameter at breast height (dbh) in cm. This model was successfully used earlier in estimating tree biomass in some tropical forests of northeast India (Baishya *et al.* 2009). The below ground biomass (BGB) of trees was estimated following the equation of Cairns *et al.* (1997):

$$Y = \exp [- 1.059 + 0.884 \ln (AGB) + 0.284]$$

The total C stock was calculated by assuming that the carbon content is 47.4 % of the total biomass (Martin & Thomas 2011). The variation in tree density, biomass and C stock due to difference in management practices was analysed across the diameter classes using two-way ANOVA (fixed effect model) (SYSTAT 10.10). The assumptions of ANOVA were met through tests for normality of variables (Kolmogorov-Smirnov test), homogeneity of group variances (Levene's test), and additivity.

Results

Stand characteristics and tree diversity

A total of 131 tree species that belonged to 107 genera and 49 families were recorded from the six forest stands. The species richness was highest in the WLS (67 species) followed by the RFs, i.e, MSF2 (49 - 61) and MSF1 (33 - 35) (Table 2). The Shannon-Wiener diversity index was highest in the WLS (3.87) followed by MSF2 (3.32 - 3.54) and MSF1 (1.75 - 1.84). The tree density of the six stands ranged between 560 and 846 trees ha^{-1} with a mean value of 673 ± 40 ha^{-1} (Table 2). The density was greater in WLS (846 trees ha^{-1}) than the RFs (570 - 690). The dominant tree species in all the RFs except Rongrengiri was *Shorea robusta* (78 - 376 trees ha^{-1}). In Rongrengiri, *Ochna integerrima* (82 trees ha^{-1}) dominated the stand. In terms of IVI, *Shorea robusta* dominated all the RFs with IVI ranging from 39.29 - 179.81. Other important species include *Schima wallichii* (DC.) Korth., *Polyalthia simiarum* (Hk.f.&Th.) Hk.f. & Thoms., *Litsea monopetala* (Roxb.) Pers., *Eurya acuminata* DC., *Castanopsis armata* Spach., *Ochna integerrima* (Lour.) Merr., *Dillenia pentagyna* Roxb., *Lagerstroemia parviflora* Roxb. and *Cryptocarya amygdalina* Nees (Appendix 1). In Siju WLS, *Schima wallichii* (IVI=29.46), *Terminalia bellirica* (Gaertn) Roxb. (IVI=15.97) and *Duabanga grandiflora* (Roxb. ex DC.) Walp. (IVI = 16.50) were the dominant and co-dominant tree species, respectively.

WLS had significantly greater tree basal area than RFs (ANOVA $F_{2, 21} = 4.50$, $P < 0.05$) (Table 3). Tree basal area was highest in the WLS (67.18 m^2 ha^{-1}), and lowest in MSF2 at Rongrengiri (42.67 m^2 ha^{-1}) (Table 2). *Shorea robusta* alone accounted for 78 - 83 % of the total stand basal area in MSF1 and 22 - 55 % in MSF2. In WLS, *Terminalia bellirica*, *Schima wallichii* and *Shorea robusta* together accounted for 28 % of the total stand basal area (Appendix 1). In all the stands, lower diameter class (< 15 cm dbh) had the highest density of trees. The tree density decreased with increase in tree diameter (Table 3). The proportion of individuals both in the lowest and highest diameter classes i.e. 5 - 15 cm and > 65 cm was low in MSF1 (21 % and 1 %) and MSF2 (31 - 37 % and 2 - 3 %) as compared to WLS (37 % and 6 %). In spite of the high density of young trees (5 - 15 cm dbh) in all the stands under both forest management regimes, the basal area was highest in > 65 cm diameter class in the WLS, and in intermediate diameter classes (26 - 45 cm) in MSF2 and MSF1 (Table 3).

Table 2. Species diversity, AGB, BGB and C stock in WLS and RFs (MSF1 and MSF2) in Garo hills of Meghalaya, northeast India.

Parameters	Management regime Site					
	RF (MSF1)		RF (MSF2)			WLS
	Dambu	Darugiri	Songsak	Rongrengiri	Baghmara	Siju
Number of species	35	33	61	55	49	67
Number of genera	28	32	51	52	45	60
Number of family	25	26	30	34	30	39
Density (trees ha^{-1})	570	608	688	640	690	846
Basal area (m^2 ha^{-1})	54.9	54.09	58.09	42.67	49.21	67.18
Diversity index	1.84	1.76	3.32	3.54	3.45	3.87
Dominance index	0.39	0.39	0.09	0.04	0.04	0.03
Evenness index	0.52	0.50	0.80	0.88	0.89	0.92
AGB (Mg ha^{-1})	259. 8	255.96	272.83	204.15	233.24	314.02
AGB C (Mg C ha^{-1})	123.14	121.32	129.32	96.77	110.56	148.85
BGB (Mg ha^{-1})	56.90	56.21	59.48	45.6	51.54	68.21
BGB C (Mg C ha^{-1})	26.97	26.64	28.19	21.61	24.4	32.33

Table 3. Distribution of density (D, ha^{-1}), and basal area (BA, m^2 ha^{-1}) in different diameter classes in WLS and RFs (MSF1 and MSF2) in Garo hills of Meghalaya, northeast India.

Diameter class (cm)	Management regime Site											
	RF (MSF1)				RF (MSF2)						WLS	
	Dambu		Darugiri		Songsak		Rongrengiri		Baghmara		Siju	
	D	BA	D	BA	D	BA	D	BA	D	BA	D	BA
5-15	118	0.84	130	0.81	214	1.93	236	2.07	226	1.56	310	2.75
16-25	72	2.94	120	4.91	152	5.61	126	4.43	160	5.84	188	6.51
26-35	180	14.16	164	11.98	160	12.25	162	11.84	176	13.06	182	13.78
36-45	108	14.42	122	16.95	64	8.39	62	7.97	68	8.93	60	8.12
46-55	56	11.71	42	8.52	28	5.93	20	4.06	24	4.97	24	4.82
56-65	34	10.14	22	5.91	38	11.23	16	4.55	20	5.72	30	8.74
>65	2	0.71	8	5.01	32	12.75	18	7.74	16	9.13	52	22.46
Total	570	54.92	608	54.09	688	58.09	640	42.67	690	49.21	846	67.18

Table 4. Distribution of AGB and C stock (%) in different diameter classes in WLS and RFs (MSF1 and MSF2) in Garo hills of Meghalaya, northeast India.

Diameter class (cm)	Management regime Site											
	RF (MSF1)				RF (MSF2)						WLS	
	Dambu		Darugiri		Songsak		Rongrengiri		Baghmara		Siju	
	AGB	C (%)	AGB	C (%)	AGB	C (%)	AGB	C (%)	AGB	C (%)	AGB	C (%)
5 - 15	5.01	1.93	4.86	1.90	11.29	4.14	12.17	5.96	9.28	3.98	16.08	5.12
16 - 25	15.32	5.90	25.59	10.00	29.46	10.80	23.36	11.44	30.74	13.18	34.38	10.95
26 - 35	69.94	26.92	59.56	23.27	60.65	22.23	58.87	28.84	64.81	27.79	68.28	21.74
36 - 45	68.22	26.26	79.91	31.22	39.78	14.58	37.82	18.53	42.28	18.13	38.31	12.20
46 - 55	53.35	20.54	38.92	15.21	27.01	9.90	18.57	9.10	22.69	9.73	22.06	7.03
56 - 65	44.88	17.28	26.36	10.30	49.69	18.21	20.22	9.90	25.40	10.89	38.77	12.35
> 65	3.06	1.18	20.76	8.11	54.95	20.14	33.14	16.23	38.04	16.31	96.14	30.62
Total	259.78	100.00	255.96	100.00	272.83	100.00	204.15	100.00	233.24	100.00	314.02	100.00

Tree above- and below-ground biomass and C stock

Total tree biomass (AGB + BGB) was highest in WLS (382 Mg ha^{-1}) followed by RFs (250 - 332 Mg ha^{-1}). Amongst all the stands, Siju WLS had the highest total AGB (314 Mg ha^{-1}). The values for the RFs were lower as compared to the WLS, and ranged between 204 and 273 Mg ha^{-1} (Table 2). Though the density of individuals in < 15 cm dbh class dominated all the stands (Table 3), the AGB accumulation was greater in intermediate diameter classes (26 - 45 cm) in the RFs (Table 4). In the WLS, the dbh class > 65 cm had the highest AGB of 96 Mg ha^{-1}. The BGB was also highest in the WLS (68 Mg ha^{-1}). The values for the RFs were lower as compared to the WLS, and ranged between 46 and 59 Mg ha^{-1} (Table 2).

The total C stock (AGBC + BGBC) was highest in WLS (181.17 Mg C ha^{-1}), followed by RFs (118-158). The C stock in the AGB was highest in WLS (149 Mg C ha^{-1}) followed by RFs - Songsak (129), Dambu (123), Darugiri (121), Baghmara (111) and Rongrengiri (97). The C stock varied significantly between the management regimes i.e., WLS and RFs ($F_{2, 21}$ = 4.59, P < 0.05) and among different dbh classes ($F_{6, 21}$ = 22.87, P < 0.001). The percent C stock in AGB in the highest diameter class (765 cm) was 1 - 8 % in MSF1, 16 - 20 % in MSF2 and 31 % in WLS. The young trees (5 - 15 cm dbh) had just 2 %, 4 - 6 % and 5 % of the total C in MSF1, MSF2 and WLS, respectively (Table 3).

Discussion

Because most site characteristics were more or less similar, significantly greater species diversity in the WLS than the RF stands may be attributed to the contrasting management practices adopted. Siju being a WLS has never been subjected to any human management intervention such as clear or selection felling thereby harboured high species richness. Relatively lower species diversity in MSF1 than MSF2 may be attributed to the forest management practices that have been adopted in these two forests where clear felling was undertaken about 60 years back and replanted with sal trees. In contrast, the management intervention in MSF2 was much milder, where only gap areas were planted with sal and the species in the surrounding natural forests were retained. Lower species richness in the managed sal forests as compared to primary forests in other parts of Garo hills and north India was also reported by Kumar *et al.* (2006) and Tripathi & Singh (2009), respectively. The greater Shannon-Wiener and lower Simpson dominance indices for the primary forests than the secondary and plantation forests have been reported from tropical forests of Hainan island, China (Meng *et al.* 2011) and Meghalaya, northeast India (Thapa *et al.* 2011).

The density of tree species recorded in the RFs (570-690 trees ha^{-1}) was greater than the other sal forests studied in north India (254 - 644) (Rawat & Bhainsora 1999). The tree density in the WLS (846 trees ha^{-1}) reported in this study was within the range of other tropical forests (387 - 1561 trees ha^{-1}) (Adekunle *et al.* 2013; Baithalu *et al.* 2013; Johnston & Gillman 1995; Valencia *et al.* 1994). Similarly, the basal area recorded in sal forests (43 - 58 m^2 ha^{-1}) is within the range (14.5 - 71.8 m^2 ha^{-1}) reported from other sal forests of India (Singh *et al.* 1995; Shukla & Pandey 2000, Kumar *et al.* 2011). The basal area of WLS (67 m^2 ha^{-1}) is close to other natural tropical forests (51 - 77 m^2 ha^{-1}) of the region (Baishya *et al.* 2009; Thapa *et al.* 2011) as well as other tropical forests (55-94 m^2 ha^{-1}) (Campbell *et al.* 1992; Nadkarni *et al.* 1995; Parthasarathy *et al.* 1992).

The differential management practices adopted in WLS and RFs 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. The highest tree biomass and C stock was in the WLS, where no visible management intervention was undertaken and no disturbance was allowed as compared to RFs where silvicultural operations were undertaken about 50 - 60 years back in the form of clear felling and replanting as per approved working plan. Liao *et al.* (2010) in their studies also observed decreased AGB, BGB and litter mass in plantations as compared to natural forests.

AGB value (314 Mg ha^{-1}) in the WLS is close (324 Mg ha^{-1}) to the values obtained for the other tropical forest of northeast India (Baishya *et al.* 2009) and tropical evergreen forest of Tamil Nadu, India (307 Mg ha^{-1}) (Ramachandran *et al.* 2007). The value is within the range (150 - 446 Mg ha^{-1}) reported from various tropical forests of the world (Brown & Lugo 1982; 1984; Muller 1982, Terakunpisut *et al.* 2007). The value of AGB (204 - 273 Mg ha^{-1}) obtained for the sal forests is within the range (78 - 378 Mg ha^{-1}) reported from tropical sal forests of the Himalayas (Gautam *et al.* 2011) and north India (Singh *et al.* 1992; Kumar *et al* 2011). However, these values are much lower than the values (406 Mg ha^{-1}) reported from sal forests of northeast India (Baishya *et al.* 2009) and Central Nepal (337 - 698 Mg ha^{-1}) (Shrestha *et al.* 2000). The range of BGB (46 - 68 Mg ha^{-1}) in the present study is similar to the findings (46 - 87 Mg ha^{-1}) of Cairns *et al.* (1997).

The biomass and C stocks are primarily determined by the size-frequency distribution of trees and the factors causing variation in forest structure including species composition (Clark & Clark 2000). The RF stands dominated by sal and with lesser number of associated species had lower biomass and C stock than the WLS, where the diversity was much greater. However, there was a weak relationship between stand species richness and total C content ($r = 0.34$, $P < 0.503$). The high contribution (31 %) of large trees (> 65 cm dbh) to the total AGB in the WLS is similar to the findings of Baishya *et al.* (2009), Brown & Lugo (1992) and Clark & Clark (1996), who reported up to 50 % AGB in larger trees and is an indicator of the absence of past human disturbance (Brown 1996). In RFs the low contribution of large trees to AGB indicates that large trees have been removed by past cultural practices. Thus the highest dbh class contained greater C in natural forest than the RFs where the intermediate dbh classes contained highest C stock. The contribution of intermediate dbh classes to the biomass and C stock in the RF stands indicates the greater future potential of the stands to accumulate large quantities of atmospheric C being younger in age as compared to the WLS. In contrast, the high proportion of biomass in higher size classes in natural forest of WLS reveals the important role of large trees in C storage that contributed to the present high stock.

Conclusions

The RFs had lower species diversity than the WLS, which was related to the management practices being followed in these forests. Similarly, high biomass and C stock in the WLS as compared to the plantation forests of RFs were associated with land use / management history and forest stand structure. While the RFs had potential for future C sequestration owing to the dominance of trees belonging to intermediate dbh classes, the WLS with larger trees represented a high C storage ecosystem. Although less in proportion compared to AGB and BGB, other biomass carbon compartments in the forest such as coarse woody debris, lianas, shrubs, vines, herbaceous plants, and microbial biomass do contribute to the total carbon budget of the forest. In tropical forests, coarse woody debris accounts for about 10 - 40 % of total biomass of forest (Brown & Lugo 1992; Malhi *et al.* 2009), and shrubs, vines and herbaceous plants contribute to about 3 % or less to the total forest biomass (Brown & Lugo 1992). In the present study, however, only tree biomass was studied incorporating AGB and BGB. Nevertheless, the findings of the present study clearly demonstrate the impact of two forest management regimes on tree biomass and C stock of tropical forests.

Acknowledgements

The support received from the Meghalaya state forest department and Botanical Survey of India, Shillong is thankfully acknowledged. We are also thankful to two anonymous reviewers for their critical comments on the manuscript.

References

Adekunle, V. A. J., A. O. Olagoke & S. O. Akindele. 2013. Tree species diversity and structure of a Nigerian strict nature reserve. *Tropical Ecology* **54**: 275-289.

Baishya, R., S. K. Barik & K. Upadhaya. 2009. Distribution pattern of aboveground biomass in natural and plantation forests of humid tropics in northeast India. *Tropical Ecology* **50**: 295-304.

Baishya, R. & S. K. Barik. 2011. Estimation of tree biomass, carbon pool and net primary production of an old-growth *Pinus kesiya* Royle ex. Gordon forest in north-eastern India. *Annals of Forest Science* **68**: 727-736.

Baithalu, S., M. Anbarashan & N. Parthasarathy. 2013. Two-decadal changes in forest structure and tree diversity in a tropical dry evergreen forest on the Coromandel Coast of India. *Tropical Ecology* **54**: 397-403.

Balakrishnan, N. P. 1981-1983. *Flora of Jowai*. 2 Vols, Botanical Survey of India, Howrah.

Barik, S. K. & S. K. Mishra. 2008. Assessment of the contribution of forests to the economy of the northeastern states of India. *International Forestry Review* **10**: 349-361.

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

Brown, S. & A. E. Lugo. 1984. Biomass of tropical forests: a new estimate based on forest volume. *Science* **223**: 1290-1293.

Brown, S. & A. E. Lugo. 1992. Aboveground biomass estimates for tropical moist forests of the Brazilian

Amazon. *Interciencia* **17**: 8-18.

Brown, S. 1996. Tropical forests and the global carbon cycle: estimating state and change in biomass density. pp. 13-44. *In*: M. J. Apps & D. T. Price (eds.) *Forest Ecosystems, Forest Management and the Global Carbon Cycle*. Springer, Berlin.

Cairns, M. A., S. Brown, E. H. Helme & G. A. Baumgardner. 1997. Root biomass allocation in the world's upland forests. *Oecologia* **111**: 1-11.

Campbell, D. G., J. L. Stone & A. Jr. Rosas. 1992. A comparison of the phytosociology and dynamics of three flood plain (Varzae) forests of known ages, Rio Jurua, Western Brazilian Amazon. *Botanical Journal of the Linnean Society* **108**: 213-237.

Chambers, J. Q., dos J. Santos, R. J. Ribeiro & N. Higuchi. 2001. Tree damage, allometric relationships and aboveground net primary production in central Amazon forest. *Forest Ecology and Management* **152**: 73-84.

Chaturvedi, R. K., A. S. Raghubanshi & J. S. Singh. 2011. Carbon density and accumulation in woody species of tropical dry forest in India. *Forest Ecology and Management* **262**: 1576-1588.

Chen, G. S., Y. S. Yang, J. S. Xie, J. F. Guo, R. Gao, & W. Oian. 2005. Conversion of a natural broad-leafed evergreen forest into pure plantation forests in a subtropical area: Effects on carbon storage. *Annals of Forest Science* **62**: 659-668.

Clark, D. B. & D. A. Clark. 1996. Abundance, growth, and mortality of very large trees in neotropical lowland rain forest. *Forest Ecology and Management* **80**: 235-244.

Clark, D. B. & D. A. Clark. 2000. Landscape-scale variation in forest structure and biomass in a tropical rain forest. *Forest Ecology and Management* **137**: 185-198.

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

Gautam, M. K., A. K. Tripathi & R. K. Manhas. 2011. Assessment of critical loads in tropical sal (*Shorea robusta* Gaertn. F.) forests of Doon valley Himalayas, India. *Water Air and Soil Pollution* **218**: 235-264.

Haridasan, K. & R. R. Rao. 1985-1987. *Forest Flora of Meghalaya*. 2 Vols. Bishen Singh Mahendrapal Singh, Dehra Dun, India.

Johnston, M. A. & M. P. Gillman. 1995. Tree population studies in low-diversity forests, Guyana. I. Floristic composition and stand structure. *Biodiversity and Conservation* **4**: 339-362.

Joseph, J. 1982. *Flora of Nongpoh and Vicinity*. Forest Department, Government of Meghalaya.

Kanjilal, V. N., P. C. Kanjilal, A. Das, R. N. De & N. L. Bor. 1934-1940. *Flora of Assam*. 5 Vols. Government Press, Shillong.

Kumar, A., B. G. Marcot & A. Saxena. 2006. Tree species diversity and distribution patterns in tropical forests of Garo hills. *Current Science* **91**: 1370-1381.

Kumar, R., S. R. Gupta, S. Singh, P. Patil & V. K. Dhadwal. 2011. Spatial distribution of forest biomass using remote sensing and regression models in northern Haryana, India. *International Journal of Ecology and Environmental Sciences* **37**: 37-47.

Liao, C., Y. Luo, C. Fang & B. Li. 2010. Ecosystem carbon stock influenced by plantation practice: Implications for planting forests as a measure of climate change mitigation. *PLoS ONE* 5(5), e10867. doi:10.1371/journal.pone.0010867.

Malhi, Y., L. E. O. C. Aragão, D. B. Metcalfe, R. Paiva, C. A. Quesada, S. Almeida, L. Anderson, P. Brando, J. Q. Chambers, A. C.. L. da Costa, L. R. Hutyra, P. Oliveira, S. Patino, E. H. Pyle, A. L. Robertson, L. M. Teixeira. 2009. Comprehensive assessment of carbon productivity, allocation and storage in three Amazonian forests. *Global Change Biology* **15**: 1255-1274.

Martin, A. R. & S. C. Thomas. 2011. A reassessment of carbon content in tropical trees. *Plos One* **6:** e23533.

Meng, J., Y. Lu, X. Lei & G. Liu. 2011. Structure and floristics of tropical forests and their implications for restoration of degraded forests of China's Hainan Island. *Tropical Ecology* **52**: 177-191.

Misra, R. 1968. *Ecology Work Book*. Oxford and IBH Publishing Company, New Delhi.

Muller, R. N. 1982. Vegetation pattern in mixed mesophytic forest of eastern Kentucky. *Ecology* **63**: 1901-1917.

Nadkarni, N. M., T. J. Matelson & W. A. Haber. 1995. Structural characteristic and floristic composition of neotropical cloud forest, Montenerde, Costa Rica. *Journal of Tropical Ecology* **11**: 482-495.

Parthasarathy, N., V. Kinhal & L. Praveenkumar. 1992. Plant species diversity and human impacts in the tropical wet evergreen forests of south Western Ghats. pp. 26-27. *In*: *Indo-French Workshop on Tropical Forest Ecosystems: Natural Functioning and Anthropogenic Impact*. French Institute, Pondicherry.

Pielou, E. C. 1969. *An Introduction to Mathemetical Ecology*. Wiley, New York.

Ramachandran, A., S. Jayakumar, R. M. Haroon, A. Bhaskaran & D. I. Arockiasamy. 2007. Carbon sequestration: estimation of carbon stock in natural forests using geospatial technology in the Eastern

Ghats of Tamil Nadu, India. *Current Science* **92**: 323-331.

Rawat, G. S. & N. S. Bhainsora. 1999. Woody vegetation of Shivaliks and outer Himalaya in north western India. *Tropical Ecology* **40**: 119-128.

Shannon, C. E. & W. Weaver. 1963. *The Mathematical Theory of Communication*. University of Illinois Press, Urbana.

Shrestha, R., S. B. Karmacharya & P. K. Jha. 2000. Vegetational analysis of natural and degraded forests in Chitrepani in Siwalik region of Central Nepal. *Tropical Ecology* **41**: 111-114.

Shukla, R. P. & S. K. Pandey. 2000. Plant diversity and community features of the forested landscape adjacent to foot-hills of Central Himalyas. pp. 15-37. *In*: S. C. Tiwari & P. P. Dabral (eds.) *Natural Resources, Conservation and Management for Mountain Development*. International Book Distributor, Dehradun.

Singh, A., V. S. Reddy & J. S. Singh. 1995. Analysis of woody vegetation of Corbett National Park, India. *Vegetatio* **120**: 69-79.

Singh, O., D. C. Sharma & J. K. Rawat. 1992. Biomass and nutrient release in natural sal, eucalyptus and poplar plantations in Uttar Pradesh. *Van Vigyan* **30**: 134-140.

Simpson, E. H. 1949. Measurement of diversity. *Nature* **163**: 688.

Terakunpisut, J., N. Gajaseni & N. Ruankawe. 2007. Carbon sequestration potential in aboveground biomass of Thong pha phun national forest, Thailand. *Applied Ecology and Environmental Research* **5**: 93-102.

Thapa, N., K. Upadhaya, R. Baishya & S. K. Barik. 2011. Effect of plantation on plant diversity and soil status of tropical forest ecosystems in Meghalaya, northeast India. *International Journal of Ecology and Environmental Sciences* **37**: 61-73.

Tripathi, K. P. & B. Singh. 2009. Species diversity and vegetation structure across various strata in natural and plantation forests in Katerniaghat Wildlife Sanctuary, North India. *Tropical Ecology* **50**: 191-200.

Valencia, R., H. Balslev & C. G. P. Y. Miño. 1994. High tree alpha-diversity in Amazonian Ecuador. *Biodiversity and Conservation* **3:** 21-28.

Winjum, J. K. & P. E. Schroeder. 1997. Forest plantations of the world: their extent, ecological attributes, and carbon storage. *Agriculture and Forest Meteorology* **84**: 153-167.

Young, R., B. R. Wilson, M. McLeod & C. Alston. 2005. Carbon storage in the soils and vegetation of contrasting land uses in northern New South Wales. *Australian Journal of Soil Research* **43**: 21-31.

(Received on 28.07.2012 and accepted after revisions, on 21.10.2013)

Appendix Table 1. Density (D, stems ha^{-1}), basal area (BA, $m^2\ ha^{-1}$) and importance value index (IVI) of tree species in six tropical forest stands of Garo hills in Meghalaya.

Name of species	Reserved forest															Wildlife sanctuary		
	Dambu			Darugiri			Songsak			Rongrengiri			Baghmara			Siju		
	D	BA	IVI	D	BA	IVI	D	BA	IVI	D	BA	IVI	D	BA	IVI	D	BA	IVI
Alangium chinensis (Lour.) Harms.	-	-	-	-	-	-	-	-		10	0.08	3.09	-	-	-	20	0.04	4.06
Bauhania purpurea Linn.	-	-	-	-	-	-	12	0.22	4.29	-	-	-	4	0.03	1.48	26	0.01	6.03
Castanopsis purpurella (Miq.) Balakr.	-	-	-	8	1.67	7.44	-	-	-	-	-	-	-	-	-	8	1.43	4.38
Castanopsis armata Spach.	-	-	-	-	-	-	40	4.76	19.2	20	3.24	14.26	8	2.66	7.40	-	-	-
Cryptocarya amygdalina Nees	-	-	-	-	-	-	-	-	-	-	-	-	56	3.30	23.26	-	-	-
Dillenia pentagyna Roxb.	8	0.50	5.21	4	0.40	2.92	8	0.86	3.95	28	1.45	12.64	-	-	-	16	1.67	6.01
Duabanga grandiflora (Roxb. ex DC.) Walp.	2	0.53	2.04	-	-	-	-	-	-	-	-	-	-	-	-	24	7.20	16.5
Dysoxylum gobara (Buch.-Ham.) Merr.	-	-	-	22	0.37	10.35	18	0.38	5.88	12	0.19	4.53	12	0.06	3.97	4	0.46	1.49
Elaeocarpus floribundus Bl.	6	0.05	2.60	10	0.05	4.02	12	1.03	6.13	10	0.10	3.57	10	0.65	4.88	10	0.18	2.76
Elaeocarpus tectorius (Lour.) Poir.	4	0.10	2.34	-	-	-	12	0.49	4.32	-	-	-	-	-	-	4	0.09	1.26
Erythrina stricta Roxb.	-	-	-	6	0.25	2.20	-	-		-	-	-	-	-	-	-	-	-
Eurya acuminata DC.	-	-	-	20	0.14	8.84	22	0.18	6.55	-	-	-	24	0.08	7.44	22	0.12	5.4
Callindra umbrosa (Wall.) Benth.	-	-	-	-	-	-	4	0.03	1.51	-	-	-	48	0.14	12.73	-	-	-
Garcinia cowa Roxb. ex DC.	12	0.37	5.68	-	-	-	4	0.03	1.50	4	0.14	1.83	4	0.15	1.72	26	0.25	6.39
Glochidion hirsutum Muell.-Arg.	-	-	-	-	-	-	12	0.06	4.03	10	0.05	3.44	-	-	-	24	0.13	5.97
Grewia disperma Roth.	12	0.04	5.80	-	-	-	-	-	-	14	0.06	4.55	16	0.07	4.58	8	0.11	2.08

Contd...

Appendix Table 1. Continued.

Name of species	Reserved forest															Wildlife sanctuary		
	Dambu			Darugiri			Songsak			Rongrengiri			Baghmara			Siju		
	D	BA	IVI	D	BA	IVI	D	BA	IVI	D	BA	IVI	D	BA	IVI	D	BA	IVI
Hibiscus macrophyllus Roxb. ex Hornem.	-	-	-	-	-	-	-	-	-	-	-	-	22	1.65	9.91	16	1.39	6.24
Lagerstroemia speciosa (Linn.) Pers.	2	0.16	1.37	4	0.12	2.39	8	0.25	3.33	26	2.67	14.74	18	1.62	9.28	14	2.24	6.96
Leea alata Edgew.	-	-	-	-	-	-	10	0.04	3.27	16	0.19	5.59	-	-	-	18	0.33	4.91
Litsea monopetala (Roxb.) Pers.	26	0.10	12.0	18	0.07	7.64	-	-	-	18	0.09	4.79	22	0.10	6.35	50	0.22	11.8
Licuala peltata Roxb.	-	-	-	48	0.17	17.30	-	-	-	-	-	-	-	-	-	-	-	-
Mallotus philippensis (Lam.) Muell.-Arg	-	-	-	-	-	-	-	-	-	14	0.75	6.60	-	-	-	-	-	-
Melia dubia Cav.	12	1.06	7.66	2	0.29	1.62	4	0.11	1.65	-	-	-	-	-	-	2	0.26	0.96
Neolitsea cassia (Linn.) Koster.	-	-	-	-	-		-	-	-	-	-	-	26	1.45	10.52	-	-	-
Ochna integerrima (Lour.) Merr.	-	-	-	2	0.15	1.37	4	0.24	1.87	82	5.35	34.64	14	0.91	5.99	8	0.32	2.4
Ostodes paniculata Bl.	-	-	-	6	0.27	3.01	-	-	-	-	-		-	-	-	-	-	-
Polyalthia simiamum (Hk.f.&Th.) Hk.f.&Th.	12	0.25	6.19	4	0.17	1.72	4	0.06	1.56	2	0.27	1.38	14	0.57	5.72	2	1.51	2.81
Polyalthia jenkensii Benth. & Hk.f.	12	0.62	6.86	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Schima wallichii (DC.) Korth.	30	1.42	14.37	32	1.63	17.37	44	1.77	14.66	18	0.79	7.75	50	3.57	7.25	90	7.16	29.46
Shorea robusta Gaertn.	356	45.35	179.8	376	42.21	177.0	190	31.99	98.78	78	13.34	50.96	82	11.21	39.29	34	6.94	17.62
Sterculia villosa Roxb.	4	0.18	2.48	-	-	-	6	0.60	2.78	12	0.65	5.17	22	1.04	9.10	-	-	-
Tectona grandis Linn.f.	-	-	-	-	-	-	28	0.43	6.54	8	0.07	1.85	-	-	-	-	-	-
Termenalia bellirica (Gaertn.) Roxb.	8	1.12	6.34	-	-	-	8	0.48	3.29	-	-	-	8	1.67	6.24	44	5.26	15.97
Others	64	3.07	39.25	46	6.13	34.8	238	14.08	104.9	258	13.19	118.6	230	18.28	122.9	376	29.86	138.5
Total	570	54.92	300	608	54.09	300	688	58.09	300	640	42.67	300	690	49.21	300	846	67.18	300

· indicates absence.