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Tree Population Structure and Carbon Stock of Tropical Wet Evergreen Forest in Dehing Patkai National Park, Assam, Northeast India

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ABSTRACT

The present study was conducted within the tropical wet evergreen forests of Dehing Patkai National Park, Assam. The primary objective was to analyse the tree population structure and carbon stock of tree species within the forest. The findings of the study unveiled a total of 64 tree species belonging to 51 genera and 34 families. Among these species, the highest number of individuals (567 individuals ha^{-1}) were found in the lower girth class of 30-60 cm. Total carbon density (TCD) and total carbon stock (TCS) was estimated to be 217.56 t ha^{-1} and 458.16 t ha^{-1}, respectively. *Dipterocarpus retusus*, *Mesua ferrea* and *Castanopsis indica* were identified as the species with the highest number of individuals ha^{-1}. One-way analysis of variance (ANOVA) was conducted to assess the differences in girth, height, total biomass density (TBD) and TCD among the tree species, which revealed a significant difference ($p<0.05$). The results of the regression analysis demonstrated a significant positive correlation ($p<0.01$) of TCD with density ($r^2 = 0.85$) and DBH ($r^2 = 0.11$). However no relationship observed between TCD and height. These findings suggest that the tree species, encompassing individuals across different girth classes, store a substantial amount of carbon within their biomass indicating a huge potential to grow in future.

Key words: Biomass, density, forest, girth, total carbon stock, tree species

INTRODUCTION

Forest plays a significant role in providing many ecological services to man and environment. While delivering provisioning services like edible fruits, vegetables, timber, fuel and fodder, which human receive direct benefits, it also helps to regulate water regimes, protection to the soil and offers huge potential to sequestered CO_2 from atmosphere to plant biomass. Nevertheless, the ecological changes in forest composition are frequent, and its transformation can be seen through the population structure. Tree population dynamics are influenced by forest succession and long-term climate variabilities (Balmford and Bond 2005, Mathys et al. 2021). Similarly, the structure and function of the forest ecosystem are determined primarily by plant component (Richards 1996). Since forest ecosystems cover approximately 30% of the terrestrial land, they play an essential part in the atmospheric carbon cycle; thus, the effects of their loss could cascade through the Earth's system and lead to global warming and climate change (Pragasan 2016). The soils in the forest also sequester and store much more organic carbon than other terrestrial ecosystems (Thokchom and Yadava 2017, Guan et al. 2019, Zhang et al. 2022).

Tropical forests encompass less than one-fifth of the earth's terrestrial surface (Dinerstein et al. 2017) and act as storehouses for rich biological diversity (Chandrasekharan 1960) of the planet. Pan et al. (2011) reported the tropical forests store about 68% of the total forest carbon. While tropical wet evergreen forests harbour about seven percent of the total area of it. In 2021 India's forest and tree cover was 80.9 million hectares, accounting for 24.62% of the country's total area (FSI 2021). The Himalayan dense forests account for about 33% of soil organic reserves in India (Bhattacharyya et al. 2008). The tropical forests being serve as rich reservoirs for terrestrial ecosystems with rich species diversity are often exploited. They are heavily impacted by human interventions like overexploitation of resources, overgrazing, urbanisation, fuel and fodder extraction, forest fires, road-building and other development activities. Overexploitation and loss of tropical forests have led to detrimental global environmental and economic problems (Hare et al. 1997). The loss of forests due to increasing demand and long-term climatic variations are responsible for changes in the global carbon pool. As tropical forests are considered important regulators of the global carbon cycle therefore, there is an urgent need to study and quantify the amount of carbon storage in these forest ecosystems (David et al. 2017). The carbon fixation inside the soil is also twice as adequate as the carbon stored in the atmosphere.

Studies have been carried out in the tropical wet evergreen forests in and around northeast India and Western Ghats, focussing on species diversity and tree population structure (Mishra et al. 2005, Nath et al. 2005, Ramachandran and Bharath 2020, Tynsong et al. 2022), while studies on the population dynamics and carbon sequestration in tropical wet evergreen forests in the northeast India are lacking. The effective management of these forests requires a comprehensive assessment of carbon stocks in relation to tree species richness that would help in the quantification of large stocks of carbon stored by the forest ecosystem. Hence, it is crucial to quantify and comprehend population distribution and carbon storage in order to develop efficient strategies for addressing climate change.

MATERIALS AND METHODS

Study area

The present study was undertaken in the Soraipung range of Dehing Patkai National Park (27.2983 E and 95.5165 N), located in the Dibrugarh and Tinsukia districts of Assam (Fig. 1). The forest is known as the last remaining stretches of Assam Valley tropical wet evergreen forest with an area of 231.65 km^2, and the climate of the region is characterized as primarily tropical with an annual rainfall receiving more than 4000 mm (Gogoi et al. 2023). The forest was upgraded to National Park from Wildlife Sanctuary on 09th June 2021 by the forest department of Assam. The Soraipung range lies between latitudes 27°172533 N and longitudes 95°302593 E and forms the main access point of the National Park. The park harbours rich biodiversity and is often called the ‘Amazon of the East’. The forest is mainly dominated by the state tree of Assam, i.e., *Dipterocarpus retusus* Blume. It is home to several significant wild animals like elephants, hoolock gibbons, clouded leopard and other mammals, including reptiles and butterflies. The region also forms a significant part of Indo Myanmar biodiversity hotspots.

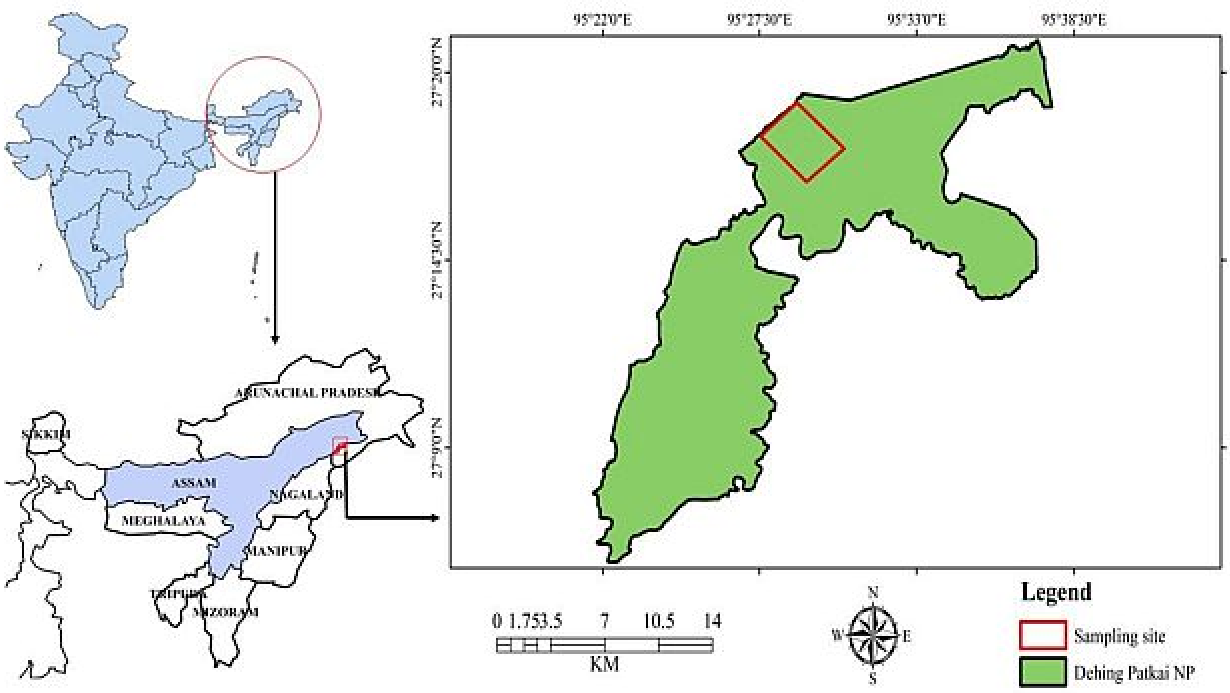

Figure 1. Study site at Soraipung range of Dehing Patkai National Park in Assam

Data analysis

To determine the population structure and carbon stock of the forest, hundred (100) quadrats of 10 x 10 m size were laid randomly following random sampling method in Soraipung range of Dehing Patkai National Park. All individuals of tree species recorded within the sampling units were recorded in term of their number, height and basal area. Individuals having ≥30 cm girth at breast height (GBH) of 1.37 m were considered adult (Khan et al. 1987). For the study of population structure of adult individuals, the individuals were grouped into six different girth classes, i.e. 30-60, 60-90, 90-120, 120-150, 150-180 and 180-210 cm. A clinometer was used to measure the height of individual trees. The specific density of species was obtained from the relevant database (Brown 1997, ICRAF ecological database). A non-destructive method was carried out to assess carbon stock in tree species. Aboveground biomass (AGB), belowground biomass (BGB), total biomass density (TBD), and total carbon density (TCD) were determined.

For AGB, the model developed by Nath et al. (2019) for the forests of Northeast India was followed, while the regression equation given by Cairns et al. (1997) was used to estimate BGB.

$$AGB = 0.32(D^2H\delta)^{0.75}\times1.34$$

Where, D = Diameter, H = Height, δ = Specific density

$$BGB= \exp\{-1.059+0.884\times \text{In}AGB+0.284\}$$

For the estimation of TBD, AGB and BGB were summed up.

$$TBD = AGB+BGB$$

The total carbon density (TCD) was calculated using the formula of IPCC (2000).

$$TCD = B_0 \times (0.5)\ C\ Mg\ ha^{-1}$$

Where, C is Carbon and B_0 is Biomass.

Soil organic carbon (SOC) was calculated from the formula given by Pearson et al. (2007).

$$SOC = p \times d \times \%C$$

Where, d = depth of the soil samples (cm); %C = carbon concentration (%); p = soil bulk density (g/cm^3).

Total carbon stock (TCS) was estimated by summing AGB, BGB, and SOC (Schmitt-Harsh et al. 2012, Daba et al. 2022, Dantas et al. 2020)

$$TCS= AGB+BGB+SOC$$

The data were analysed using SPSS version 25 statistical software. One-way analysis of variance was used to compare the mean values of girth, height, TBD and TCD with different tree species. Correlation and regression analysis was performed to study the linear relationship between the independent and dependent variables. The density, DBH, and height are independent variables, while TCD is dependent variable.

RESULTS AND DISCUSSION

Population structure

A total of 64 tree species under 51 genera and 34 families were recorded from the study area. *Dipterocarpus retusus* Blume was the dominant species, comprising 253 individuals ha^{-1}, while *Mesua ferrea* L. was found as codominant species with 182 individuals ha^{-1}. The lower girth class (30-60 cm) exhibited the maximum number of individuals, with a total of 567 individuals ha^{-1} compared to the higher girth class ≥60 cm (Fig. 2). The girth class of 60-90 cm and 90-120 cm showed 431 and 215 individuals ha^{-1}, respectively. In the girth classes of 120-150, 150-180, and 180-210 cm, there were 44, 58 and 5 individuals ha^{-1}, respectively. It was observed that with an increase in girth class, there is decrease in the number of individuals. The variation in girth sizes among individuals can be attributed to different age and growth factors. The age structure of a population is influenced by fertility and mortality of species which are species specific (Gonçalves et al. 2017). Further, the growth of a species is contingent upon its ability to adapt to specific environmental conditions. Prakasha et al. (2008), also reported similar finding that basal area variations depend on species composition, growth patterns, tree age and anthropogenic disturbances. The diversification of forest species plays a vital role in ecosystem functioning and the provision of services (Mathys et al. 2021). The population structure of tree species in the forest, based on girth classes, exhibits a reverse J-shaped curve. Similar pattern has been observed in various forest ecosystems (Worku et al. 2012, Sarkar and Devi

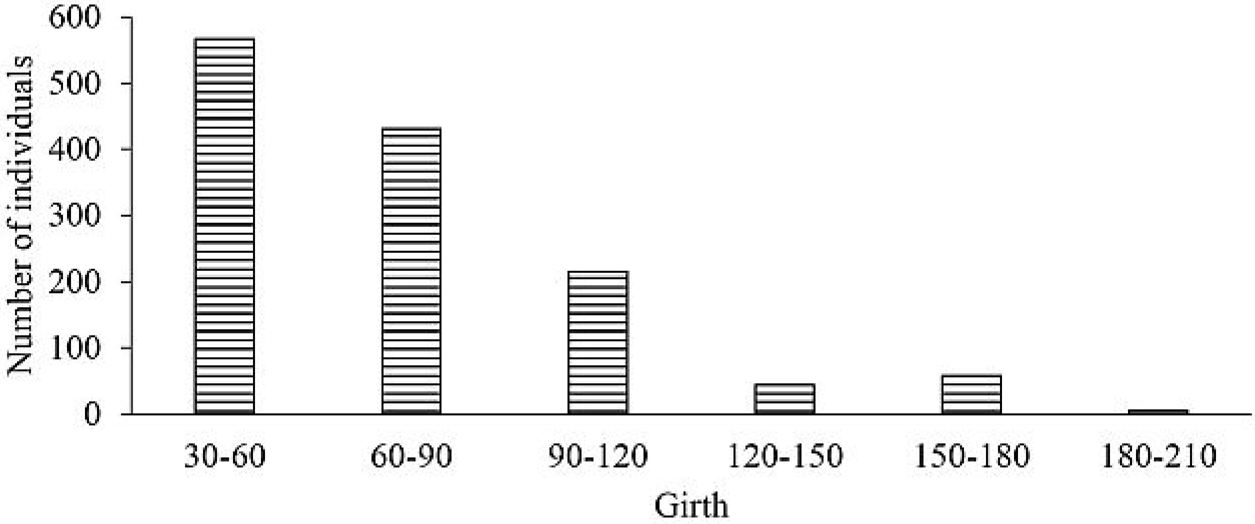

Figure 2. Population structure of trees enumerated in Dehing Patkai National Park, Assam

2014, Giroldo and Scariot 2015, Nworo et al. 2020). From the observed curve, it signifies the forest has good regeneration potential exhibiting high number of young individuals. The girth classes of 30-60 and 60-90 cm account for 42.95% and 32.65% of species richness, respectively.

The species *Dipterocarpus retusus*, *Mesua ferrea* and *Castanopsis indica* have the highest number of individuals, suggesting a higher survival rate as compared to other species. The survival rate of *Ailanthus integrifolia*, *Citrus medica*, *Dalbergia assamica*, *Syzygium jambos*, *Cinnamomum tamala*, *Magnolia baillonii*, *Citrus medica*, *Caryota urens*, *Stereospermum chelonoides*, and *Symplocos pealii* recorded only one adult individuals in different girth classes. The ability of a species to regenerate in forests is mainly determined by its adaptability to various environmental conditions. The population of species in the low category suggest a reduced progression of reproduction from seed germination. Consequently, tree species with only a single individual face a high risk of disappearing from their natural habitat. Additionally, frequent elephant movement may be another possible factor affecting the growth of seedlings and saplings. Similar results were reported in a study where elephants caused damage to seedlings (Makemba et al. 2022). Conversely, the higher number of individuals in the lower girth class depicts that the forest has a good potential for future sustainability. Forest dynamics are observed to be influenced by microclimatic conditions, edaphic factors (Saikia and Khan 2016), and biotic and abiotic factors (Baidya et al. 2022). A study by Mathys et al. (2021) established that forest structural composition and climate strongly influence species population structure.

Carbon stock

The amount of carbon stored and sequestered by plants varies depending on the growing stage of the forest and forest type. The findings of the present study demonstrate that tree species present in the studied forest possess high ability to store carbon in their biomass. The total aboveground biomass (AGB) is 353.65 t ha^{-1} ranging from 0.01 to 125.02 t ha^{-1} while the total Belowground biomass (BGB) is 82.43 t ha^{-1} that range from 0.005 to 27.39 t ha^{-1}. The AGB is found to be maximum as compared to a study conducted in different forest types of Western Ghats, India which range from 32.23 to 236.80 t ha^{-1} (Joseph et al. 2010). The total biomass density (TBD) is found to be 436.07 t ha^{-1} and total carbon density (TCD) is 217.56 t ha^{-1}. The result of carbon stock is found within the range of Central Himalayan cypress forest (Sumita et al. 2015), tropical semi-evergreen forest (Giri et al. 2019), tropical dry deciduous forest (Raha et al. 2020), tropical hill forest (Pragasan 2022), temperate forests in the Central Himalaya, India (Joshi et al. 2021), Kashmir Himalayan forests (Dar & Parthasarathy 2022), West-central Indian forest (Salunkhe et al. 2023), subtropical and other countries tropical Forest of Congo (Ekoungoulou et

Table 1. Enumeration of height, density, AGB, BGB, TBD and TCD at Soraipung range, Dehing Patkai National Park, Assam

Species	**Density (ha^{-1})**	**AGB ($t\ ha^{-1}$)**	**BGB ($t\ ha^{-1}$)**	**TBD ($t\ ha^{-1}$)**	**TCD ($t\ ha^{-1}$)**
Actinodaphne obovata (Nees) Blume	3	0.75	0.18	0.93	0.46
Ailanthus integrifolia subsp. Calycina	1	0.08	0.02	0.10	0.05
Alangium chinense (Lour.) Harms	125	8.3	2.32	10.6	5.30
Artocarpus chama Buch.-Ham.	2	0.31	0.08	0.39	0.20
Baccaurea ramiflora Lour.	19	3.99	0.98	4.97	2.49
Balakata baccata (Roxb.) Esser	9	1.96	0.48	2.44	1.22
Beilschmiedia assamica Meisn.	3	0.52	0.13	0.65	0.32
Camellia caudata Wall.	5	0.44	0.12	0.57	0.28
Canarium strictum Roxb.	14	6.13	1.39	7.52	3.76
Caryota urens L.	1	0.06	0.02	0.07	0.04
Castanopsis indica (Roxb. ex Lindl.) A.DC.	141	40.62	9.53	50.15	25.07
Catunaregam spinosa (Thunb.) Tirveng.	6	0.30	0.087	0.38	0.19
Cinnamomum tamala (Buch.-Ham.) T. Nees & C.H.Eberm.	1	0.10	0.03	0.13	0.06
Citrus medica L.	1	0.04	0.01	0.05	0.03
Croton joufra Roxb.	8	0.54	0.15	0.69	0.35
Cryptocarya amygdalina Nees	5	0.90	0.22	1.12	0.56
Dalbergia assamica Benth.	1	0.45	0.10	0.55	0.27
Dillenia indica L.	47	11.26	2.71	13.97	6.98
Diospyros melanoxylon Roxb.	14	2.26	0.57	2.83	1.42
Dipterocarpus retusus Blume	253	125.02	27.39	152.42	76.21
Donella lanceolata (Blume) Aubrév.	4	0.32	0.09	0.41	0.21
Duabanga grandiflora (Roxb. ex DC.) Walp.	5	0.58	0.15	0.74	0.37
Dysoxylum gotadhora (Buch.-Ham.) Mabb.	26	6.72	1.61	8.33	4.17
Elaeocarpus angustifolius Blume	3	0.79	0.19	0.97	0.49
Endospermum chinense Benth.	13	3.48	0.83	4.31	2.15
Ficus racemosa L.	2	0.04	0.01	0.05	0.03
Garcinia pedunculata Roxb. ex Buch.-Ham.	51	8.70	2.23	10.93	5.46
Garcinia xanthochymus Hook.f. ex T. Anderson	2	0.13	0.038	0.17	0.09
Glochidion ellipticum Wight	3	0.31	0.08	0.39	0.20
Kayea assamica Prain	2	0.34	0.09	0.42	0.21
Litsea salicifolia (Roxb. ex Nees) Hook.f.	10	1.41	0.365	1.78	0.89
Macaranga denticulata (Blume) Müll.Arg.	12	2.61	0.64	3.25	1.62
Magnolia baillonii Pierre	1	0.04	0.01	0.05	0.03
Magnolia hodgsonii (Hook.f. & Thomson) H.Keng	6	1.17	0.29	1.46	0.73
Magnolia insignis Wall.	2	0.13	0.037	0.17	0.08
Magnolia oblonga (Wall. ex Hook.f. & Thomson) Figlar	16	2.01	0.53	2.54	1.27
Mallotus paniculatus var. paniculatus	4	0.76	0.19	0.95	0.47
Meliosma simplicifolia (Roxb.) Walp.	4	0.53	0.14	0.66	0.33
Mesua ferrea L.	182	59.22	13.68	72.90	36.45
Monoon simiarum (Buch.-Ham. ex Hook.f. & Thomson) B.Xue & R.M.K.Saunders	15	0.01	0.005	0.02	0.01

Species	**Density (ha^{-1})**	**AGB ($t\ ha^{-1}$)**	**BGB ($t\ ha^{-1}$)**	**TBD ($t\ ha^{-1}$)**	**TCD ($t\ ha^{-1}$)**
Nauclea parvifolia (Roxb.) Korth.	2	2.82	0.70	3.52	1.76
Phoebe bootanica (Meisn.) M.Gangop.	6	0.57	0.15	0.72	0.36
Premna bengalensis C.B.Clarke	13	3.94	0.92	4.86	2.43
Pterospermum lanceifolium Roxb. ex DC.	12	1.46	0.38	1.84	0.92
Salix tetrasperma Roxb.	2	0.22	0.06	0.27	0.14
Shorea assamica Dyer	11	3.3	0.8	4.1	2.05
Sterculia villosa Roxb. ex Sm.	2	0.44	0.11	0.55	0.28
Stereospermum chelonoides (L.f.) DC.	1	0.16	0.041	0.20	0.10
Strobocalyx arborea (Buch.-Ham.) Sch.Bip.	6	2.13	0.50	2.63	1.32
Symplocos acuminata (Blume) Miq.	24	3.19	0.83	4.02	2.01
Symplocos pealii King ex Das	1	0.20	0.05	0.25	0.12
Syzygium cumini (L.) Skeels	20	7.82	1.78	9.59	4.80
Syzygium jambos (L.) Alston	1	0.08	0.02	0.10	0.05
Terminalia bellirica (Gaertn.) Roxb.	41	4.57	1.21	5.78	2.89
Terminalia chebula Retz.	16	4.51	0.96	5.46	2.73
Terminalia myriocarpa Van Heurck & Müll.Arg.	10	1.52	0.39	1.91	0.96
Tetrapilus dioicus (Roxb.) L.A.S.Johnson	21	4.57	1.21	5.78	2.89
Toona ciliata M. Roem.	13	2.02	0.51	2.53	1.27
Trema orientale (L.) Blume	2	0.13	0.04	0.17	0.09
UK 1	1	0.06	0.02	0.08	0.04
UK2	17	2.32	0.60	2.92	1.46
UK 3	1	0.09	0.02	0.11	0.06
UK4	1	0.78	0.18	0.96	0.00
Vatica lanceifolia (Roxb.) Blume	62	13.4	3.27	16.7	8.34

Note: UK – Unidentified species

al. 2015), Sal forest of Nepal (Pandey and Bhusal 2016). Among the total biomass density, AGB and BGB contribute 81.13% and 18.87%, respectively, with the majority of the biomass stored in above-ground biomass. AGB plays a crucial role in the global carbon cycle (Poorter et al. 2015; Dumitracu et al. 2020). The dominant species *Dipterocarpus retusus* Blume exhibits the highest carbon stock with a TCD of 76.21 t ha^{-1} (Table 1). Similarly, a study by Ullah and Al-Amin (2012) in the forest of Bangladesh recorded the dominant *Dipterocarpus* spp. with high carbon stock capacity. In most tropical forests, *Dipterocarps* tree species are considered as the key species because of their economic and ecological value (Calago and Diola 2022).

The growth of the individuals is an essential factor for the estimation of tree biomass in any forest (Návar 2010). Increased biomass with stand age results in the storage of a significant carbon sink (Alexandrov 2007). Understanding the relationship between forest stand age and biomass is essential for managing the forest component of the global carbon cycle (Alexandrov 2007). The density and basal area have a significant impact on the total tree biomass of forest ecosystems (Gogoi et al. 2020). The results of One-way analysis of variance indicate a significant difference in girth, height, TBD and TCD among the investigated tree species ($p<0.05$). TCD showed a significant positive correlation with DBH and density while no relationship was observed with height (Fig. 3). While height and DBH revealed a significant positive association. The regression analysis also revealed that TCD exhibited a substantial positive correlation with DBH ($r^2 = 0.11$ $p<0.01$) and density ($r^2 = 0.85$, $p<0.01$) of trees (Table 2). The results exhibit that density and DBH significantly greatly affects TCD. The abundance of tree individuals significantly influences the Total Carbon Density

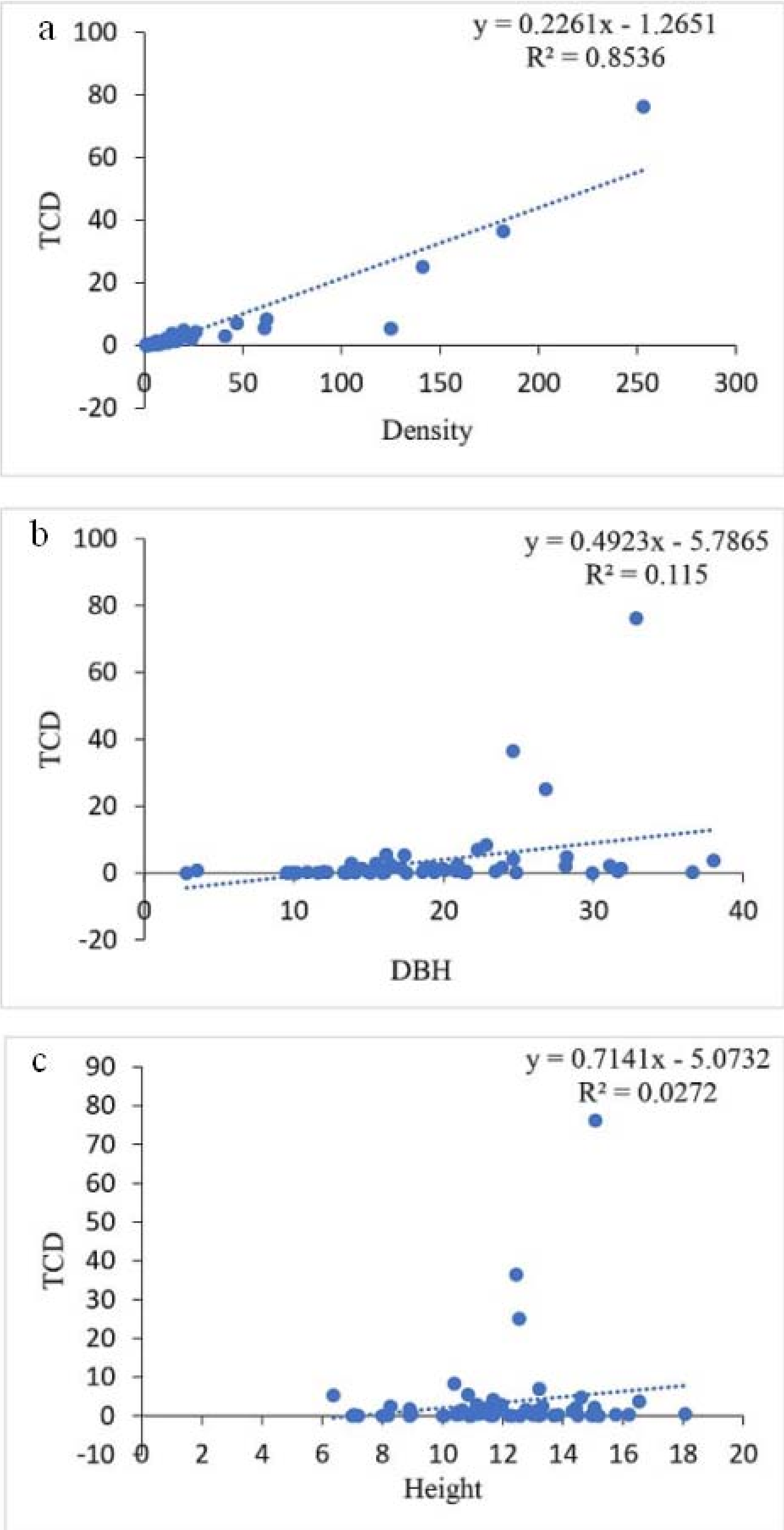

Figure 3. Relationship of TCD with density (a), DBH (b) and height (c)

Table 2. Correlation analysis between number of individuals, height, girth, AGB, BGB and TCD

Variables	Density	Height	DBH	TCD
Density (ha^{-1})	1			
Height (m)	0.048	1		
DBH	0.301*	0.321**	1	
TCD	0.924**	0.165	0.339**	1

*Correlation is significant at the 0.05 level (2-tailed) and ** Correlation is significant at the 0.01 level (2-tailed).

(TCD). Moreover, TCD exhibiting a positive response with increase of DBH of species reveals the significance of analysing population structure in the forest ecosystems. In the present study greater DBH correspond to increased TCD whereas low DBH of species would result in the low TCD. These findings indicate forest with a higher number of individuals and larger girth play a key role for storing a substantial amount of carbon. The SOC in the forest is found to be 22.08 t ha^{-1}. SOC values in tropical forests range from 10.13–119.65 t C ha^{-1} (Sahoo et al. 2021). Owing to its heterogeneous environment, soil type and topography, SOC stocks in mountainous regions exhibit significant spatial variability (Hoffmann et al. 2014). The presence of a large expanse of forests and trees directly and indirectly influence carbon stocks (Meentemeyer and Berg 1986). The total carbon stock (TCS) calculated by summing AGB, BGB and SOC is found to be 458.16 t ha^{-1}. The recorded TCS in the study site is higher than the studies carried out in different forest types (Sierra et al. 2007, Schmitt-Harsh et al. 2012, Cruz-Amo et al. 2020, Daba et al. 2022, Gogoi et al. 2017, Dantas et al. 2020) which ranged from 211.51 to 637.54 t ha^{-1} and lower than the studies carried out by Oumer et al. (2020) and Leley et al. (2022) which reports the carbon stock of 637.54 to 682.08 t ha^{-1} in forest-landscape ecosystem in Drylands of Northern Kenya and dry Afromontane forest in South-Eastern Ethiopia, respectively. In the forests, majority of individuals are in the small girth class (0-30 cm), however it may be speculated that these trees will grow and will store more carbon in their biomass. Hence, the forest has a significant potential for increased carbon sequestration in the future.

CONCLUSION

The findings of the study indicate that the Soraipung range of Dehing Patkai National Park possesses a diverse range of tree species, with 253 individuals ha^{-1} distributed across various girth classes. The population curve demonstrates a reversed J shaped, indicating a promising potential for future good forest regeneration, as maximum tree individuals are concentrated in the lower girth class. Additionally, the study highlights the total carbon stock (458.16 t ha^{-1}) present in the forest has a high potential in carbon storage which is responsible in mitigating climate change. The positive correlation observed between the density, DBH, with TCD suggests that these parameters have a substantial influence on carbon storage in the present study site. The study also exhibits a considerable amount of soil organic carbon (SOC), indicating extensive plant decomposition and the accumulation of organic matter. It is important to note that even a small alteration in the terrestrial carbon pool can have far reaching consequences on global atmospheric carbon levels. Therefore, long term monitoring and effective forest management are necessary to enhance the carbon sequestration potential of individual species, contributing to global climate mitigation efforts.

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Authors' contributions: All authors contributed equally

Conflict of interest: Authors declare no conflict of interest

REFERENCES

Alexandrov, G. 2007. Carbon stock growth in a forest stand: the power of age. Carbon Balance Management, 2, 4. https://doi.org/10.1186/1750-0680-2-4.

Baidya, S., Thakur, B. and Devi, A. 2022. The influence of tree population structure on regeneration potential in the sacred forests of Assam, India. Tropical Ecology, 63, 239-251. https://doi.org/10.1007/s42965-021-00208-8.

Balmford, A. and Bond, W. 2005. Trends in the state of nature and their implications for human well-being. Ecology Letters, 8, 1218-1234. https://doi.org/10.1111/j.1461-0248.2005.00814.x.

Bhattacharyya, T., Pal, D.K., Chandran, P., Ray, S.K., Mandal, C. and Telpande, B. 2008. Soil carbon storage capacity as a tool to prioritize areas for carbon sequestration. Current Science, 95, 482-494.

Brown, S. 1997. Estimating biomass and biomass change of tropical forests: A primer (FAO Forestry Paper-134). Food and Agriculture Organization of the United Nations, Rome.

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

Calago, J.C. and Diola, A.G. 2022. Population structure and spatial pattern of critically endangered Dipterocarpaceae tree species in Mt. Malindang range Natural Park, Mindanao, Philippines. Open Journal of Ecology, 12, 407-433. https://doi.org/10.4236/oje.2022.127024.

Chandrasekharan C. 1960. Forest types of Kerala state. Special paper submitted for Diploma in Forestry. New Forest, Dehra Dum, India.

Cruz-Amo, L., Bañares-de-dios, G., Cala, CÍ., Cerda, Í.G., Espinosa, C.I., Ledo, A., Salinas, N. and Macía, M.J. 2020. Trade-offs among aboveground, belowground, and soil organic carbon stocks along altitudinal gradients in Andean tropical montane forests. Frontiers in Plant Science, 11, 1–11. https://doi.org/10.3389/fpls.2020.00106

Daba, D.E., Dullo, B.W. and Soromessa, T. 2022. Effect of forest management on carbon stock of Tropical moist Afromontane Forest. International Journal of Forestry Research, 2022,1-14. https://doi.org/10.1155/2022/3691638.

Dantas, D., Terra, M.C.N.S., Pinto, L.O.R., Calegario, N. and Maciel, S.M. 2020. Above and belowground carbon stock in a tropical forest in Brazil. Acta Scientiarum, 43, 1-13. https://doi.org/10.4025/actasciagron.v43i1.48276.

Dar, A.A. and Parthasarathy, N. 2022. Patterns and drivers of tree carbon stocks in Kashmir Himalayan forests: implications for climate change mitigation. Ecological Processes, 11, art 58. https://doi.org/10.1186/s13717-022-00402-z.

David, H.C., Araújo, E.J.G. de., Morais, V.A., Scolforo, J.R.S., Marques, J.M., Péllico Netto, S. and MacFarlane, D.W. 2017. Carbon stock classification for tropical forests in Brazil: Understanding the effect of stand and climate variables. Forest Ecology and Management, 404: 241–250. doi:10.1016/j.foreco.2017.08.044

Dinerstein, E., Olson, D., Joshi, A., Vynne, C., Burgess, N.D., Wikramanayake, E., Hahn, N., Palminteri, S., Hedao, P., Noss, R., Kormos, C., Martin, V., Crist, E., Sechrest, W., Price, L., Baillie, J.E.M., Weeden, D., Suckling, K., Davis, C., Sizer, N., Moore, R., Thau, D., Birch, T., Potapov, P., Turubanova, S., Tyukavina, A., de Souza, N., Pintea, L., Brito, J.C., Llewellyn, O.A., Miller, A.G., Patzelt, A., Ghazanfar, S.A., Timberlake, J., Kloser, H., Shennan-Farpon, Y., Kindt, R., Lilleso, J-P.B., van Breugel, P., Graudal, L., Voge, M., Al-Shammari, K.F. and Saleem M. 2017. An ecoregion-based approach to protecting half the terrestrial realm. Bioscience, 67, 534-545. https://doi.org/10.1093/biosci/bix014.

Dumitraºcu, M., Kucsicsa, G., Dumitricã, C., Popovici, E., Vrînceanu A., Mitricã, B., Mocanu, I. and ˆerban P. 2020. Estimation of future changes in aboveground forest carbon stock in Romania. A prediction based on forest-cover pattern scenario. Forests, 11, 1-24. https://doi.org/10.3390/F11090914.

Ekoungoulou, R., Niu, S., Joël, L.J. and Suspense, I.A. 2015. Evaluating the carbon stock in above-and below- ground biomass in a moist central African forest. Applied Ecology and Environmental Sciences, 3, 51-59. https://doi.org/10.12691/aees-3-2-4.

Forest Survey of India. 2021. State of Forests 2021. Retrieved on 15/08/2023. https://fsi.nic.in/forest-report-2021-details.

Giri, K., Buragohain, P., Konwar, S. and Pradhan, B. 2019. Tree diversity and ecosystem carbon stock assessment in Nambor wildlife sanctuary, Assam. Proceedings of the National Academy of Sciences, India Section B: Biological Sciences, 89, 1421-1428. https://doi.org/10.1007/s40011-018-01072-8.

Giroldo, A.B. and Scariot, A. 2015. Land use and management affects the demography and conservation of an intensively harvested Cerrado fruit tree species. Biological Conservation, 191, 150-158. https://doi.org/10.1016/j.biocon.2015.06.020.

Gogoi, A., Sahoo, U.K. and Singh, S.L. 2017. Assessment of biomass and total carbon stock in a tropical Wet Evergreen Rainforest of Eastern Himalaya along a disturbance gradient. Journal of Plant Biology & Soil Health, 4, art 8. https://doi.org/10.13188/2331-8996.1000014

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, 142-149. https://doi.org/10.1007/s42965-020-00061-1.

Gogoi, R., Chetry, A. and Bhuyan, A. 2023. Diversity and species richness of butterfly in Soraipung range of Dehing Patkai National Park, Assam, India. The Journal of Basic and Applied Zoology, 84,1-9. https://doi.org/10.1186/s41936-023-00327-9.

Gonçalves, F.M.P., Revermann, R., Gomes, A.L., Finckh, M. and Juergens, N. 2017. Tree species diversity and composition of miombo woodlands in South-Central Angola: A chronosequence of forest recovery after shifting cultivation. International Journal of Forestry Research, 2017, 1-13. https://doi.org/10.1155/2017/6202093.

Guan, J.H., Deng, L., Zhang, G., He, Q., She, W., Li, G. and Du, S. 2019. Soil organic carbon density and its driving factors in forest ecosystems across a northwestern province in China. Geoderma, 352, 1-12. https://doi.org/10.1016/j.geoderma.2019.05.035

Hare, M.A., Lantagne, D.O., Murphy, P.G. and Checo, H.M. 1997. Structure and tree species composition in a subtropical dry forest in the Dominican Republic: comparison with a dry forest in Puerto Rico. Tropical Ecology, 38, 1-17.

Hoffmann, U., Hoffmann, T., Jurasinski, G., Glatzel, S. and Kuhn. N. J. 2014. Assessing the spatial variability of soil organic carbon stocks in an alpine setting (Grindelwald, Swiss Alps). Geoderma 232–234, 270-283. doi:https://doi.org/10.1016/j.geoderma.2014.04.038.

ICRAF. Ecological Database. Retrieved on 20 November 2020 from http://db.worldagroforestry.org/wd.

IPCC. 2000. Land Use, Land-Use Change and Forestry: A special report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Edinburgh.

Joseph, S., Reddy, S.C., Thomas, A.P. and Srivastava, S.K. 2010. Spatial interpolation of carbon stock: A case study from the Western Ghats biodiversity hotspot, India. International Journal of Sustainable Development and World Ecology, 17, 481-486. https://doi.org/10.1080/13504509.2010.516107.

Joshi, R.. Pangeni, M.. Neupane, S.S. and Yadav, N.P. 2021. Regeneration status and carbon accumulation potential in community managed sal (*shorea robusta*) forests of far-western terai region, Nepal. European Journal of Ecology, 7, 26-39. https://doi.org/10.17161/EUROJECOL.V7I1.15005.

Khan, M.L., Rai, J.P.N. and Tripathi, R.S. 1987. Population structure of some tree species in disturbed and protected subtropical forests of north-east India. Acta Oecologica, 8, 247-255.

Leley, N.C., Langat, D.K., Kisiwa, A.K., Maina, G.M. and Muga, M.O. 2022. Total carbon stock and potential carbon sequestration economic value of Mukogodo forest-landscape ecosystem in Drylands of Northern Kenya. Open Journal of Forestry, 12,19-40.

Makemba, R. N., F. Tosso, C. Moupela, G. Ligot, Y. Brostaux, and J. L. Doucet. 2022. Enrichment of logging gaps with high-value timber species: how far fertilizer, biochar and mammal predation affect performances of Cylicodiscus gabunensis harms seedlings. Forests 13.1-16. doi:10.3390/f13111937.

Mathys, A.S., Brang, P., Stillhard, J., Bugmann, H. and Hobi, M.L. 2021. Long-term tree species population dynamics in Swiss forest reserves influenced by forest structure and climate. Forest Ecology and Management, 481, 118666. https://doi.org/https://doi.org/10.1016/j.foreco.2020.118666.

Meentemeyer, V. and Berg, B. 1986. Regional variation in rate of mass loss of *Pinus sylvestris* needle litter in Swedish pine forest as influenced by climate and litter quality. Scandinavian Journal of Forest Research, 1, 167-180. https://doi.org/ 10.1080/02827588609382409.

Mishra, B.P., Tripathi, O.P. and Laloo, R.C. 2005. Community characteristics of a climax subtropical humid forest of Meghalaya and population structure of ten important tree species. Tropical Ecology, 46, 241-251.

Nath, A.J., Tiwari, B.K., Sileshi, G.W., Sahoo, U.K., Brahma, B., Deb, S., Bijayalaxmi Devi, N., Das, A.K., Reang, D., Chaturvedi, S.S., Tripathi, O.P., Das, D.J. and Gupta, A. 2019. Allometric models for estimation of forest biomass in North East India. Forests, 10(2), art103. https://doi.org/10.3390/f10020103.

Nath, P.C., Arunachalam, A., Khan, M.L. and Barbhuiya, A.R. 2005. Vegetation analysis and tree population structure of tropical wet evergreen forests in and around Namdapha National Park, northeast India. Biodiversity Conservation, 14, 2109-2135. https://doi.org/10.1007/s10531-004-4361-1.

Návar, J.C. 2010. Biomass allometry for tree species of northwestern Mexico. Tropical and Subtropical Agroecosystems, 12, 507-519.

Nworo, F.B., Ndah, N.R. and Andrew, E.E. 2020. Stand structure, regeneration status and distribution patterns of six important tree species along altitudinal gradients at the Kilum-Ijim Forest Reserve, Cameroon. Journal of Agriculture and Ecology Research International, 21, 41-57.

Oumer, M.R.H., Abdi, A.B. and Yusuf, M.M. 2020. Biomass and soil organic carbon stocks of woody species at Ades dry Afromontane forest, South-Eastern Ethiopia. International Journal of Soil Science, 15, 8-15. 10.3923/ijss.2020.8.15.

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, 988-993. https://doi.org/10.1126/science.1201609.

Pandey, H.P. and Bhusal, M. 2016. A comparative study on carbon stock in Sal (*Shorea robusta*) forest in two different ecological regions of Nepal. Banko Janakari, 26, 24-31. https://doi.org/10.3126/banko.v26i1.15498.

Pearson, T.R.H., Brown, S. and Birdsey, R. 2007. Measurement guidelines for the sequestration of forest carbon. United States Department of Agriculture, Washington, DC, USA.

Poorter, L., van der Sande, M.T., Thompson, J., Arets, E.J.M.M., Alarcon, A., Alvarez-Sanchez, J., Ascarrunz, N., Balvanera, P., Barajas-Guzman, G., Boit, A., Bongers, F., Carvalho, F.A., Casanoves, F., Gornejo-Tenorio, G., Costa, F.R.C., de Castilho, C.V., Duivenvoorden, J.F., Dutrieux, L.P., Enquist, B.J., Fernandez-Mendez, F., Finegan, B., Gormley, L.H.L., Healey, J.R., Hoosbeek, M.R., Ibarra-Manriqueq, G., Junqueira, A.B., Levis, C., Licona, J.C., Lisboa, L.S., Magnusson, W.E., Martinez-Ramos, M., Martinez-Yrizar, A., Martorano, L.G., Maskell, L.C., Mazzei, L., Meave, J.A., Mora, F., Munoz, R., Nytch, C., Pansonato, M.P., Parr, T.W., Paz, H., Perez-Garcia, E.A., Renteria, L.Y., Rodriguez-Velazquez, J., Rozendaal, D.M.A., Ruschel, A.R., Sakschewski, B., Salgado-Negret, B., Schietti, J., Simoes, M., Sinclair, F.L., Souza, P.F., Souza, F.C., Stropp, J., ter Steege, H., Swenson, N.G., Thonicke, K., Toledo, M., Uriarte, M., van der Hout, P., Walker, Zamora, N. and Pena-Claros, M. 2015. Diversity enhances carbon storage in tropical forests. Global Ecology and Biogeography, 24, 1314-1328. https://doi.org/10.1111/geb.12364.

Pragasan, L.A. 2016. Assessment of carbon stock of tree vegetation in the Kolli hill forest located in India. Applied Ecology and Environmental Research, 14, 169-183. https://doi.org/10.15666/aeer/1402_169183.

Pragasan, L.A. 2022. Tree carbon stock and its relationship to key factors from a tropical hill forest of Tamil Nadu, India. Geology, Ecology, and Landscapes, 6, 32-39. https://doi.org/10.1080/24749508.2020.1742510.

Prakasha, H.M., Nanda, A. and Krishnamurthy, Y.L. 2008. Stand structure of a tropical dry deciduous forest in Bhadra wildlife sanctuary, Karnataka, Southern India. Bulletin of the National Institute of Ecology, 19, 1-7

Raha, D., Dar, J.A., Pandey, P.K., Lone, P., 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, 109-120. https://doi.org/10.1080/17583004.2020.1712181.

Ramachandra, T.V. and Bharath, S. 2020. Carbon sequestration potential of the forest ecosystems in the Western Ghats, a Global Biodiversity Hotspot. Natural Resources Research, 29, 2753-2771. https://doi.org/10.1007/s11053-019-09588-0.

Richards, M. 1996. Protected areas, people and incentives in the search for sustainable forest conservation in Honduras. Environmental Conservation, 23, 207-217. https://doi.org/10.1017/S0376892900038820.

Sahoo, U.K., Tripathi, O.P., Nath, A.J., Deb, S., Das, D.J., Gupta, A., Bijayalaxmi Devi, N., Chaturvedi, S.S., Singh, S.L., Kumar, A. and Tiwari, B.K. 2021. Quantifying tree diversity, carbon stocks, and sequestration potential for diverse land uses in Northeast India. Frontiers in Environmental Science, 9, 1-14. https://doi.org/10.3389/fenvs.2021.724950

Saikia, P. and Khan, M.L. 2016. Tree species diversity and its population and regeneration status in homegardens of upper Assam, Northeast India. Journal of Forest and Environmental Science, 32, 129-139. https://doi.org/10.7747/jfes.2016.32.2.129.

Salunkhe, O.R., Valvi, G.R., Singh, S., Rane, G.M., Khan, M.L., Saxena, V. and Khare, P.K.. 2023. Forest carbon stock and biomass estimation in West Central India using two allometric models. Carbon Research, 2, art 9. https://doi.org/10.1007/s44246-023-00039-3.

Sarkar, M. and Devi, A. 2014. Assessment of diversity, population structure and regeneration status of tree species in Hollongapar Gibbon Wildlife Sanctuary, Assam, Northeast India. Tropical Plant Research, 1, 26-36. https://www.tropicalplantresearch.com/vol1Issue2/pdf/5.1.pdf

Saxena, A.K. and Singh, J.S. 1984. Tree population structure of certain Himalayan forest associations and implications concerning their future composition. Vegetation, 58, 61-69. https://doi.org/10.1007/BF00044928.

Schmitt-harsh, M., Evans, P.T., Castellanos, E. and Randolph, J.C. 2012. Carbon stocks in coffee agroforests and mixed dry tropical forests in the western highlands of Guatemala. Agroforestry System, 86, 141-157. https://doi.org/10.1007/s10457-012-9549-x

Sierra, C.A., Valle, J.I., Orrego, S.A. and Moreno, F. 2007. Total carbon stocks in a tropical forest landscape of the Porce region, Colombia. Forest Ecology Management, 243, 299-309. https://doi.org/10.1016/j.foreco.2007.03.026.

Sumita, R., Kiran, B. and Bargali, S.S. 2015. Assessment of plant diversity, regeneration status, biomass and carbon stock in a Central Himalayan cypress forest. International Journal of Biodiversity Conservation 7, 321-329. https://doi.org/10.5897/ijbc2015.0855.

Thokchom, A. and Yadava, P.S. 2017. Biomass and carbon stock along an altitudinal gradient in the forest of Manipur, Northeast India. Tropical Ecology, 58, 389-396

Tynsong, H., Dkhar, M. and Tiwari, B.K. 2022. Tree diversity and vegetation structure of the tropical evergreen forests of the southern slopes of Meghalaya, North East India. Asian Journal of Research, 6, 22-33. https://doi.org/10.13057/asianjfor/r060104.

Ullah, M.R. and Al, A.M 2012. Above- and below-ground carbon stock estimation in a natural forest of Bangladesh. Journal of Forest Science, 58, 372-379. https://doi.org/10.17221/103/2011-JFS

Worku, A., Teketay, D., Lemenih, M. and Fetene, M. 2012. Diversity, regeneration status, and population structures of gum and resin producing woody species in Borana, southern Ethiopia. Forests, Trees and Livelihoods, 21, 85-96.

Zhang, Y., Li, P., Liu, X., Li, T. and Wang, D. 2022. The response of soil organic carbon to climate and soil texture in China. Frontiers in Earth Science 16, 835-845. https://doi.org/10.1007/s11707-021-0940-7.

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