International Journal of Ecology and Environmental Sciences 50: 757-769, 2024
ISSN: 2320-5199 (Online); https://doi.org/10.55863/ijees.2024.0200

Diversity, Biomass and Carbon Stock of Woody Species in Community Reserves of Meghalaya, Northeast India

KHROTE-U LASUSHE[1], PREM PRAKASH SINGH[2], KANHAIYA LAL CHAUDHARY[4], HIRANJIT CHOUDHURY[3] AND KRISHNA UPADHAYA[3]*

[1]Department of Environmental Studies, [2]Department of Botany, [3]Department of Basic Sciences and Social Sciences, North-Eastern Hill University, Shillong, 793022, India

[4]Department of Botany, Lady Keane College, Shillong, 793001, India

E-mail: khrotel18@gmail.com, prem12flyhigh@gmail.com, klchaudhary31@gmail.com, hiranjit41@gmail.com, upkri@yahoo.com

***Corresponding author**

ABSTRACT

Diversity, biomass and carbon (C) stock (above- and below-ground) of woody species (≥5 cm dbh) were studied in 15 Community Reserves (CRs) of Meghalaya, Northeast India. A total of 287 species belonging to 72 families and 165 genera were enumerated from 7.5 ha sampled area. The number of individuals ranged from 888 to 1582 ha^{-1} with a mean density of 1182.4±57.76 individuals ha^{-1}. The basal area ranged from 22.27 to 59.22 $m^2\,ha^{-1}$ with a mean value of 41.60±3.23 $m^2\,ha^{-1}$ in the studied sites. The total biomass and C stock ranged from 147.57 to 343.25 Mg ha^{-1} and 69.95 to 162.7 Mg C ha^{-1}, respectively. The contribution of AGB and BGB to the total biomass and C stock was 79-82% and 18-21%, respectively. The variation in species richness, density, basal area, biomass, and carbon stock observed in the studied CRs can be attributed to their past land use and management history. The present study highlights that these CRs possess a high potential to act as carbon sinks, indicating that creating more CRs in the state could prove highly beneficial. Such an approach would not only help to preserve the region's rich biodiversity but also aid in sequester the atmospheric carbon dioxide.

Key words: Above-ground biomass, Carbon sink, Climate change, Species diversity, Protected area

INTRODUCTION

The primary driver of global warming and climate change is the increased concentration of carbon dioxide (CO_2) in the atmosphere (Anonymous 2014). Prior to the industrial era, the concentration of atmospheric CO_2 was about 280 ppm (Prentice et al. 2001), but it escalated considerably with the dawn of the industrial revolution to over 420.13 ppm (Anonymous 2021, Boetcher et al. 2023). With the current rate of increase, the projected CO_2 concentration is predicted to reach 800 ppm by 2100 (Anonymous 2022, Singh 2017). Such an increase in CO_2 concentration would have a significant repercussion on global warming and climate change. Therefore, there is a pressing need for mitigation of global warming through C sinks, whereby the excess atmospheric CO_2 can be captured (Pragasan 2015).

Forest ecosystems play an important role in global C cycle regulation (Mir et al. 2021). They are considered as the most productive terrestrial ecosystems and act as one of the major carbon sinks on earth (Nabuurs et al. 2007). Forests account for about 80% of the earth's total plant biomass (Kindermann et al. 2008) and stores more carbon in their biomass and soils than that present in the atmosphere (Pan et al. 2011). However, forests are highly threatened by anthropogenic activities (Htun et al. 2011). Poverty, population pressure, agricultural expansion/intensification and infrastructural development are the major causes of deforestation and loss of biodiversity (Bargali et al. 2022, Bisht et al. 2023) which causes an increase in CO_2 in the atmosphere. In recent years, carbon emissions from deforestation have been on the rise accounting for 20% of global carbon emissions (Anonymous 2007), second only to that produced by fossil fuel combustion (Campbell et al. 2008). As a result, the loss of forest cover not only endangers biodiversity but also contributes to climate change (Shivanna 2022). Therefore, proper management along with the maintenance of C pool becomes important from the context of arresting further environmental degradation (Karki et al. 2022, Pandey et al. 2023). An effective measure to combat the loss of biodiversity and mitigate climate change is to protect natural habitats. Protected areas, apart from their role in biodiversity conservation also secure ecosystem services (Deguignet et al. 2017, Xu et al. 2017, Wang et al. 2022). Thus, strengthening of the current protected area and designation of new protected areas could deliver multiple benefits (Campbell et al. 2008). Though designated with the objective of conserving biodiversity, protected areas also fulfill an important role in maintaining terrestrial C stocks (Campbell et al. 2008). Throughout the world, protected areas cover 12.2% of the land surface and contain over 312 GtC or 15.2% of the global terrestrial C stock (Campbell et al. 2008). The C stored in protected area network are effective sink of global C among the terrestrial ecosystems (Tian et al. 2023).

In India, legally protected areas include National Parks, Wildlife Sanctuaries, and Biosphere Reserves. In addition to these, the Wildlife (Protection) Amendment Act of 2002 introduced a new category of protected area that falls under IUCN Category VI called the Community Reserves (CRs). At present, there are 220 CRs covering an area of 1446.28 km^2, and accounts to about 0.04% of the total geographical area of the country (Anonymous 2023b). The CRs are set up on biodiversity abundant lands that are privately- or community-owned, and are managed by the individual(s)/communities in possession of the area (Anonymous 2010). They may also serve as buffer zones to National Parks and Sanctuaries or corridors between protected areas. Unlike other categories of protected area, CRs recognizes the role of local communities in the protection of natural resources including threatened species (Anonymous 2017). Out of the 220 CRs present in India, Meghalaya a small state in north-east India has a total of 74 CRs covering an area of 62.93 km^2 (Anonymous 2023b). This expansion of protected areas by designating community-owned forests as CRs would help not only in conserving biodiversity but also in providing several ecosystem services.

A number of studies have been carried out to understand the floristic diversity of the protected areas in the state of Meghalaya (Kumar et al. 2006, Baishya et al. 2009, Prabhu et al. 2010, Thapa et al. 2011, Singh and Borthakur 2015, Upadhaya et al. 2015, Parkash 2021). However, only a few studies had estimated the biomass and C stock of the protected areas (Baishya et al. 2009, Upadhaya et al. 2015) with little or no emphasis on CRs. Therefore, there is a need to estimate the C stock of forest ecosystems of the region that would help to evaluate the role of CRs in addressing climate change at the local and regional level and also provide baseline data for further studies. Hence, the present study was carried out to (i) assess the woody species diversity (ii) estimate the contribution of above ground biomass (AGB) and below ground biomass (BGB) to forest C stock and (iii) evaluate the distribution pattern of biomass and C stock in different age groups of the individuals in the CRs of Meghalaya.

MATERIALS AND METHODS

Site description

A total of 15 CRs spread across six districts of Meghalaya were selected (Fig. 1). The size of the CRs ranged from 7 ha to 311.44 ha and their status varied in terms of ownership and past management practices operated prior to its recognition as CR's (Table 1). Of the 15 CRs studied, eight were conserved as sacred groves, two clan forests, one private forest and four village forests. Based on floristic composition and altitude, nine CRs (CR1-CR9) falls under subtropical and the remaining six CRs (CR10-CR15) represents tropical vegetation (Champion and Seth 1968).

The climate of the study area is monsoonal and is influenced by southwest and northeast winds. The northern part of Khasi hills being located at lower elevation experiences high temperature (29^{o}C) relative to the climate of the central and eastern Meghalaya (Khasi and Jaintia Hills) where the temperature is lower (24^{o}C). The average rainfall ranges from 2689-4000 mm with the wet season extending from May to October, and the dry season extends from November to March.

Vegetation sampling

In each of the selected CRs, quantitative plant diversity assessment was carried out following transect method. A belt transect of 250 x 20m (0.50 ha) was laid in each CRs. The transect was further divided into quadrats of 10 x 10m, and all individuals having a diameter of $\geq$5 cm at breast height were

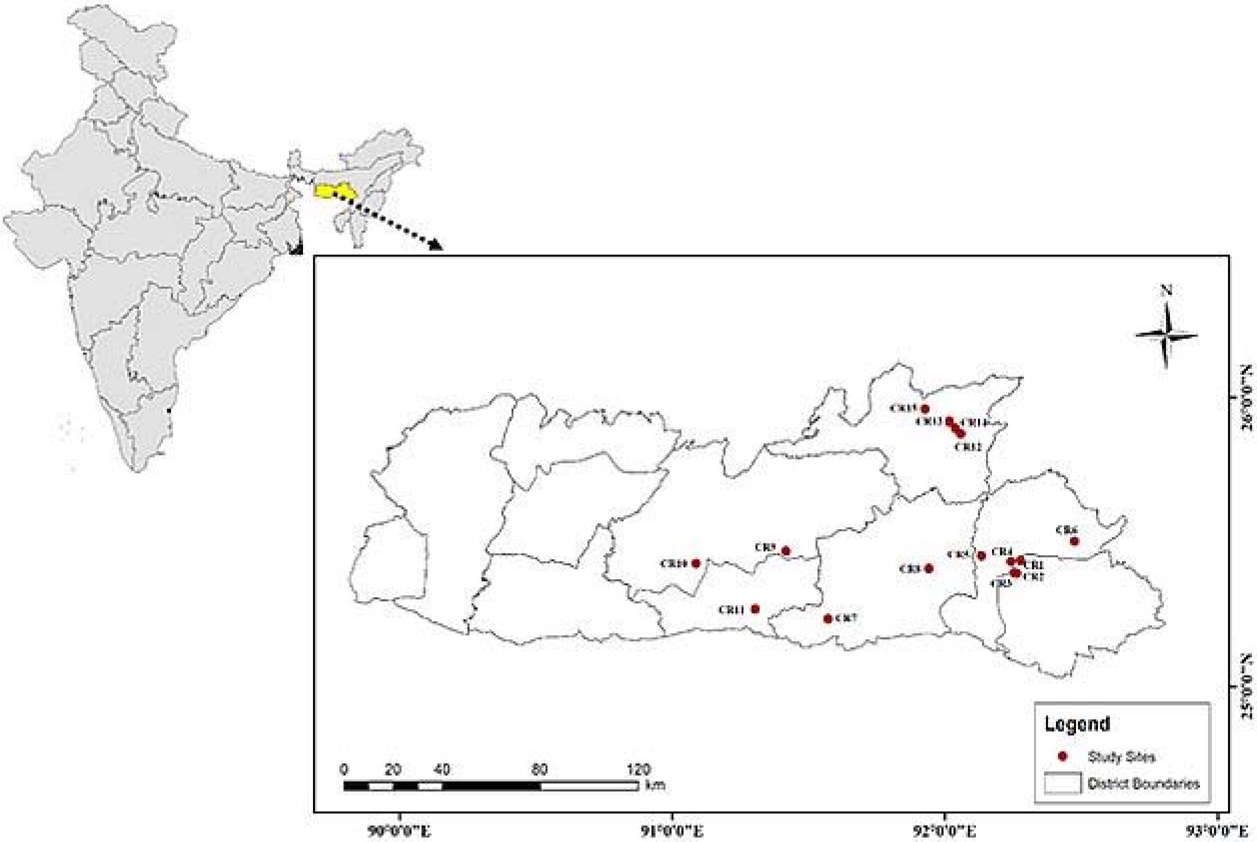

Figure 1. Map of Meghalaya indicating the CRs (CR1" Khloo Blai Sein Raij Tuber CR, CR2" Ka Khloo Thangbru Umsymphu CR, CR3" Ka Khloo Pohblai Mooshutia CR, CR4" Khloo Blai Chyrmang Sein Raij Kongwasan Chyrmang Kmai CR, CR5" Ka Khloo Langdoh Kur Pyrtuh CR, CR6" Khloo Blai Ka Raij U Langdoh Ionglang CR, CR7" Lawbah CR, CR8"Ryngibah CR, CR9" Kpoh Eijah CR, CR10" Miewsyiar CR, CR11" Umsum Pitcher Plant CR, CR12" Nongsangu CR, CR13" Raid Nongbri CR, CR14" Lum Jusong CR, CR15" Raid Nonglyngdoh /Pdah Kyndeng CR).

measured using a meter tape. In case of multiple stems, dbh of each stem was measured and converted to a single dbh by taking the square root of the sum of all squared stem. Plant species were identified with the help of available literature (Kanjilal et al. 1934-1940, Balakrishnan 1981-1983, Haridasan and Rao 1985-1987, Upadhaya et al. 2021). The Herbaria at Botanical Survey of India, Eastern Regional Circle, Shillong was consulted for correct identification of the specimens. The nomenclature of the plant species follows the online database i.e., Plants of the World Online (Anonymous 2023a).

Data analysis

The community parameters such as frequency, density, basal area, and importance value index (IVI) were calculated following Misra (1968) and Mueller-Dombois and Ellenberg (1974). Various diversity indices such as Shannon-Wiener index of diversity, Simpson's dominance index and Pielou's evenness index were computed to analyze species diversity and dominance in the community following Magurran (1988).

The biomass and C stock were estimated by non-destructive sampling method. For broadleaved species, the above-ground biomass (AGB) was estimated from the diameter value (D) using allometric equation developed by Chambers et al. (2001) as shown below:

$$ABG = \exp\{-0.37+0.333\ln(D)+0.933\ln(D^2)-0.122\ln{}^*D^3)\}$$

For lianas, the AGB was computed using the allometric equation developed by Schnitzer et al. (2006):

$$ABG = \exp\{-1.484+2.65\ln(D)\}$$

The belowground biomass (BGB) for broadleaved species and lianas was estimated from the respective AGB values, following the equation developed by

Table 1. Site characteristics of the studied CRs in Meghalaya

Community Reserve name and vegetation zone	Altitude (m asl)	Area (ha)	Year of notification	Status of the CRs before recognition
Subtropical				
Khloo Blai Sein Raij Tuber CR	1379	89.43	No.FOR.17/2013/134, Dt.10.7.2013	Sacred grove
Ka Khloo Thangbru Umsymphu CR	1305	19.6	No.FOR.17/2013/Pt/44, Dt.4.3.2014	Village reserve forest
Ka Khloo Pohblai Mooshutia CR	1257	33.5	No.FOR.17/2013/Pt/45, Dt.4.3.2014	Sacred grove
Khloo Blai Chyrmang Sein Raij Kongwasan Chyrmang Kmai CR	1381	7	No.FOR.17/2013/135, Dt.10.7.2013	Sacred grove
Ka Khloo Langdoh Kur Pyrtuh CR	1454	15.4	No.FOR.17/2013/Pt/46, Dt.4.3.2014	Sacred grove
Khloo Blai Ka Raij U Langdoh Ionglang CR	1129	15.12	No.FOR.17/2013/Pt/144, Dt.07.03.2016	Sacred grove
Lawbah CR	937	311.44	No.FOR.17/2013/209, Dt.05.9.2016	Village forest
Ryngibah CR	1620	96.91	No.FOR.17/2013/214, Dt.29.11.2016	Village forest
Kpoh Eijah CR	1607	17	No.FOR.17/2013/Pt/117, Dt. 04.12.2014	Clan forest
Tropical				
Miewsyiar CR	755	87	No.FOR.17/2013/Pt/118, Dt.04.12.2014	Clan forest
Umsum Pitcher Plant CR	900	40	No.FOR.17/2013/Pt/119, Dt.04.12.2014	Private forest
Nongsangu CR	807	100	No.FOR.17/2013/181, Dt.10.3.2014	Village reserve forest
Raid Nongbri CR	750	70	No.FOR.17/2013/182, Dt.10.3.2014	Sacred grove
Lum Jusong CR	924	130.46	No.FOR.17/2013/210, Dt.05.9.2016	Sacred grove
Raid Nonglyngdoh /Pdah Kyndeng CR	440	75	No.FOR.17/2013/185, Dt.10.3.2014	Sacred grove

Cairns et al. (1997):

$$BGB=\exp\{-1.059+0.884\ln(AGB)+0.284\}$$

For *Pinus kesiya*, the AGB and BGB were determined separately following the equations developed by Baishya and Barik (2011) as shown below:

$$Log(ABG)=1.3503+(-3.4145)logD+4.8678(log(D)^2+(-1.352)(log(D)^3$$

$$Log(BGB)=-9.8635+17.8955logD+(-8.9558)log(D^2)+1.4511log(D^3)$$

The total tree biomass of each CR was then calculated by summing up the AGB and BGB of all the species and the C stock was derived as 47.4% of the total biomass (Martin and Thomas 2011, Thomas and Martin 2012).

To assess the contribution of different age groups to density, basal area, biomass and C stock, all individuals were classified into two categories, *viz.*, juveniles (≥5 cm to 30 cm dbh) and adults (≥31 cm dbh).

RESULTS

Species diversity

A total of 287 woody species (≥5 cm dbh) were recorded from 15 CRs. They include 235 trees, 41 shrubs and 11 lianas distributed among 72 families and 165 genera. The highest number of species was recorded in CR2 (Thangbru CR) and CR12 (Nongsangu CR) with a total of 78 species each, while the lowest number of species was observed in CR9 (Kpoh Eijah CR) with 35 species. The various community attributes of the studied CRs are given in Table 2.

Shannon-Wiener's diversity index (H′) ranged from 2.48 to 3.94, with the highest value in CR3 (Mooshutia CR) and the lowest in CR9 (Kpoh Eijah CR). On the other hand, Simpson's dominance index (D) showed a reverse trend to that of Shannon-Wiener's diversity index (H') with values ranging from 0.03 to 0.12. Pielou's evenness index (J) ranged between 0.70 and 0.91 in the studied CRs (Table 2).

In terms of family richness, Lauraceae was the dominant family with 29 species followed by Rubiaceae (17 species), Moraceae and Fabaceae (14 species each), Phyllanthaceae and Fagaceae (12 species each), Anacardiaceae (11 species), Araliaceae, Malvaceae, Myrtaceae and Rosaceae (9 species each), Euphorbiaceae (8), Clusiaceae, Elaeocarpaceae, Lamiaceae, Primulaceae and Theaceae (6 each), Pentaphylacaceae, Rutaceae and Symplocaceae (5 each), Ericaceae, Magnoliaceae, Oleaceae and Urticaceae (4 each), Apocynaceae, Aquifoliaceae, Celastraceae, Meliaceae, Salicaceae and Sapindaceae (3 each). There were 14 families

Table 2. Community attributes and diversity indices of woody species (≥5 cm dbh) in CRs of Meghalaya

Community Reserves	No. of species	No. of genera	No. of families	Density (ind ha^{-1})	Basal area (m^2 ha^{-1})	Shannon index (H′)	Simpson's index (D)	Pielou's index (J)
CR1	70	56	40	1084	43.49	3.56	0.05	0.84
CR2	78	57	39	944	27.38	3.89	0.03	0.89
CR3	74	57	40	1084	36.23	3.94	0.03	0.91
CR4	64	50	33	1060	45.29	3.59	0.04	0.86
CR5	47	38	32	898	54.34	3.24	0.06	0.84
CR6	77	68	42	1112	59.22	3.43	0.07	0.81
CR7	52	44	32	1426	43.91	3.32	0.05	0.84
CR8	61	52	35	1138	22.27	3.47	0.05	0.84
CR9	35	31	24	1208	43.21	2.48	0.12	0.70
CR10	65	51	31	1582	24.54	3.56	0.04	0.85
CR11	45	41	28	1140	23.04	2.92	0.08	0.77
CR12	78	61	31	1464	44.01	3.67	0.06	0.84
CR13	63	55	33	1158	54.80	3.49	0.04	0.84
CR14	48	43	23	1548	43.45	2.89	0.11	0.75
CR15	54	48	27	888	40.17	3.37	0.05	0.85

that were bispecific and the remaining 27 families were monospecific. The top 15 dominant families accounted for 60% of the total woody species (Fig. 2). Among the genera, *Ficus* was the most dominant with 13 species, followed by *Litsea* (9 species), *Syzygium* (8), *Glochidion* (7), *Elaeocarpus* and *Machilus* (6 each), *Castanopsis*, *Cinnamomum*, *Garcinia* and *Symplocos* (5 each), *Heptapleurum*, *Magnolia*, *Prunus*, *Quercus* and *Wendlandia* (4 each), and, *Albizia*, *Casearia*, *Eurya*, *Ilex*, *Lindera*, *Lithocarpus*, *Psychotria* and *Toxicodendron* (3 each). Of the remaining, 28 genera were represented by two species each and 118 genera were monospecific.

Density and basal area

The density of woody species varied across the CRs and ranged from 888 individuals ha^{-1} (CR15) to 1582 individuals ha^{-1} (CR10) with a mean density of 1182.4±57.76 individuals ha^{-1} (Table 2). Out of 287 woody species, 15 species contributed 36% to the total density and the rest (172 species) accounted for 64% of the total density in these CRs (Table 3). The dominant species in terms of density contribution includes *Schima wallichii* (8.46%), *Castanopsis tribuloides* (4.38%), *Lithocarpus dealbatus* (2.83%), *Sarcosperma griffithii* (2.81%) and *Castanopsis purpurella* (2.77%) (Table 3).

The value of basal area ranged from 22.27 (CR8) to 59.22 m^2 ha^{-1} (CR6) with a mean value of 40.36±3.01 m^2 ha^{-1} in the studied CRs (Table 2). The top 15 species contributed to 51.5 % of the total basal area, whereas, rest of the species accounted for 48.5% of the total basal area (Table 3). Across the CRs, *Schima wallichii* was the most dominant contributor to basal area (10.68%) followed by *Castanopsis tribuloides* (6.48%), *Machilus odoratissimus* (5.71%), *Castanopsis purpurella* (5.41%) and *Engelhardia spicata* (3.28%) (Table 3).

Biomass and carbon stock

The AGB of woody species in the studied CRs ranged from 117.6 (CR8) to 280.7 Mg ha^{-1} (CR 6) with a mean value of 220.5±13.4 Mg ha^{-1} (Table 4). Similarly, the BGB ranged from 29.9 to 62.49 Mg ha^{-1} with a mean of 47.1±2.7 Mg ha^{-1}. The above-ground biomass carbon (AGBC) ranged from 55.8 to 133.1 Mg C ha^{-1} (Mean = 95±6.3 Mg C ha^{-1}) and below-ground biomass carbon (BGBC) ranged from 14.2 to 29.6 Mg C ha^{-1} (Mean = 22.3±1.3 Mg C ha^{-1}). Total tree biomass (AGB+BGB) and carbon stock (AGBC+BGBC) was lowest in CR8 (147.6 and 69.6 Mg C ha^{-1}) while the highest value was observed in CR6 (343.25 and 162.70 Mg C ha^{-1}) (Table 4). AGB and AGBC accounted about 79-82% while BGB and BGBC contributed to 18-21% (Table 4) of the total biomass and carbon stock.

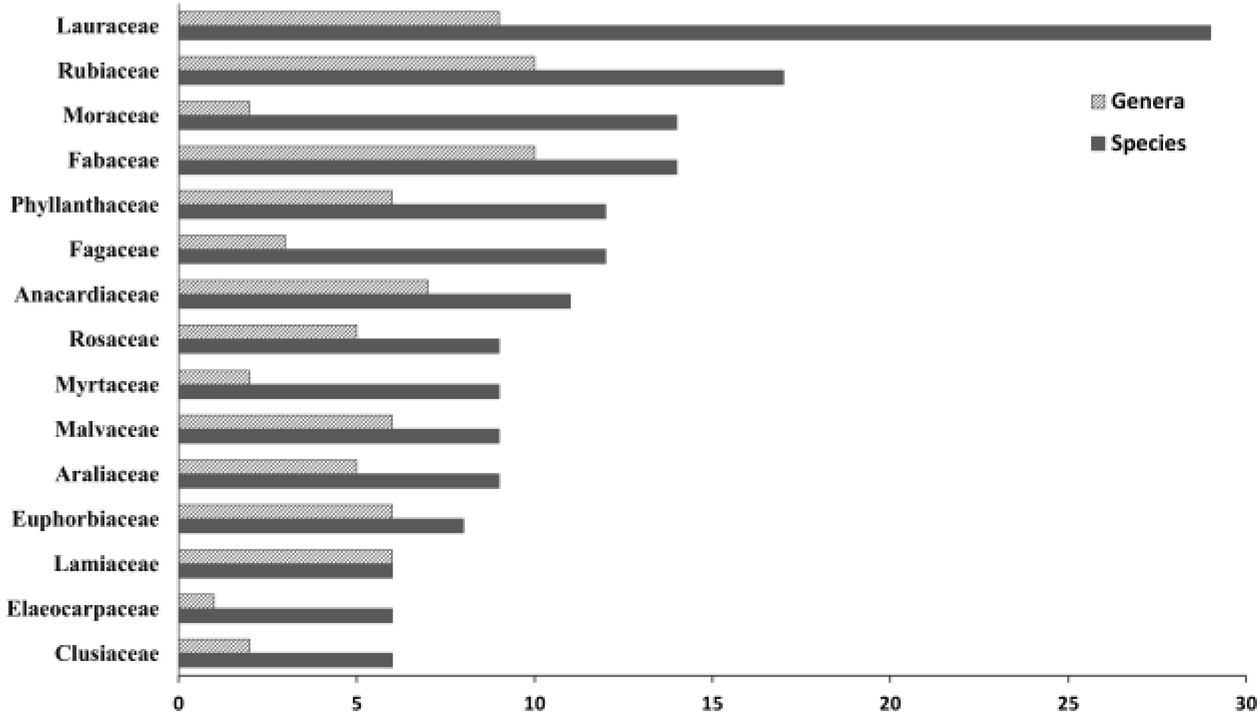

Figure 2. Dominant families of woody species (≥5 cm dbh) in terms of species and genera

Table 3. Dominant 15 species and their contribution to density, basal area and above ground biomass in terms of percentage (%) in the studied CRs of Meghalaya

Species Name	**Density (%)**	**Basal area (%)**	**Aboveground biomass (%)**
Schima wallichii Choisy	8.46	10.68	10.81
Castanopsis tribuloides (Sm.) A.DC.	4.38	6.48	6.44
Machilus odoratissimus Nees	1.97	5.71	5.20
Castanopsis purpurella (Miq.) N.P.Balakr.	2.77	5.41	5.21
Engelhardia spicata Lechen ex Blume	2.14	3.28	3.16
Lithocarpus dealbatus (Hook.f. & Thomson ex Miq.) Rehder	2.83	3.11	3.12
Sarcosperma griffithii Hook.f. ex C.B.Clarke	2.81	2.54	2.56
Exbucklandia populnea (R.Br. ex Griff.) R.W.Br.	1.45	2.49	2.41
Lithocarpus elegans (Blume) Hatus. ex Soepadmo	1.64	1.91	1.86
Machilus parviflora Meisn.	1.27	1.89	1.84
Quercus glauca Thunb.	1.23	1.71	1.69
Quercus serrata Murray	1.16	1.69	1.66
Knema angustifolia (Roxb.) Warb.	1.38	1.62	1.62
Pinus kesiya Royle ex Gordon	0.58	1.56	0.41
Careya arborea Roxb.	1.48	1.47	1.51
Total	**35.55**	**51.54**	**49.50**

Among the 287 woody species enumerated in all CRs, the dominant 15 species accounted for 49.5% of the total ABG and C stocks in these CRs (Table 3). Species-wise, *Schima wallichii* accumulated the greatest biomass and C stocks (10.81%) followed by *Castanopsis tribuloides* (6.44%), *C. purpurella* (5.21%), *Machilus odoratissimus* (5.2%) and *Engelhardia spicata* (3.16%) (Table 3).

Age structure

In all the CRs, there was a higher proportion of juvenile individuals (80-98%), whereas the adult individuals made up to 2-20 % of the total density (Fig. 3). However, in different age groups, the adult individuals accounted for 55-78% of the total basal area in eight CRs (CR1, CR2, CR3, CR4, CR5, CR6, CR13 and CR15), while 22-45% was contributed by the juvenile population. Conversely, in seven CRs (CR7, CR8, CR9, CR10, CR11, CR12 and CR14) the contribution to basal area by the juvenile individuals were greater (52-87%) than those of adult individuals (13-48%) (Fig. 3).

Similarly, the mean percentage contribution of adult individuals to the total AGB and AGBC was 60±2.9 in eight CRs (CR1, CR2, CR3, CR4, CR5, CR6, CR13 and CR15). In contrast, the juvenile individuals had a mean percentage value of 70±4.2 in the remaining seven CRs. Overall, the AGB of adult individuals in the study area ranged from 15.9 to 194.3 Mg ha^{-1} (mean = 99.3±14.3 Mg ha^{-1}), while AGB of juvenile individuals ranged from 63.5 to 161.1 Mg ha^{-1} (mean =101.2±6.7 Mg ha^{-1}). The AGBC of adult individuals ranged from 7.5 to 92.1 Mg C ha^{-1} (mean = 47.1±6.8), while AGBC of juvenile individuals ranged from 30.1 to 76.4 Mg C ha^{-1} (mean = 48.0±3.2 Mg C ha^{-1}) (Fig. 3).

DISCUSSION

The effectiveness of any protected area for conservation of biodiversity depends on the degree of protection and adoption of various management strategies (Cazalis et al. 2020). The present study showed variation in species richness, density, basal area, biomass and C stock across the studied CRs. Such variation may be attributed to a number of factors such as land use history and anthropogenic disturbances in the past and geographical proximity to human habitation (Echeverría et al. 2007). Forest that had the status of sacred groves or reserved village forests prior to its recognition as CRs showed high species richness due to low human disturbances as

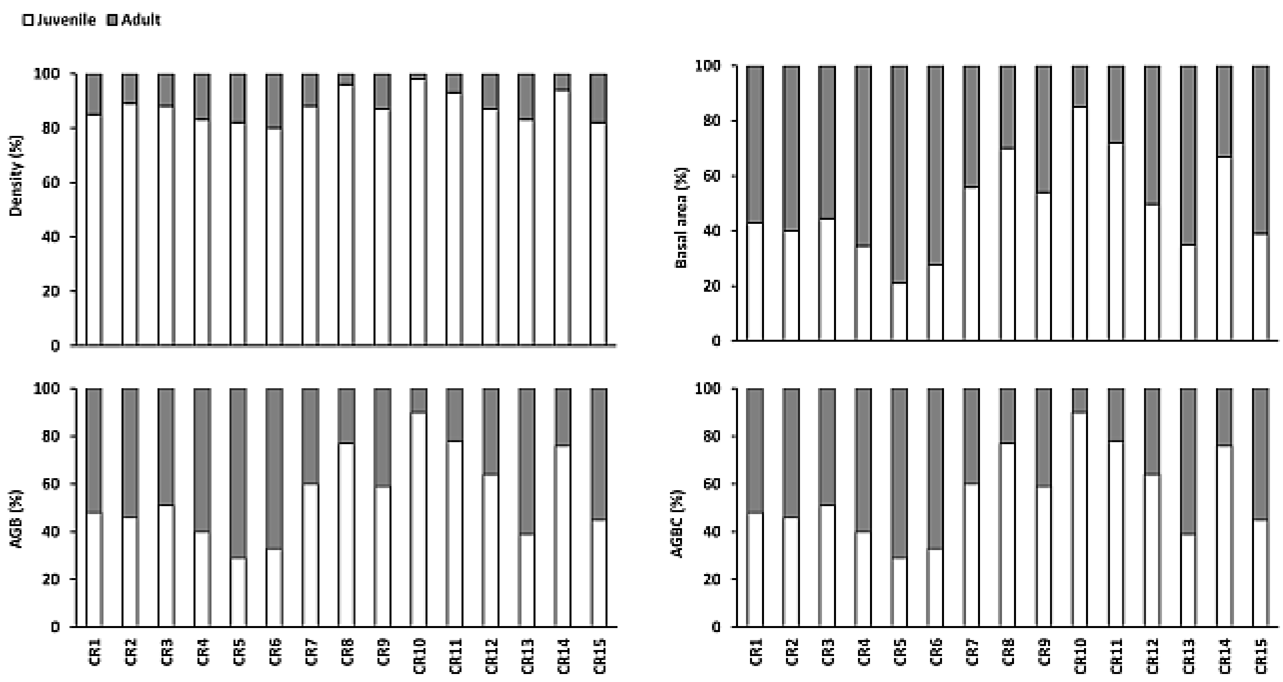

Figure 3: Percentage contribution of juvenile and adult woody species to density (a), basal area (b), AGB (c) and AGBC (d) in the studied CRs of Meghalaya

Table 4. Above ground biomass (AGB), below ground biomass (BGB) and C stock of woody species in the studied CRs of Meghalaya

Community Reserves	AGB ($Mg\ ha^{-1}$)	BGB ($Mg\ ha^{-1}$)	Total biomass ($Mg\ ha^{-1}$)	AGBC ($Mg\ C\ ha^{-1}$)	BGBC ($Mg\ C\ ha^{-1}$)	Total biomass carbon ($Mg\ C\ ha^{-1}$)
CR1	213.97	49.88	263.85	101.42	23.64	125.06
CR2	139.56	32.76	172.32	66.15	15.53	81.68
CR3	182.80	43.31	226.10	86.65	20.53	107.17
CR4	244.91	55.44	300.35	116.09	26.28	142.37
CR5	251.18	54.22	305.40	119.06	25.70	144.76
CR6	280.76	62.49	343.25	133.08	29.62	162.70
CR7	224.56	54.63	279.18	106.44	25.89	132.33
CR8	117.63	29.94	147.57	55.76	14.19	69.95
CR9	205.94	48.47	254.40	97.61	22.97	120.59
CR10	134.23	35.55	169.78	63.62	16.85	80.47
CR11	121.98	31.07	153.05	57.82	14.73	72.55
CR12	207.90	49.77	257.67	98.54	23.59	122.13
CR13	263.45	59.27	322.72	124.88	28.09	152.97
CR14	221.09	53.93	275.02	104.80	25.56	130.36
CR15	197.82	45.68	243.50	93.77	21.65	115.42

compared to village forests, private and clan forests. This finding is similar to that observed by earlier workers from the state of Meghalaya (Mir and Upadhaya 2017, Mir et al. 2021).

The density of woody species (888-1582 individuals ha^{-1}) recorded in the present study are comparable with the range (894-1637 individuals ha^{-1}) reported from various forests of the state (Upadhaya et al. 2004, Baishya et al. 2009, Mishra and Jeeva 2012, Upadhaya 2015, Chaudhury and Upadhaya 2016, Gogoi et al. 2020). In all the CRs, the density of juvenile individuals was higher (80-98%) as compared to the adult individuals (2-20%). This finding is consistent with that of tropical dry forests of Eastern Ghats (Naveenkumar et al. 2017), tropical deciduous forest of Central India (Dar et al. 2022) and tropical semi-evergreen forest (Thapa et al. 2011) and subtropical forests (Mir et al. 2021) of northeast India.

The range of basal area (22.27 and 59.22 $m^2\ ha^{-1}$) observed in the present study is similar to those reported from subtropical humid forests (36-71 $m^2\ ha^{-1}$) of Khasi Hills, Meghalaya (Upadhaya et al. 2004), tropical wet evergreen forest (28-81 $m^2\ ha^{-1}$) of Kodayar, Western Ghats (Sundarapandian and Swamy 2000), subtropical forests (34.9-50.5 $m^2\ ha^{-1}$) of Nepal (Paudel and Sah 2015), tropical evergreen and semi-evergreen forests (40.5-74.05 $m^2\ ha^{-1}$) of Assam (Nandy and Das 2013) and subtropical and temperate forest (33.42-51.58 $m^2\ ha^{-1}$) of Central Himalaya (Joshi et al. 2021a). The CRs that were protected earlier in the form of sacred groves showed greater basal area due to strict prohibition on tree cutting and forest product extraction. This led to higher basal cover in these forests (Upadhaya et al. 2003). The adult individuals contributed to higher proportion of total basal area in CR1, CR2, CR3, CR4, CR5, CR6, CR13 and CR15, is a characteristic feature of old growth forest. On the other hand, CR7, CR8, CR9, CR10, CR11, CR12 and CR14 had higher basal area in the juvenile category. This suggests that these CRs experienced human disturbances in the past and now represent a regenerating forest.

The AGB values (117.6-280.76 $Mg\ ha^{-1}$) observed in the present study is within the range (32-577 $Mg\ ha^{-1}$) reported from various forests of northeast India and the Himalayas (Baishya et al. 2009, Baishya and Barik 2011, Thokchom and Yadava 2013, Upadhaya et al. 2015, Chaudhury and Upadhaya 2016, Gogoi et al. 2020, Joshi et al. 2021b, Mir et al. 2021). The contributions of AGB (79-82%) and BGB (18-21%) obtained in the study are consistent with that reported for other forests of India (Chhabra et al. 2002, Dar and Sundarapandian 2015). Similarly, the total C

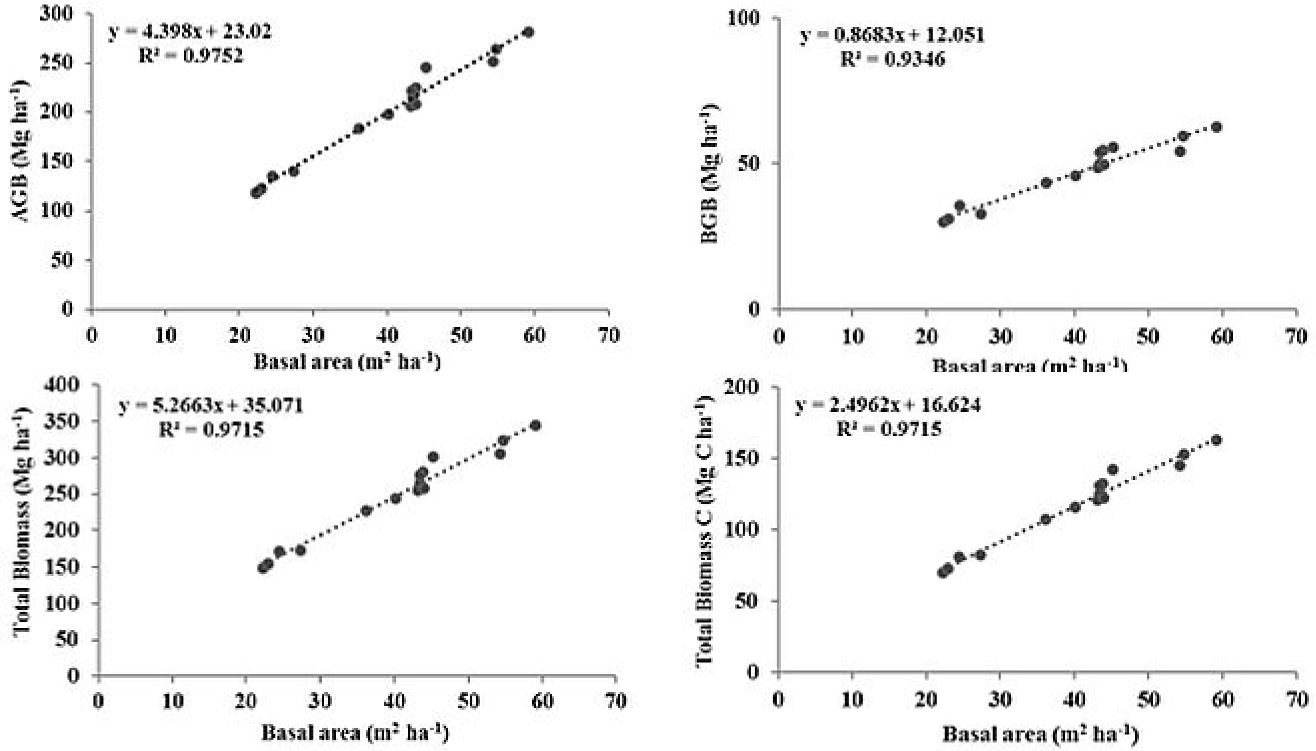

Figure 4: Relationship between AGB (a), BGB (b), total biomass (c) and total biomass carbon (d) with basal area (BA) in the studied CRs

stock values observed in the present study (71.89-162.70 Mg C ha^{-1}) are close to the range (108-274 Mg C ha^{-1}) reported from various forest types of northeast India (Upadhaya et al. 2015, Chaudhury and Upadhaya 2016, Deb et al. 2021, Mir et al. 2021) and the Himalayas (Joshi et al. 2021b). The values showed inclination towards the upper range of 16-140.4 Mg C ha^{-1} recorded from other forests of the region (Bora et al. 2013, Gogoi et al. 2020, Deb et al. 2021, Mir et al. 2021).

Species diversity and other community characteristics have a profound effect on biomass and C stock in the studied CRs. Among the community parameters, basal area was found to have a significant influence on biomass and C stock as evident by a significant positive correlation (Fig. 4). This finding corroborates to that observed in tropical dry deciduous forest of Central India (Raha et al. 2020) and subtropical forests of northeast India (Gogoi et al. 2020, Mir et al. 2021). Thus, basal area can provide a general indication of tree biomass and C stock. C stock in tree biomass increases with the stand age and with the number of larger trees (Vanninen et al. 1996; Zhang et al. 2011). The contribution of large individuals to higher C stock is similar to the findings reported from other forests of the region (Baishya et al. 2009, Upadhaya et al. 2015) as well as other tropical forests (Brown and Lugo 1992, Clark and Clark 1994). Conversely, the high contribution of juvenile category to AGB and AGBC in certain CRs indicates their future potential to accumulate large quantities of atmospheric CO_2 if left undisturbed (Mir et al. 2021).

CONCLUSIONS

This study highlights the significance of Community Reserves for biodiversity conservation and long term ecological maintenance. The variation in community characteristics across the CRs in terms of species richness, density, basal area, biomass, and C stock, is influenced by land use history, anthropogenic disturbances, and proximity to human habitation. Sites that were maintained as sacred forests prior to its recognition as CRs showed higher species richness and basal area due to low human disturbances. The present study showed a significant positive correlation between basal area and biomass/C stock. Thus, basal area can be used as a proxy for estimation of tree biomass and C storage in forest ecosystem. The preponderance of juvenile individuals in all CRs indicates their future potential to sequester atmospheric CO_2. This study may serve as a baseline data for studies related to C stocks in protected areas, particularly the Community Reserves of India. The establishment of more CRs at local and regional level would not only aid in the abatement of deforestation and conserving biodiversity but also in reducing carbon emissions.

ACKNOWLEDGEMENTS

The authors are thankful to the Head of Office, Botanical Survey of India, Eastern Regional Circle, Shillong for allowing us to consult the herbarium. The necessary permission for conducting the study granted by CRs management committee is acknowledged. The financial support received by first author in the form of fellowship from NFST (201718-NFST-NAG-00225) is also acknowledged.

Authors' Contribution: All authors contributed equally.

Conflict of interest: The authors declare that there is no conflict of interest.

REFERENCES

Anonymous. 2007. Climate Change 2007: Mitigation of Climate Change. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

Anonymous. 2010. The Wildlife Amendment (Protection) Act 2002. MoEF, New Delhi. Available from http://www.envfor.nic.in/legis/wildlife/wild_act_02.htm (accessed 18 February 2013).

Anonymous. 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

Anonymous. 2017. The Meghalaya State Biodiversity Strategy and Action Plan (Draft). Wildlife Institute of India. Ministry of Environment, Forest and Climate Change, Government of India.

Anonymous. 2021. Carbon dioxide peaks near 420 ppm at Mauna Loa observatory, https://research.noaa.gov/article/artmid/587/articleid/2764/coronavirus-response-barely-slows-rising-carbon-dioxide

Anonymous 2022. Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

Anonymous. 2023a. Plants of the World Online. Facilitated by the Royal Botanic Gardens, Kew. http://www.plantsoftheworldonline.org/

Anonymous. 2023b. Wildlife Institute of India. Ministry of Environment, Forest and Climate Change, Government of India.

Baishya, R. and Barik, S.K. 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(4), 727-736. https://doi.org/10.1007/s13595-011-0089-8

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

Balakrishnan, N.P. 1981-1983. Flora of Jowai, 2 vols. Botanical Survey of India, Howrah. 666 pages.

Bargali, S.S., Shahi, C., Bargali, K., Negi, B. and Khatri, K. 2022. Energy and monetary efficiencies at the different altitudinal agroecosystems in Central Himalaya, India / Heliyon, 8, e11500. https://doi.org/10.1016/j.heliyon.2022.e11500

Bisht, S., Rawat, G.S., Bargali, S.S., Rawat, Y.S. and Mehta, A. 2023. Forest vegetation response to anthropogenic pressures: a case study from Askot Wildlife Sanctuary, Western Himalaya. Environment, Development and Sustainability, 26, 10003-10027. https://doi.org/10.1007/s10668-023-03130-2

Boetcher, S.K.S., Perskin, J.B., Maidenberg, Y., Traum, M.J. and von Hippel, T. 2023. Direct atmospheric cryogenic carbon capture in cold climates. Carbon Capture Science and Technology, 8, 100127. https://doi.org/10.1016/j.ccst.2023.100127

Bora, N., Nath, A.J. and Das, A.K. 2013. Aboveground biomass and carbon stocks of tree species in tropical forests of Cachar District, Assam, Northeast India. International Journal of Ecology and Environmental Science, 39(2), 97-106. https://nieindia.org/Journal/index.php/ijees/article/view/133/80

Brown, S. and Lugo, A.E. 1992. Aboveground biomass estimates for tropical moist forests of the Brazilian Amazon. Interciencia Caracas, 17(1), 8-18.

Cairns, M.A., Brown, S., Helmer, E. H. and Baumgardner, G.A. 1997. Root biomass allocation in the world's upland forests. Oecologia, 111, 1-11. https://doi.org/10.1007/s004420050201

Campbell, A., Clark, S., Coad, L., Miles, L., Bolt, K. and Roe, D. 2008. Protecting the future: Carbon, forests, protected areas and local livelihoods. Biodiversity, 9(3–4), 117-121. https://doi.org/10.1080/14888386.2008.9712916

Cazalis, V., Princé, K., Mihoub, J.-B., Kelly, J., Butchart, S.H.M. and Rodrigues, A.S.L. 2020. Effectiveness of protected areas in conserving tropical forest birds. Nature Communications, 11(1), 4461. https://doi.org/10.1038/

s41467-020-18230-0.

Chambers, J. Q., dos Santos, J., Ribeiro, R. J. and Higuchi, N. 2001. Tree damage, allometric relationships, and above-ground net primary production in central Amazon forest. Forest Ecology and Management, 152(1-3), 73-84. https://doi.org/10.1016/S0378-1127(00)00591-0

Champion, H.G. and Seth, S.K. 1968. A revised survey of the forest types of India. Manager of publications, New Delhi. 404 pages.

Chaudhury, G. and Upadhaya, K. 2016. Biomass and carbon stock in subtropical broad-leaved forest ecosystem of Meghalaya, northeast India. International Journal of Ecology and Environmental Sciences, 42(2), 125-133. https://nieindia.org/Journal/index.php/ijees/article/view/797/261

Chhabra, A., Palria, S. and Dadhwal, V. K. 2002. Growing stock-based forest biomass estimate for India. Biomass and Bioenergy, 22(3), 187-194. https://doi.org/10.1016/S0961-9534(01)00068-X.

Clark, D.A. and Clark, D.B. 1994. Climate-Induced Annual Variation in Canopy Tree Growth in a Costa Rican Tropical Rain Forest. Journal of Ecology, 82(4), 865-875. https://doi.org/10.2307/2261450.

Dar, J.A. and Sundarapandian, S. 2015. Variation of biomass and carbon pools with forest type in temperate forests of Kashmir Himalaya, India. Environmental Monitoring and Assessment, 187, 1-17. https://doi.org/10.1007/s10661-015-4299-7

Dar, J.A., Kothandaraman, S., Khare, P.K. and Khan, M.L. 2022. Sacred groves of Central India: Diversity status, carbon storage, and conservation strategies. Biotropica, 54(6), 1400-1411. https://doi.org/10.1111/btp.13157

Deb, D., Jamatia, M., Debbarma, J., Ahirwal, J., Deb, S. and Sahoo, U.K. 2021. Evaluating the Role of Community-Managed Forest in Carbon Sequestration and Climate Change Mitigation of Tripura, India. Water, Air and Soil Pollution, 232(5), 1-17. https://doi.org/10.1007/s11270-021-05133-z

Deguignet, M., Arnell, A., Juffe-Bignoli, D., Shi, Y., Bingham, H., MacSharry, B. and Kingston, N. 2017. Measuring the extent of overlaps in protected area designations. PloS One, 12(11), e0188681. https://doi.org/10.1371/journal.pone.0188681.

Echeverría, C., Newton, A.C., Lara, A., Benayas, J.M.R. and Coomes, D.A. 2007. Impacts of forest fragmentation on species composition and forest structure in the temperate landscape of southern Chile. Global Ecology and Biogeography, 16(4), 426-439. https://doi.org/10.1111/j.1466-8238.2007.00311.x

Gogoi, R.R., Adhikari, D., Upadhaya, K. and Barik, S.K. 2020. Tree diversity and carbon stock in a subtropical broadleaved forest are greater than a subtropical pine forest occurring in similar elevation of Meghalaya, north-eastern India. Tropical Ecology, 61(1), 142-149. https://doi.org/10.1007/s42965-020-00061-1

Haridasan, K. and Rao, R.R. 1985-1987. Forest Flora of Meghalaya, 2 vols. Bishen Singh Mahendra Pal Singh, Dehra Dun, India. 937 pages.

Htun N.Z., Mizoue, N. and Yoshida, S. 2011. Tree species composition and diversity at different levels of disturbance in Popa Mountain Park, Myanmar. Biotropica, 43, 597-603. https://doi.org/10.1111/j.1744-7429.2011.00753.x

Joshi, V.C., Bisht, D., Sundriyal, R.C. and Pant, H. 2021a. Species richness, diversity, structure, and distribution patterns across dominating forest communities of low and mid-hills in the Central Himalaya. Geology, Ecology, and Landscapes, 7(4), 329-339. https://doi.org/10.1080/24749508.

Joshi, V.C., Negi, V.S., Bisht, D., Sundriyal, R.C. and Arya, D. 2021b. Tree biomass and carbon stock assessment of subtropical and temperate forests in the Central Himalaya, India. Trees, Forests and People, 6, 100147. https://doi.org/10.1016/j.tfp.2021.100147

Kanjilal, U.N., Kanjilal, P.C., Das, A., De, R.N. and Bor, N.L. 1934-1940. Flora of Assam, 5 vols. Government Press, Shillong.

Karki, H., Bargali, K. and Bargali, S.S. 2022. Dynamics of fine root and soil nitrogen in *Mangifera indica* based agroforestry systems in Central Himalaya, India. Land Degradation and Development, 33 (17), 3523-3538. https://doi.org/10.1002/ldr.4406

Kindermann, G.E., McCallum, I., Fritz, S. and Obersteiner, M. 2008. A global forest growing stock, biomass and carbon map based on FAO statistics. Silva Fennica, 42(3), 387-396. https://pure.iiasa.ac.at/id/eprint/8616/1/article244.pdf

Kumar, A., Marcot, B. G. and Saxena, A. 2006. Tree species diversity and distribution patterns in tropical forests of Garo Hills. Current Science, 91, 1370-1381. https://www.jstor.org/stable/24094061

Magurran, A. E. 1988. Ecological Diversity and its Measurement. Princeton University Press, Princeton, New Jersey. 179 pages.

Martin, A.R. and Thomas, S.C. 2011. A Reassessment of Carbon Content in Tropical Trees. PLoS One, 6(8), e23533. https://doi.org/10.1371/journal.pone.0023533

Mir, A. H., Chaudhury, G., Barbhuyan, H.S.A., Sarma, K. and Upadhaya, K. 2021. Impact of disturbance on community structure, biomass and carbon stock in montane evergreen forests of Meghalaya, northeast India. Carbon Management, 12(2), 215-233. https://doi.org/10.1080/17583004.2021.1899752.

Mir, A.H. and Upadhaya, K. 2017. Effect of traditional management practices on woody species composition and structure in montane subtropical forests of Meghalaya, Northeast India. Journal of Mountain Science, 14(8), 1500-1512. https://doi.org/10.1007/s11629-016-4145-6.

Mishra, B.P. and Jeeva, S. 2012. Plant diversity and community attributes of woody plants in two climax subtropical humid forests of Meghalaya, Northeast India. Applied Ecology and Environmental Research, 10(4), 417-436. https://www.aloki.hu/indvol10_4.htm

Misra, R. 1968. Ecology workbook. Oxford and IBH Publishing Company, New Delhi. 244 pages.

Mueller-Dombois, D. and Ellenberg, H. 1974. Aims and methods of vegetation analysis. John Wiley and Sons, New York. 547 pages.

Nabuurs, G.J., Masera, O., Andrasko, K., Benitez-Ponce, P., Boer, R., Dutschke, M., Elsiddig, E., Ford-Robertson, J., Frumhoff, P. and Karjalainen, T. 2007. Forestry. Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA. (Eds.). Cambridge University Press, Cambridge, UK.

Nabuurs, G.J., Masera, O., Andrasko, K., Benitez-Ponce, P., Boer, R., Dutschke, M., Elsiddig, E., Ford-Robertson, J., Frumhoff, P. and Karjalainen, T. 2007. Forestry. Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Metz B., Davidson O.R., Bosch P.R., Dave R. and Meyer L.A. (Eds.). Cambridge University Press, Cambridge, UK.

Nandy, S. and Kumar Das, A. 2013. Comparing tree diversity and population structure between a traditional agroforestry system and natural forests of Barak valley, Northeast India. International Journal of Biodiversity Science, Ecosystem Services and Management, 9(2), 104-113. https://doi.org/10.1080/21513732.2012.748691

Naveenkumar, J., Arunkumar, K.S. and Sundarapandian, S.M. 2017. Biomass and carbon stocks of a tropical dry forest of the Javadi Hills, Eastern Ghats, India. Carbon Management, 8(5-6), 351-361. https://doi.org/10.1080/17583004.2017.1362946

Pan, Y., Birdsey, R.A., Fang, J., Houghton, R., Kauppi, P.E., Kurz, W.A., Phillips, O.L., Shvidenko, A., Lewis, S.L., Canadell, J.G., Ciais, P., Jackson, R.B., Pacala, S.W., McGuire, A.D., Piao, S., Rautiainen, A., Sitch, S. and Hayes, D. 2011. A large and persistent carbon sink in the world's forests. Science, 333(6045), 988-993. https://doi.org/10.1126/science.1201609

Pandey, R., Bargali, S.S., Bargali, K. and Pandey, V.C. 2023. Temporal variability in fine root dynamics in relation to tree girth size in sub-tropical *Shorea robusta* forests. Land Degradation and Development, 34(5), 1522-1537. https://doi.org/10.1002/ldr.4550

Parkash, V. 2021. Floristic and ethnic perspective on wild forest plant species of Nongkhyllem Reserve Forest, Nongpoh, Meghalaya, India. Asian Journal of Ethnobiology, 4(2), 93-105. https://doi.org/10.13057/asianjethnobiol/y040204

Paudel, S. and Sah, J. P. 2015. Effects of different management practices on stand composition and species diversity in subtropical forests in Nepal: Implications of community participation in biodiversity conservation. Journal of Sustainable Forestry, 34(8), 738-760. https://doi.org/10.1080/10549811.2015.1036298.

Prabhu, S.D., Barik, S.K., Pandey, H.N. and Tripathi, R.S. 2010. Impact of landuse changes on plant species diversity of Nokrek Biosphere Reserve, Meghalaya, India. Journal of the Bombay Natural History Society, 107(2), 146-158.

Pragasan, L.A. 2015. Total carbon stock of tree vegetation and its relationship with altitudinal gradient from the Shervarayan hills located in India. Journal of Earth Science and Climatic Change, 6(4), 1000273. https://doi.org/10.4172/2157-7617.1000273.

Prentice, I. C., Farquhar, G. D., Fasham, M. J. R., Goulden, M. L., Heimann, M., Jaramillo, V. J., Kheshgi, H. S., Quéré, C. Le, Scholes, R. J., Wallace, D.W.R., 2001. The carbon cycle and atmospheric carbon dioxide. 185-237. https://hal.science/hal-03333974

Raha, D., Dar, J.A., Pandey, P.K., Lone, P.A., Verma, S., Khare, P.K. and Khan, M.L. 2020. Variation in tree biomass and carbon stocks in three tropical dry deciduous forest types of Madhya Pradesh, India. Carbon Management, 11(2), 109-120. https://doi.org/10.1080/17583004.2020.1712181.

Schnitzer, S.A., DeWalt, S.J. and Chave, J. 2006. Censusing and Measuring Lianas: A Quantitative Comparison of the Common Methods1. Biotropica, 38(5), 581-591. https://doi.org/10.1111/j.1744-7429.2006.00187.x.

Shivanna, K.R. 2022. Climate change and its impact on biodiversity and human welfare. Proceedings of the Indian National Science Academy, 88(2), 160-171. https://doi.org/10.1007/s43538-022-00073-6

Singh, B. and Borthakur, S.K. 2015. Phenology and Geographic Extension of Lycophyta and Fern flora in Nokrek Biosphere Reserve of Eastern Himalaya. Proceedings of the National Academy of Sciences India Section B - Biological Sciences, 85(1), 291-301. https://doi.org/10.1007/s40011-014-0342-7

Singh, J. S. 2017. Environment: A futuristic view. Current Science, 113(2), 210-217. https://www.jstor.org/stable/26293852

Sundarapandian, S.M. and Swamy, P.S. 2000. Forest ecosystem structure and composition along an altitudinal gradient in the Western Ghats, South India. Journal of Tropical Forest Science, 12(1), 104-123. https://www.jstor.org/stable/23616407

Thapa, N., Upadhaya, K., Baishya, R. and Barik, S.K. 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(1), 61-73. https://nieindia.org/Journal/index.php/ijees/article/view/136/86

Thokchom, A. and Yadava, P.S. 2013. Biomass and carbon stock assessment in the sub-tropical Forests of Manipur, northeast India. International Journal of Ecology and Environmental Sciences, 39(2), 107-113. https://nieindia.org/Journal/index.php/ijees/article/viewFile/134/81

Thomas, S.C. and Martin, A.R. 2012. Carbon content of tree tissues: a synthesis. Forests, 3(2), 332-352. https://doi.org/10.3390/f3020332

Tian, J., Feng, C., Fu, G., Fan, L. and Wang, W. 2023. Contribution of different types of terrestrial protected areas to carbon sequestration services in China: 1980–2020. Frontiers in Ecology and Evolution, 11, 1074410. https://doi.org/10.3389/fevo.2023.1074410

Upadhaya, K. 2015. Structure and floristic composition of subtropical broad-leaved humid forest of Cherapunjee in Meghalaya, Northeast India. Journal of Biodiversity Management and Forestry, 4 (4), 1000149. https://doi:10.4172/2327-4417.1000149.

Upadhaya, K., Pandey, H.N., Law, P.S. and Tripathi, R.S. 2003. Tree diversity in sacred groves of the Jaintia hills in

Meghalaya, northeast India. Biodiversity and Conservation, 12(3), 583-597. https://doi.org/10.1023/A:1022401012824

Upadhaya, K., Pandey, H.N., Law, P.S. and Tripathi, R.S. 2004. Diversity and population characteristics of woody species in subtropical humid forests exposed to cultural disturbances in Meghalaya, Northeast, India. Tropical Ecology, 45(2), 303-314.

Upadhaya, K., Roy, D.K., Chaudhary, K.L., Mir, A.H. and Singh, P.P. 2021. Flowering Plants of Meghalaya: A Pictorial Guide. Meghalaya Biodiversity Board, Shillong. 304 pages.

Upadhaya, K., Thapa, N. and Barik, S.K. 2015. Tree diversity and biomass of tropical forests under two management regimes in Garo hills of north-eastern India. Tropical Ecology, 56(2), 257-268.

Vanninen, P., Ylitalo, H., Sievänen, R. and Mäkelä, A. 1996. Effects of age and site quality on the distribution of biomass in Scots pine (*Pinus sylvestris* L.). Trees, 10(4), 231-238. https://doi.org/10.1007/BF02185674

Wang, F., Yuan, X., Zhou, L. and Zhang, M. 2022. Integrating ecosystem services and landscape connectivity to construct and optimize ecological security patterns: a case study in the central urban area Chongqing municipality, China. Environmental Science and Pollution Research, 29 (28), 43138-43154. https://doi.org/10.1007/s11356-021-16281-4

Xu, W., Xiao, Y., Zhang, J., Yang, W., Zhang, L., Hull, V., Wang, Z., Zheng, H., Liu, J., Polasky, S., Jiang, L., Xiao, Y., Shi, X., Rao, E., Lu, F., Wang, X., Daily, G.C. and Ouyang, Z. 2017. Strengthening protected areas for biodiversity and ecosystem services in China. Proceedings of the National Academy of Sciences of the United States of America, 114(7), 1601-1606. https://doi.org/10.1073/pnas.1620503114

Zhang, Y., Duan, B., Xian, J.R., Korpelainen, H. and Li, C. 2011. Links between plant diversity, carbon stocks and environmental factors along a successional gradient in a subalpine coniferous forest in Southwest China. Forest Ecology and Management, 262(3), 361-369. https://doi.org/10.1016/j.foreco.2011.03.042.

Received: 13th February 2024
Accepted: 5th May 2024