INTL J TROP DRYLANDS
Volume 8, Number 2, December 2024
Pages: 95-105

E-ISSN: 2775-6130
DOI: 10.13057/tropdrylands/t080204

Unveiling the interplay between tree stand attributes, species diversity, and biomass carbon in Chunati Wildlife Sanctuary, Southeastern Bangladesh

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Manuscript received: 1 October 2024. Revision accepted: 3 December 2024.

Abstract. *Rakib MH, Hossain SMS, Sadnan MWM, Chowdhury MIH. 2024. Unveiling the interplay between tree stand attributes, species diversity, and biomass carbon in Chunati Wildlife Sanctuary, Southeastern Bangladesh. Intl J Trop Drylands 8: 95-105.* Biodiversity plays a pivotal role in maintaining ecosystem health and resilience, especially in tropical forest landscapes. This study investigates the intricate relationships between stand structure, biodiversity indices, and biomass carbon within forest ecosystems, specifically focusing on the Chunati Wildlife Sanctuary (CWS), a tropical forestland in Southeastern Bangladesh. The key structural attributes, i.e. tree height, diameter at breast height (DBH), basal area, and stand density, as well as biodiversity indices, were analyzed to understand their correlations with biomass carbon. The study exhibits the measured soil carbon levels ranging from 35.26 to 93.26 Mg C ha^{-1} and tree biomass carbon from approximately 131.13 to 387.23 Mg C ha^{-1}. The findings revealed a strong positive correlation between tree height and biomass carbon ($R^2 = 0.6517$), indicating that taller trees generally store more carbon due to enhanced photosynthesis. Notably, DBH exhibited a robust correlation ($R^2 = 0.8683$), highlighting the significance of larger trees as carbon sinks. The basal area emerged as the strongest predictor of biomass carbon, with an impressive correlation ($R^2 = 0.9119$). The Shannon-Wiener and Margalef's richness indices had moderate to strong correlations with biomass carbon ($R^2 = 0.4473$ and $R^2 = 0.5663$) respectively. These results underscore the importance of maintaining diverse and structurally complex forests for effective carbon sequestration. The future study should incorporate additional ecological variables to refine models for predicting forest carbon dynamics with the vast change in tropical landscapes and inform better conservation strategies, leading to tropical biodiversity conservation and climate change mitigation efforts on tropical landscapes.

Keywords: Carbon stock, fossil carbon, phytosociology, tree biomass, tropical-forest

INTRODUCTION

Protected areas are essential for conserving biodiversity and delivering ecosystem services (Mamun et al. 2022). In Bangladesh, protected area coverage increased slightly from 1.67% in 2008 to 1.80% of the total forest land area in 2015, one of the lowest globally (Islam et al. 2022). The government has designated 49 protected areas, 17 of which are under the co-management system (Uddin et al. 2020a). Among these, Chunati Wildlife Sanctuary (CWS), covering approximately 7,764 hectares in southeastern Bangladesh, plays a vital role in conserving biodiversity while supporting the livelihoods of approximately 50,000 people across 9,400 households (Hossain et al. 2020). It encompasses various forest types, including tropical evergreen, semi-evergreen, and deciduous forests, contributing to its rich biodiversity (Festus et al. 2024). However, deforestation, illegal logging, and land conversion jeopardize this biodiversity.

The success of conservation efforts in protected areas is intricately tied to the well-being of forest-dependent communities (Hossain et al. 2020). Empowering local communities living around protected areas has been identified as a key strategy for biodiversity conservation (Rahman et al. 2018). In CWS, 70% of the population is considered poor, 19% extremely poor, 10% middle class, and just 1% rich (Rahman et al. 2016). The primary occupations include day labor and non-wage agricultural work, with an unemployment rate at 17% (Rahman et al. 2017; Rahman and Obaydullah 2020). This heavy reliance on forest resources (Akwaji and Onah 2023), coupled with high unemployment, threatens CWS's ecological integrity (Rahman and Obaydullah 2020). To mitigate forest degradation, the Bangladesh Forest Department (BFD), in collaboration with USAID, launched the Nishorgo support project in 2004, followed by the integrated protected area co-management (IPAC) initiative (Kufata et al. 2024), which promoted community co-management and alternative income activities (Chowdhury 2014). However, limited livelihood support from these projects has reduced their effectiveness in decreasing forest dependency (Roy et al. 2015).

Forests are critical for maintaining ecological balance, regulating climate, providing habitats for species, and serving as carbon sinks (Ali et al. 2022). Consequently, understanding forest ecosystems' biodiversity and carbon stock is vital for effective conservation and sustainable management (Ali et al. 2022; Islam et al. 2018, 2020). To assess species diversity, researchers use indices such as the Shannon-Wiener index, and Margaleaf richness index, which provide insights into species richness, evenness, and distribution (Kessler et al. 2009; Hasan et al. 2023; Scherer et al. 2023). These metrics inform conservation planning and biodiversity management. Assessing carbon stocks, including tree biomass carbon and soil organic carbon (SOC), is equally crucial for understanding a forest's role in carbon sequestration (Alongi 2011; Shaheed and Chowdhury 2014; Ali et al. 2022).

This study aims to evaluate the biodiversity and carbon stock in the Chunati Wildlife Sanctuary, offering a comprehensive understanding of its ecological status. The primary objectives are to analyze species diversity using the Shannon-Wiener index, Simpson's index, and Pielou's evenness index, and to quantify carbon stock by measuring both tree biomass carbon and SOC. The leading question of the study: (i) How do structural attributes such as tree height, diameter at breast height (DBH), and basal area predict biomass carbon stock in the Chunati Wildlife Sanctuary; (ii) To what extent do biodiversity indices, such as the Shannon-Wiener and Margalef's richness indices, influence the carbon sequestration capacity of tropical forest ecosystems, and how can these relationships guide conservation efforts for enhancing carbon storage?

By examining the interplay between biodiversity indices, tree stand structure, and carbon stock, this research seeks to contribute to the existing knowledge base on tropical forest biodiversity and carbon sequestration in Bangladesh. Additionally, it provides baseline data for monitoring changes in CWS's ecological parameters over time, which is essential for assessing conservation measures' effectiveness and informing forest management decisions. The findings will support policy-making at both national and international levels, particularly regarding biodiversity conservation and climate change mitigation. Insights from this study will aid in the protection and sustainable management of CWS, benefiting both local conservation initiatives and global efforts to combat climate change. By providing data on species diversity and carbon sequestration potential, this research will inform strategies to preserve biodiversity and enhance carbon storage in tropical forests.

MATERIALS AND METHODS

Study site

The Chunati Wildlife Sanctuary (CWS) is situated at 21°40' North and 92°07' East, in the southeastern part of Bangladesh (Figure 1). It encompasses the Banshkhali and Lohagara Upazila of Chittagong District and the Chakoria Upazila of Cox's Bazar District. The Chunati Wildlife Sanctuary experiences a tropical moist climate with annual rainfall ranging from 3,000 to 3,500 mm. The air temperature fluctuates between 16 and 34°C, while relative humidity remains high, typically between 70 and 90%. The soil in the sanctuary is predominantly sandy loam, supporting a rich biodiversity and influencing the carbon sequestration potential of the forest. The sanctuary covers seven Union Parishads: Chunati, Adhunagar, Herbang, Puichari, Banskhali, Borohatia, and Toitong. CWS was established in 1986 and spans 7,764 hectares of Reserve Forest. The Wildlife and Nature Conservation Division of Chittagong oversees the administration of the sanctuary. It is divided into two Forest Ranges and seven forest beats (smallest forest management unit): The Chunati range, which covers a total area of 3,332 ha and includes Chunati, Aziznagar, and Harbang beats; and the Jaldi range, which encompasses a total area of 4,432 ha and comprises Jaldi, Chambal, Napora, and Puichari (Islam et al. 2018; Mamun et al. 2022; Rahman et al. 2022).

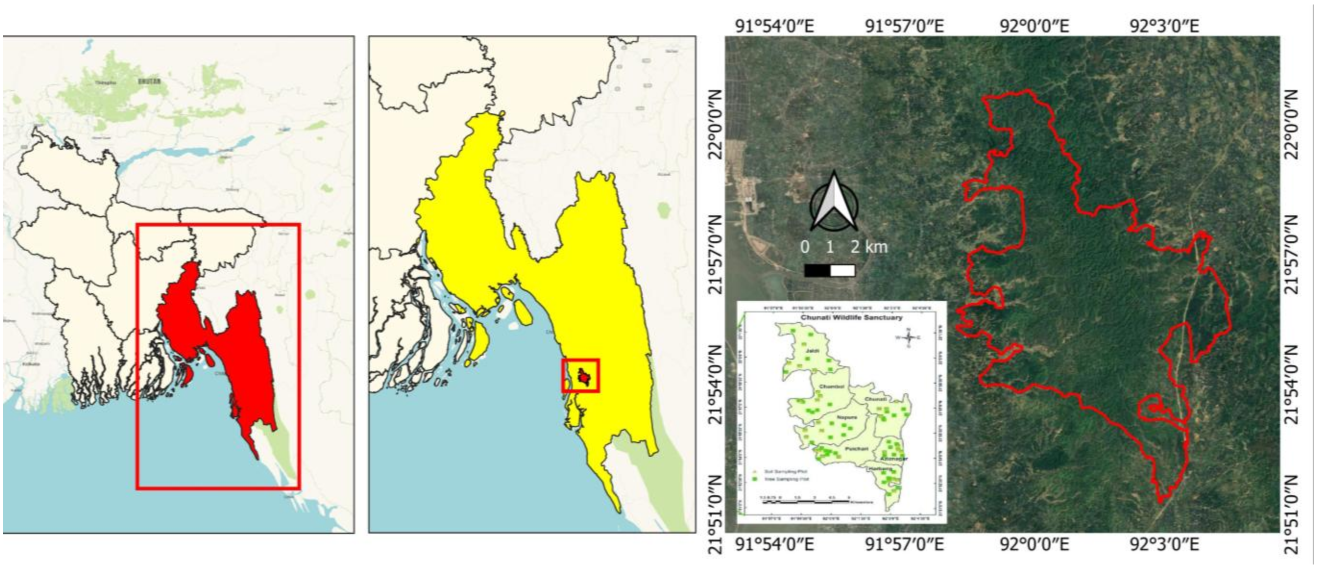

Figure 1. Map of the study area with sampling (vegetation and soil) points throughout the seven Forest Beats of the Chunati Wildlife Sanctuary. The maps are created using Arcmap10.8

Table 1. Equations used in the calculation for phytosociological parameters and biodiversity indices of tree species in this study

Equation	References
Basal area ($m^2\ ha^{-1}$) = $\frac{\Sigma \frac{\pi \times D^2}{4}}{\Sigma \text{Area of all quadrats}} \times 10000$	(Shukla and Chandel 2016); Chowdhury et al. (2019)
Relative density, R_d (%) = $\frac{S}{n} \times 100$	Dallmeier et al. (1992); Das (2024)
Relative frequency, R_f (%) = $\frac{F_i}{\Sigma F_i}$	Dallmeier et al. (1992); Das (2024)
Relative dominance, RD_o (%) = $\frac{\text{Basal area of one species}}{\text{Total Basal area}} \times 100$	Hossain et al. (2013); Chowdhury et al. (2019)
Important Value Index (IVI) = $R_d + R_f + RD_o$	Hossain et al. (2013)
Shannon-Wiener index, $H' = -\Sigma P_i \ln P_i$	Michael (1984); Hop et al. (2023)
Margalef richness index = $\frac{S-1}{\ln N}$	Kohli et al. (1996)

Note: D: The diameter at breast height, F_i: The frequency of a species, P_i: The abundance of the species in each plot, S: the total number of species, N: The total number of individuals of all the species

Table 2. Equations used in the estimation of biomass, and soil organic carbon in this study

Equation	References
AGB (kg) = $(0.0673\times(\rho\ (DBH)^2\ H)^{0.976})$	Chave et al. (2014)
Biomass C ($Mg\ ha^{-1}$) = Biomass (dry mass, $Mg\ ha^{-1}$) × 0.5 Mg C	Sandra Brown (1997); Baul et al. (2021a)
Loss of ignition, LOI % = $\frac{W_1}{W_2} \times 100$	Ball (1964)
Soil organic carbon, SOC % = 0.47 × (% LOI – 1.87)	Ball (1964); Baul et al. (2021b)
SOC stock ($Mg\ ha^{-1}$) = SOC % × BD × SD	Pearson et al. (2005)

Note: AGB (kg): Above-ground biomass, ρ wood density ($g\ cm^{-3}$), D: Tree DBH (cm), H: Tree height (m), W_1: the loss in mass (g), W_2: Oven-dried soil (g), BD: Bulk density of soil ($g\ cm^{-3}$), and SD means the soil depth (cm). Living root biomass was estimated as 15% of AGB (Macdicken K. 2015). To estimate AGB, wood density ($g\ cm^{-3}$), a required variable, was collected from the Bangladesh Forest Research Institute (Sattar et al. 1999). For those not found in BFRI publications, we used the global wood density database (Chave et al. 2009)

Data collection

Vegetation survey

Vegetation survey was conducted to assess the biodiversity indices, and biomass carbon estimation of CWS between October to December 2023. A total of 70 plots (10 from each beat) with size of 20 × 20 m were randomly located (Figure 1). In each plot, DBH (diameter at breast height; 1.3 m above the ground), the total height of all trees having dbh ≥5 cm were recorded using Range finder and Suunto clinometer. All the surveyed species were identified and recorded in local and scientific name. In the case of unknown species plant samples were collected to be identified by professional taxonomists from the Bangladesh Forest Research Institute (BFRI).

Sampling of soil

A pit of 30 cm depth, under the litter layer approximate center of the same vegetation plot, was dug using a soil auger, and soil samples were collected from three vertical layers at 0-10, 11-20, and 21-30 cm depth. Hence 12 (3 depths × 4 points) samples from each beat which makes the result of a total of 84 (12 × 7 beats) samples are collected from the CWS (Figure 1). Collected soil samples were performed under lab analysis for SOC estimation.

Data analysis

Many indices are available worldwide that measure phytosociological parameters, biodiversity indices, biomass estimation, and soil organic carbon. In this study, different phytosociological and biodiversity indices were calculated for all the beats of CWS using the equations presented in Table 1. The estimation of biomass and soil organic carbon, the equations presented in Table 2 were used.

RESULTS AND DISCUSSION

Phytosociological status

The tree species survey in the CWS recorded 100 species belonging to 41 families. Among all the families Fabaceae (9 species) contained the highest number of tree species followed by Moraceae (8 species), Myrtaceae (8 species), and Eupharbiaceae (7 species). The highest basal area was occupied by *Ficus bengalensis* (11.10 $m^2\ ha^{-1}$) in the contrary *Garcinia lanceifolia* (0.05 m^2 ha^{-1}) scored the lowest (Table 3). The highest relative density was *Acacia auriculiformis* (20.61%) followed by *Dipterocarpus turbinatus* (9.10%) and *Swietenia macrophylla* (5.11%). Among all the recorded tree species *Lagerstroemia speciosa* (2.44%) and 22 others showed identical maximum relative frequency followed by *Sterospermum personatum* (2.24%) and *A. auriculiformis* (2.21%). The species with the highest relative dominance was *F. bengalensis* (8.06%) whereas *G. lanceifolia* (0.04%) scored the lowest. The most important species of CWS in terms of IVI was *A. auriculiformis* (23.25) followed by *D. turbinatus* (14.37) and *S. robusta* (10.58), while, *G. lanceifolia* (0.17) had the lowest IVI. It is a clear indication that exotic species alongside some native species mostly dominate the CWS. These exotic species are playing a role in the overall ecosystem degradation of the CWS.

Estimation of biomass and soil organic carbon

The comparative analysis of tree biomass carbon and soil organic carbon (SOC) across the seven forest beats of Chunati Wildlife Sanctuary indicates significant variability in both tree biomass carbon and SOC. Tree biomass carbon ranges from approximately 131.13 to 387.23 Mg C ha^{-1}, with the highest values observed in beats dominated by larger trees and higher basal areas. In contrast, SOC ranges from 35.26 to 93.26 Mg C ha^{-1} across different soil layers (0-10, 11-20, and 21-30 cm), with higher values in areas with denser tree cover and organic matter input (Figure 2.B).

The substantial range in tree biomass carbon suggests that forest structure, species composition, and management practices significantly influence carbon storage capacity. The mean biomass carbon (224.43 Mg C ha^{-1}) in the study area (Figure 2.A) is considerably higher than that of other regions in Bangladesh, such as the homestead forests in Rangpur (54 Mg C ha^{-1}) and Sundarbans (99 Mg C ha^{-1}), indicating the sanctuary's critical role in carbon sequestration (Baul et al. 2021b; Jaman et al. 2016). The SOC values are comparable to those found in similar tropical ecosystems, with the mean SOC (53.59 Mg C ha^{-1}) closely matching that of the Chittagong Hill Tracts (52.83 Mg C ha^{-1}) but exceeding that of the Sal Forest (48.3 Mg C ha^{-1}) and Sundarbans (38.8 Mg C ha^{-1}) (Baul et al. 2021b; Mukul et al. 2014).

Table 3. Phytosociological attributes of vegetation in Chunati Wildlife Sanctuary, Bangladesh

Scientific name	Family	BA (m^2 ha^{-1})	R_d (%)	R_f (%)	RD_o (%)	IVI
Mangifera indica L.	Anacardiaceae	1.57	4.47	2.20	1.16	7.83
Lannea coromandelica Merr.	Anacardiaceae	0.12	0.05	0.03	0.09	0.17
Anacardium occidentale L.	Anacardiaceae	1.44	0.16	0.08	1.07	1.31
Mangifera sylvatica Roxb.	Anacardiaceae	4.70	0.27	0.13	3.47	3.87
Alstonia scholaris L.	Apocynaceae	0.78	0.27	2.44	0.57	3.28
Arenga pinnata Merr.	Arecaceae	0.18	0.05	2.44	0.14	2.63
Stereospermum personatum Hassk.	Bignoniaceae	1.07	0.59	2.24	0.79	3.62
Stereospermum suaveolens Roxb.	Bignoniaceae	0.22	0.05	0.20	0.16	0.42
Eruca vesicaria L.	Brassicaceae	0.15	0.11	2.44	0.11	2.66
Bursera serrata Wall.	Burseraceae	1.04	1.13	2.44	0.77	4.34
Bauhinia acuminata L.	Caesalpiniaceae	0.48	0.16	0.73	0.36	1.25
Senna siamea Lam.	Caesalpiniaceae	1.39	0.16	0.73	1.03	1.92
Tamarindus indica L.	Caesalpiniaceae	5.17	0.22	0.98	3.82	5.01
Bhesa robusta Roxb.	Celastraceae	1.32	0.22	2.44	0.97	3.63
Garcinia lanceifolia Roxb.	Clusiaceae	0.05	0.05	0.07	0.04	0.17
Garcinia cowa Roxb.	Clusiaceae	0.20	1.18	1.63	0.15	2.96
Garcinia speciosa Wall.	Clusiaceae	0.19	0.22	0.30	0.14	0.65
Mesua ferrea L.	Clusiaceae	0.76	0.32	0.44	0.56	1.33
Terminalia arjuna DC.	Combretaceae	1.53	1.56	0.98	1.13	3.67
Terminalia bellirica Gaertn.	Combretaceae	1.07	0.91	0.58	0.79	2.28
Terminalia chebula Retz.	Combretaceae	0.29	1.29	0.81	0.21	2.32
Terminalia paniculata Roth.	Combretaceae	1.28	0.11	0.07	0.94	1.12
Dillenia indica L.	Dilleniaceae	0.83	0.11	0.81	0.61	1.53
Dillenia pentagyna Roxb.	Dilleniaceae	0.15	0.22	1.63	0.11	1.95
Dipterocarpus costatus Gaertn.	Dipterocarpaceae	2.94	2.42	0.33	2.17	4.93
Shorea robusta Gaertn.	Dipterocarpaceae	8.24	4.04	0.55	6.09	10.68
Dipterocarpus turbinatus Gaertn.	Dipterocarpaceae	5.56	9.10	1.24	4.11	14.44
Hopea odorata Roxb.	Dipterocarpaceae	1.47	2.31	0.32	1.09	3.72
Diospyros malabarica Kostel.	Ebenaceae	0.69	0.05	2.44	0.51	3.01
Elaeocarpus serratus L.	Elaeocarpaceae	2.43	0.48	2.44	1.80	4.72
Phyllanthus emblica L.	Euphorbiaceae	1.38	0.86	0.67	1.02	2.55
Aporosa wallichii Hook.	Euphorbiaceae	0.35	0.22	0.17	0.26	0.64
Antidesma velutinum Tul.	Euphorbiaceae	0.14	0.11	0.08	0.10	0.30
Antidesma ghaesembilla Gaertn.	Euphorbiaceae	0.17	0.16	0.13	0.13	0.41
Baccaurea ramiflora Lour.	Euphorbiaceae	0.10	0.22	0.17	0.07	0.45
Trewia nudiflora L.	Euphorbiaceae	0.86	1.51	1.18	0.63	3.32

Vernicia fordii Hemsl.	Euphorbiaceae	0.35	0.05	0.04	0.26	0.35
Acacia auriculiformis A.	Fabaceae	0.59	20.61	2.21	0.43	23.26
Pongamia pinnata L.	Fabaceae	0.21	0.05	0.01	0.15	0.21
Castanopsis indica Roxb.	Fabaceae	0.49	1.18	0.13	0.36	1.67
Ormosia robusta Baker	Fabaceae	0.15	0.11	0.01	0.11	0.23
Acacia hybrida G.Lodd.	Fabaceae	0.53	0.16	0.02	0.39	0.57
Quercus dentata Thunb.	Fabaceae	0.30	0.05	0.01	0.22	0.28
Xylia xylocarpa Roxb.	Fabaceae	3.63	0.05	0.01	2.68	2.74
Erythrina variegata L.	Fabaceae	1.13	0.32	0.03	0.84	1.19
Butea monosperma Lam.	Fabaceae	0.72	0.16	0.02	0.53	0.71
Gmelina arborea Roxb.	Lamiaceae	1.13	3.28	1.75	0.84	5.87
Tectona grandis L.	Lamiaceae	2.01	1.29	0.69	1.49	3.47
Cinnamomum tamala Buch.	Lauraceae	0.72	0.11	2.44	0.53	3.08
Barringtonia acutangula L.	Lecythidaceae	0.69	0.11	2.44	0.51	3.06
Lagerstroemia speciosa (L.) Pers.	Lythraceae	0.95	1.83	2.44	0.70	4.97
Magnolia champaca (L.) Baill. ex Pierre	Magnoliaceae	2.23	0.54	2.44	1.65	4.63
Sterculia foetida L.	Malvaceae	0.89	0.05	0.17	0.66	0.89
Brownlowia elata R. Br.	Malvaceae	1.26	0.05	0.17	0.93	1.16
Bombax ceiba L.	Malvaceae	0.45	0.59	1.92	0.33	2.84
Abroma augustum (L.) L. f.	Malvaceae	0.75	0.05	0.17	0.55	0.78
Chukrasia tabularis A. Juss.	Meliaceae	0.70	1.83	0.60	0.52	2.95
Swietenia macrophylla King	Meliaceae	4.15	5.11	1.68	3.07	9.86
Azadirachta indica A. Juss.	Meliaceae	2.59	0.43	0.14	1.91	2.48
Aphanamixis polystachya (Wall.) R. Parker	Meliaceae	0.52	0.05	0.02	0.39	0.46
Albizia lebbeck (L.) Benth.	Mimosaceae	1.99	0.48	0.32	1.47	2.27
Acacia mangium Willd.	Mimosaceae	0.71	0.48	0.32	0.52	1.33
Samanea saman (Jacq.) Merr.	Mimosaceae	4.62	1.56	1.04	3.41	6.01
Albizia richardiana (Voigt) King & Prain	Mimosaceae	4.47	0.16	0.11	3.30	3.57
Albizia procera (Roxb.) Benth.	Mimosaceae	2.41	0.97	0.65	1.78	3.39
Ficus religiosa L.	Moraceae	1.38	0.38	0.12	1.02	1.52
Ficus benghalensis L.	Moraceae	11.10	0.32	0.11	8.21	8.64
Artocarpus chama Buch.-Ham.	Moraceae	0.78	1.88	0.62	0.57	3.08
Artocarpus lacucha Buch.-Ham.	Moraceae	1.35	0.43	0.14	1.00	1.57
Ficus racemosa L.	Moraceae	0.36	2.15	0.71	0.26	3.12
Artocarpus heterophyllus Lam.	Moraceae	0.58	1.72	0.57	0.43	2.72
Ficus auriculata Lour.	Moraceae	0.24	0.05	0.02	0.18	0.25
Streblus asper Lour.	Moraceae	1.11	0.48	0.16	0.82	1.47
Muntingia calabura L.	Muntingiaceae	0.26	0.48	2.44	0.20	3.12
Syzygium grande (Wight) Walp.	Myrtaceae	1.74	4.31	1.04	1.29	6.64
Eucalyptus globulus Labill.	Myrtaceae	0.45	2.10	0.51	0.34	2.94
Syzygium cumini (L.) Skeels	Myrtaceae	3.60	1.13	0.27	2.66	4.06
Melaleuca alternifolia (Maiden & Betche) Cheel	Myrtaceae	0.79	0.05	0.01	0.58	0.65
Psidium guajava L.	Myrtaceae	0.26	0.70	0.17	0.19	1.06
Syzygium praecox (Roxb.) Rathakr. & Chithra	Myrtaceae	0.11	0.22	0.05	0.08	0.35
Syzygium fruticosum (Roxb.) A. M. Cowan & Cowan	Myrtaceae	0.79	1.40	0.34	0.59	2.32
Eucalyptus hybrida (no specific authority, hybrid designation)	Myrtaceae	0.69	0.16	0.04	0.51	0.71
Nyctanthes arbor-tristis L.	Oleaceae	0.20	0.05	2.44	0.15	2.64
Averrhoa carambola L.	Oxalidaceae	0.52	0.32	2.44	0.38	3.14
Glochidion lanceolarium (Roxb.) Voigt	Phyllanthaceae	0.67	1.29	2.44	0.50	4.23
Ziziphus mauritiana Lam.	Rhamnaceae	0.21	0.16	2.44	0.16	2.76
Prunus amygdalus Batsch	Rosaceae	1.03	0.16	2.44	0.76	3.36
Adina cordifolia (Roxb.) Hook. f. ex Brandis	Rubiaceae	1.32	0.11	0.41	0.97	1.49
Neolamarckia cadamba (Roxb.) Bosser	Rubiaceae	5.75	0.54	2.03	4.25	6.82
Zanthoxylum rhetsa (Roxb.) DC.	Rutaceae	1.31	0.05	0.81	0.97	1.83
Aegle marmelos (L.) Corrêa	Rutaceae	0.95	0.05	0.81	0.70	1.57
Citrus limetta Risso	Rutaceae	0.05	0.05	0.81	0.04	0.91
Litchi chinensis Sonn.	Sapindaceae	0.14	0.65	2.44	0.10	3.19
Madhuca longifolia (J. König) J. F. Macbr.	Sapotaceae	0.38	0.05	2.44	0.28	2.78
Spondias mombin L.	Spondiadaceae	3.05	0.05	2.44	2.25	4.75
Sterculia villosa Roxb.	Sterculiaceae	0.27	0.11	2.44	0.20	2.75
Tamarix dioica Roxb. ex Roth	Tamaricaceae	0.46	0.48	2.44	0.34	3.26
Aquilaria malaccensis Lam.	Thymelaeaceae	0.66	0.48	2.44	0.49	3.41
Vitex peduncularis Wall. ex Schauer	Verbenaceae	0.30	0.05	0.49	0.22	0.76
Vitex pinnata L.	Verbenaceae	0.83	0.22	1.95	0.61	2.78
Total		135.3	100	100	100	300

Note: basal area (BA m^2 ha^{-1}), relative density (Rd %), relative frequency (Rf %), relative dominance (Rdo %), and important value index (IVI) found from the recorded tree species

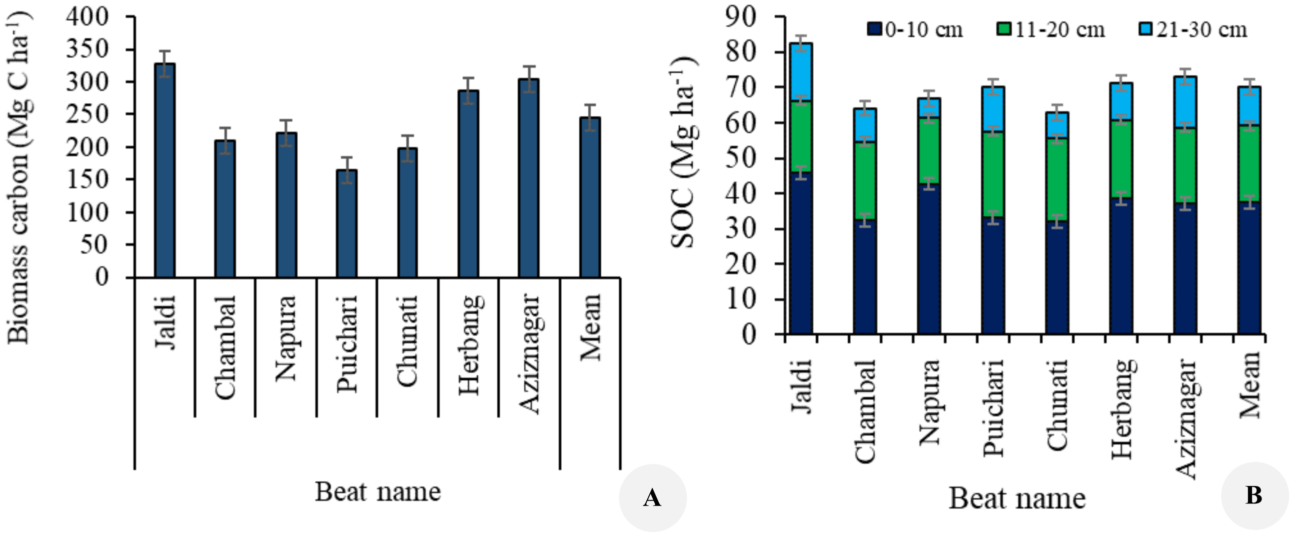

Figure 2. A beat-wise comparison among the seven beats in Chunati Wildlife Sanctuary in term of: A. tree biomass carbon stock; B. average soil organic carbon across 3 vertical layers (0-10, 11-20, 21-30 cm). The error bar represents the standard error of the mean

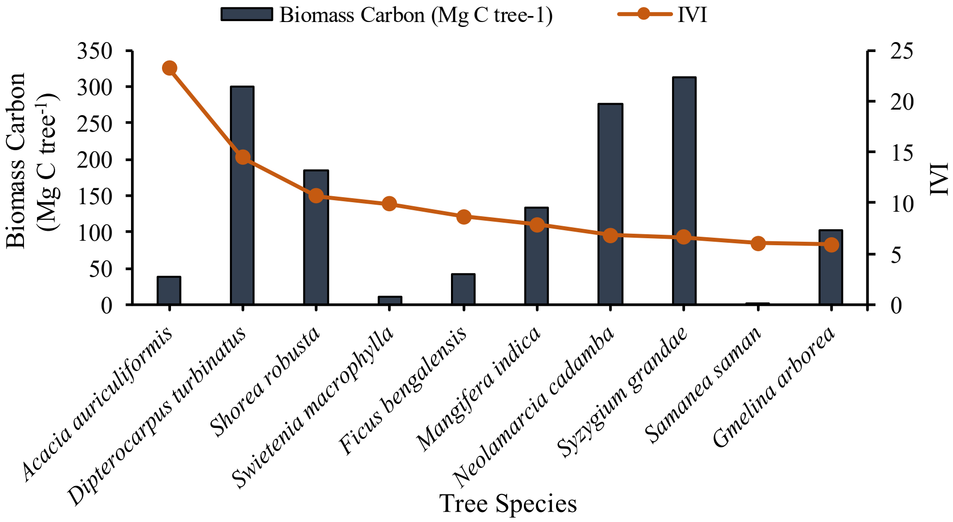

Figure 3. The tree biomass carbon of ten tree species with the most Important Value Index (IVI) in the Chunati Wildlife Sanctuary

This figure underscores the importance of both tree biomass and soil carbon in assessing the overall carbon storage potential of tropical forests. The variation across different beats highlights the need for site-specific forest management strategies to maximize carbon sequestration while maintaining biodiversity (Rahman et al. 2018). The findings align with existing literature, which emphasizes the crucial role of forest structure in carbon dynamics and highlights the potential of tropical forest ecosystems for significant carbon sequestration (Chave et al. 2014).

Figure 3 illustrates the biomass carbon contributions of the ten most dominant tree species in Chunati Wildlife Sanctuary based on their Importance Value Index (IVI). Species like *Dipterocarpus turbinatus*, *Shorea robusta*, and *Neolamarckia cadamba* demonstrate the highest biomass carbon storage, indicating their significant role in carbon sequestration within the sanctuary. In contrast, fast-growing exotic species such as *Acacia auriculiformis* and *Swietenia macrophylla*, despite being dominant by IVI, show relatively lower biomass carbon, suggesting that while these species thrive in number, they contribute less to carbon storage compared to native slow-growing species. This disparity highlights the ecological importance of preserving native species for maximizing carbon sequestration in tropical forests.

Interplay between tree stands structure and biomass carbon

The relationship between tree biomass carbon and various stand structure parameters is crucial for understanding forest carbon dynamics and for developing effective strategies for carbon sequestration in forest ecosystems. Figure 4 illustrates these relationships by examining tree height, tree diameter at breast height (DBH), basal area, and stand density, all of which are key structural attributes of forest stands (Pozo and Säumel

2018). By analyzing these parameters, we can gain insights into how forest structure influences carbon storage and, by extension, the role of forests in mitigating climate change.

Tree height and biomass carbon

Tree height is a fundamental parameter in forestry as it often correlates with the overall growth and productivity of a tree. Figure 4.A shows the relationship between tree height and biomass carbon is shown to be positively correlated. The regression equation $y = 32.99x - 201.07$ reveals that biomass carbon increases with tree height. The coefficient of determination $R^2 = 0.6517$ indicates that approximately 65% of the variation in biomass carbon can be explained by tree height (Ali et al. 2022; Chowdhury and Das 2024a; Chowdhury and Rakib 2024b). This strong correlation suggests that taller trees generally accumulate more biomass carbon, likely due to their greater leaf area and increased photosynthetic capacity, which leads to higher growth rates and carbon assimilation. However, the fact that 35% of the variation remains unexplained suggests that other factors (Scherer et al. 2023), such as species-specific growth patterns (Hossain et al. 2020), soil fertility (Mamun et al. 2022), and climatic conditions, also play significant roles in determining biomass carbon. This finding aligns with previous studies that have emphasized the importance of tree height in carbon storage but also highlight the need to consider additional factors that might influence carbon sequestration at different stages of tree growth (Zukswert et al. 2023).

Tree DBH and biomass carbon

Tree DBH is another critical indicator of forest stand structure and is often used in allometric equations to estimate tree biomass and carbon storage. Figure 4.B shows a robust positive correlation between tree DBH and biomass carbon, with a regression equation of $y = 20.376x - 268.74$ and a high $R^2 = 0.8683$. This suggests that 87% of the variation in biomass carbon is explained by tree DBH, making DBH one of the most reliable predictors of biomass carbon in forest ecosystems. Larger DBH typically indicates older and more mature trees (Rahman et al. 2018; Mehta et al. 2021), which have had more time to accumulate biomass (Sheikh et al. 2011). This strong relationship underscores the importance of preserving large-diameter trees in forests, as they serve as significant carbon sinks. The remaining 13% of unexplained variation could be attributed to factors such as tree species composition, age, and environmental conditions, which can influence how biomass is distributed within a tree and across different trees in a stand (Mamun et al. 2022; Ali et al. 2022). This finding suggests that forest management practices should prioritize the protection and maintenance of large-diameter trees to enhance carbon sequestration efforts (Hossain et al. 2020).

Basal area and biomass carbon

Basal area (BA) is a measure of the cross-sectional area of a tree trunk and is often used as an indicator of forest density and productivity. Figure 4.C demonstrates a very strong positive correlation between basal area and biomass carbon with the regression equation $y = 1.7256x - 44.008$ and an impressive $R^2 = 0.9119$. This suggests that about 91% of the variability in biomass carbon is explained by basal area, making it the strongest predictor among the variables analyzed. Basal area is directly related to the total wood volume in a forest stand, and thus, higher basal areas typically correspond to greater biomass and carbon storage (Rahman et al. 2018; Mamun et al. 2022). The strong relationship between basal area and biomass carbon highlights the importance of managing forest stands to maintain or increase basal area, particularly in the context of forest conservation and carbon sequestration efforts. The small amount of unexplained variation (9%) might be due to differences in tree form, species diversity, and stand age, which can influence the distribution of biomass within a stand (Simon et al. 2018; Hossain et al. 2020; Miah et al. 2023).

Stand density and biomass carbon

Stand density, measured as the number of trees per hectare, is another important structural attribute of forests that can influence biomass carbon. Figure 4.D shows the relationship between stand density and biomass carbon with the regression equation $y = 0.7044x - 399.7$ and $R^2 = 0.6175$. This indicates that 62% of the variation in biomass carbon is related to stand density. While this relationship is still significant, it is weaker than those observed for tree height, DBH, and basal area. Stand density can influence competition among trees for resources such as light, water, and nutrients, which in turn affects growth rates and biomass accumulation. Higher stand densities might not always lead to higher biomass carbon if competition for resources, such as light, water, and nutrients, becomes too intense among trees, leading to stunted growth, lower biomass accumulation and increased mortality (Scherer et al. 2023). Conversely, lower densities might reduce competition but also limit the total biomass that can be supported in a given area (Hossain et al. 2020). The 38% of unexplained variation suggests that stand density alone is not a sufficient predictor of biomass carbon, and that factors like species composition, stand age, and management practices must also be considered.

The interplay between tree diversity and biomass carbon

Figure 5 presents the relationship between tree biomass carbon and two diversity indices: the Shannon-Wiener diversity index and the Margalef richness index. These indices are widely used to assess biodiversity within ecological communities, and their relationship with biomass carbon offers insights into how biodiversity might influence carbon storage in forest ecosystems.

Diversity index and biomass carbon

Figure 5.A illustrates the relationship between the Shannon-Wiener diversity index and biomass carbon. The regression equation $y=109.72x - 45.844$ and the coefficient of determination $R^2 = 0.44$ indicate a positive correlation, with approximately 45% of the variation in biomass carbon explained by the Shannon-Wiener diversity index. This

suggests that higher biodiversity, as measured by the Shannon-Wiener index, is associated with greater biomass carbon storage. The Shannon-Wiener index accounts for both species richness and evenness, meaning that more diverse and evenly distributed species communities tend to support higher levels of biomass (Rahman et al. 2018). However, with 55% of the variation left unexplained, it is clear that while biodiversity is an important factor, other variables such as environmental conditions, species-specific traits, and forest management practices also significantly influence biomass carbon.

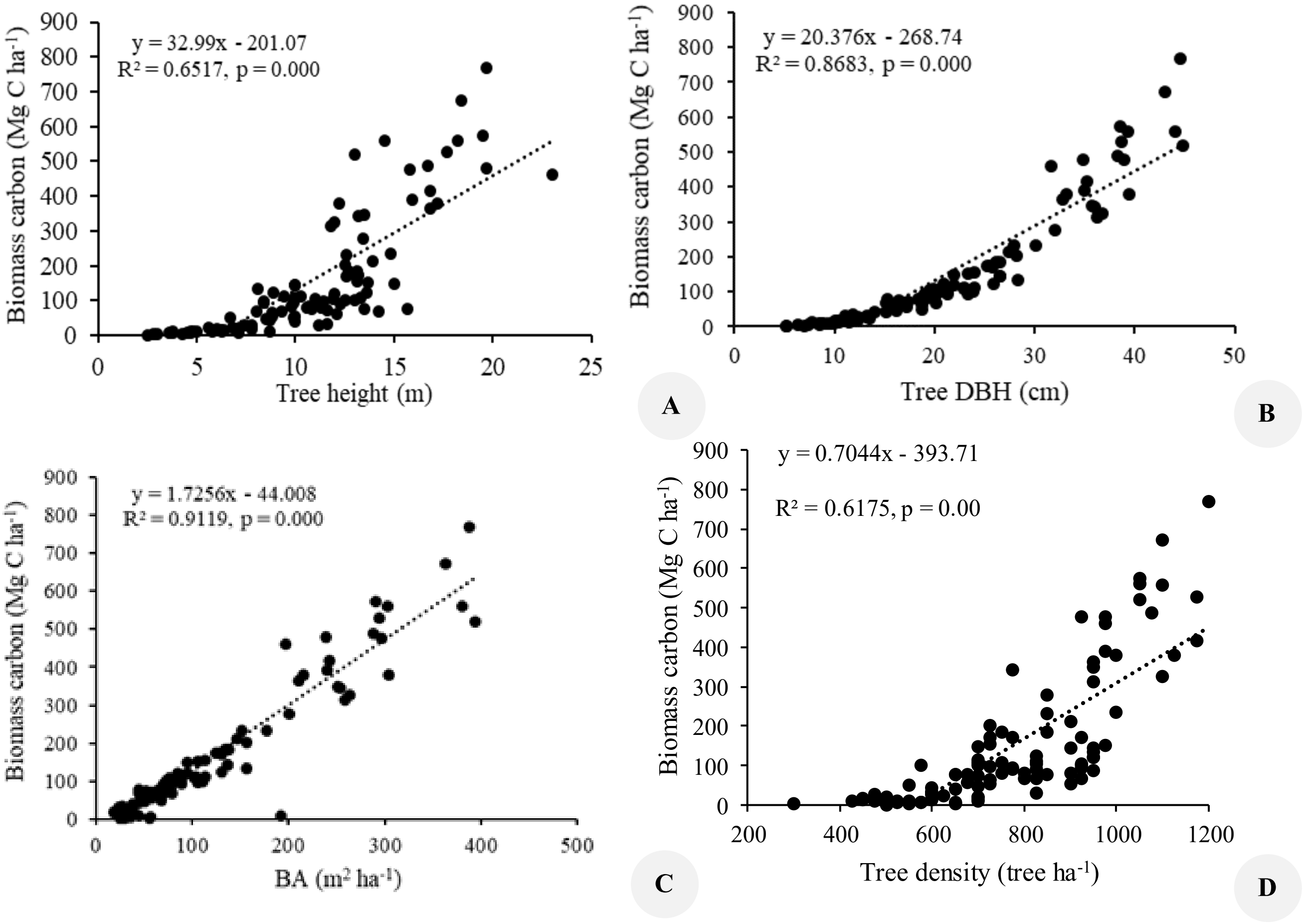

Figure 4. Relationship between tree biomass carbon and stand structure in term of: A. Tree height; B. Tree DBH; C. Basal area; and D. Stand density

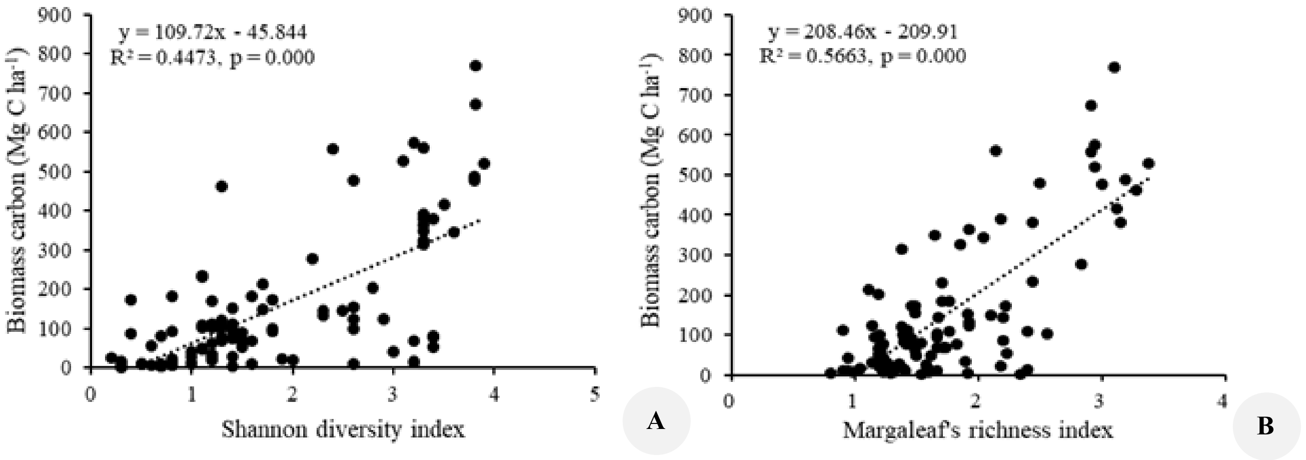

Figure 5. Relationship between tree biomass carbon and A. Shannon-Weiner diversity index; B. Margaleaf's richness index

Richness index and biomass carbon

Figure 5.B examines the relationship between the Margalef richness index and biomass carbon, showing a regression equation of y= 208.46x - 209.91 with an R^2 = 0.56. This indicates a stronger correlation compared to the Shannon-Wiener index, with about 57% of the variation in biomass carbon explained by species richness alone. The Margalef index specifically measures species richness, reflecting the number of different species within a community. The stronger relationship here suggests that species richness is a critical component of biomass carbon storage, potentially because a greater variety of species can lead to more efficient resource utilization, higher productivity, and, consequently, more biomass accumulation. However, similar to the Shannon-Wiener index, the remaining 43% of unexplained variation highlights the complexity of the factors that govern biomass carbon storage in forests (Hossain et al. 2020).

The results of this study emphasize the critical role of tree DBH (diameter at breast height) and basal area as primary predictors of biomass carbon in forest stands. These structural parameters, alongside tree height and stand density, offer significant insights into how forest composition influences carbon storage. The strong correlations observed for DBH and basal area indicate that maintaining or enhancing these attributes through sustainable forest management practices could be pivotal in maximizing carbon sequestration in forests. Nonetheless, the unexplained variation in each relationship highlights the inherent complexity of forest ecosystems and underscores the need for a comprehensive approach that considers multiple factors—including species diversity, environmental conditions, and stand dynamics—in efforts to boost forest carbon storage and mitigate climate change.

We also found that biodiversity, whether assessed through species richness or a combination of richness and evenness, plays a substantial role in determining biomass carbon levels in forest ecosystems (Rahman et al. 2018). The stronger correlation observed with the Margalef richness index suggests that species richness may have a more direct impact on biomass carbon than overall diversity captured by the Shannon-Wiener index. These findings reinforce the importance of conserving biodiversity, not only for its intrinsic value but also for its crucial role in enhancing ecosystem services like carbon sequestration (Kongsager et al. 2013). However, the considerable unexplained variation in both models indicates that biodiversity is just one component of a larger, intricate system. Future research should integrate additional ecological and environmental factors that contribute to biomass carbon storage, aiming to develop more comprehensive models capable of better-predicting carbon dynamics in diverse forest ecosystems.

This study underscores the intricate interactions between native and exotic species within the CWS, with a few dominant species significantly influencing the forest's ecological balance. These findings highlight the urgent need for targeted conservation strategies to safeguard native biodiversity and maintain the ecological integrity of the reserve (Ali et al. 2022). Future research should prioritize long-term monitoring of these species and assess the effectiveness of management practices in enhancing biodiversity and ecosystem resilience (Mitra et al.2023). Similarly, while structural attributes such as DBH and basal area are reliable indicators of biomass carbon, the complexity of forest ecosystems necessitates a holistic approach that incorporates various factors, including biodiversity (Scherer et al. 2023), environmental conditions Teets et al. (2023), and stand dynamics, to optimize carbon storage and address climate change (Hossain et al. 2020). Future studies should aim to incorporate additional ecological and environmental variables to refine models predicting carbon dynamics across diverse forest ecosystems.

ACKNOWLEDGEMENTS

We are thankful to The Divisional Forest Officer, Chattogram South Forest Division, Bangladesh for providing the necessary support during the fieldwork, and also grateful to the Institute of Forestry and Environmental Sciences for lab and library facilities to conduct the work properly.

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