

The Carbon Sequestration Potential of the Dibudalan Mountain Forest Reserve, Philippines

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Abstract

The Dibudalan Mountain Forest Reserve (DMFR) in Aurora, Philippines, is a tropical secondary forest characterized by a varied tree species and considerable carbon sequestration potential. Using 13 permanent quadrats along two belt transects, tree composition, biomass and carbon stock were assessed. A Shannon–Wiener diversity index of 3.543 was calculated from a total sampling population of 444 trees representing 57 species and 31 families, indicating a highly diverse forest status of the study area. A large amount of sequestered carbon that substantially contributed to the above-ground biomass was collectively concentrated in a few trees with large-diameter trunks, particularly *Lagerstroemia piriformis*, *Xanthostemon philippinensis*, *Wrightia pubescens*, and *Artocarpus odoratissimus*. The notable total carbon stock across quadrats, averaging 250.95 tC/ha reflects the stand's different structure and disturbance history. The ecological importance of the DMFR highlights the dominance of endemic and vulnerable species. Results underscore the need to implement forest management strategies that enhance the protection of high-biomass trees while sustaining biodiversity, safeguarding ongoing carbon sequestration and promoting ecosystem resilience.

Profile

Protected area

Dibudalan Mountain

Forest Reserve

Country

Philippines

Introduction

Forests are more than just a collection of trees, they are the world's most significant carbon sink because of their exceptional ability to absorb carbon from the atmosphere. However, the efficiency of sequestration depends on the structure, composition and biomass of the tree communities they harbour.

The Dibudalan Mountain Forest Reserve (DMFR) lies along the central–eastern section of the Sierra Madre Mountain Range in the Philippines and represents a distinctive forest ecosystem composed of diverse tree species uniquely adapted to ultramafic soils. This rare ecological system of the DMFR supports high biodiversity but remains highly sensitive to disturbance. In previous years, the increasing anthropogenic activities associated with the development of school site reservations began threatening the fragile balance of this mountain due to land-use changes.

Although carbon sequestration in tropical forests has been widely studied at both global and regional scales (Bhatia 2014; Keith et al. 2009; Fennessy & Beers 2023; Fedrigo et al. 2014), the information on carbon sequestration in the ultramafic mountain forests of Dibudalan remains scarce. This lack of data constrains the understanding of how Dibudalan Forest contributes to climate change mitigation, sustainable biodiversity conservation and sustainable forest management. Thus, addressing this knowledge gap is essential, particularly for quantifying the forest's potential carbon stock. Accordingly, this study aims to examine tree species and their taxonomic composi-

tion, richness and abundance; estimate above-ground biomass; determine carbon stored per quadrat; and assess the current conservation and endemism status of the forest. Field data were scientifically collected from the systematically established quadrats along modified transect belts. Trees with a Diameter at Breast Height (DBH) of 5 cm and above were measured, and biomass was estimated using locally developed allometric equations. A total of 444 sampling trees representing 57 species across 31 families were recorded with a Shannon index of 3.543, demonstrating a highly significant level of species diversity in the province.

A small number of mature species, such as *Lagerstroemia piriformis*, *Xanthostemon philippinensis* and *Wrightia pubescens*, contributed disproportionately to the total carbon stock of 250.95 tC/ha. In contrast, smaller species, though contributing less to biomass, were crucial for sustaining species richness, forest structures and resilience. The conservation assessment revealed a remarkable prevalence of endemic species (70.27%), underscoring the ecological significance of the DMFR and the urgency of coherent forest management.

In general, the study provides a comprehensive baseline for sustainable forest management by bringing together all the information on species composition, potential biomass stocks and conservation status. The findings led us to a vibrant conservation plan for the DMFR's continued service as a climate regulator and biodiversity protector.

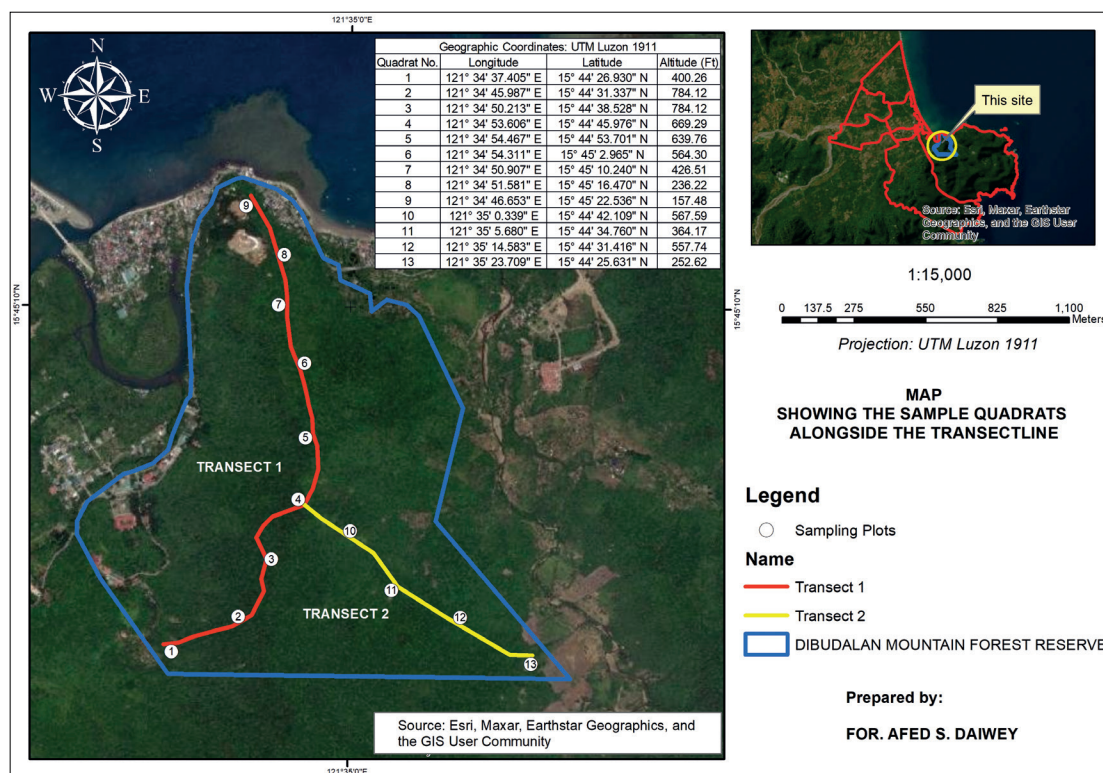


Figure 1 – Map overview of the Dibudalan Mountain Forest Reserve.

Methodology

Study site

The study was located at the Dibudalan Mountain Forest Reserve (DMFR), proclaimed under Proclamation No. 87, s. 1966 and declared as the school site civil reservation of the Aurora State College of Technology (ASCOT) through Proclamation No. 559, s. 1995 (Figure 1). The DMFR is geographically situated in the municipality of Baler, Aurora Province (Daiwey et al. 2024), which is historically known as the birthplace of President Manuel L. Quezon and the last Spanish garrison in the Philippines (Angara 2007). The DMFR lies along the Sierra Madre Mountain Range (SMMR), one of the world's ecologically vital regions, encompassing the nine eastern provinces of Luzon from Cagayan to Quezon (Ploeg et al. 2003). Dibudalan Forest supports diverse floristic species that play crucial roles in carbon sequestration, maintaining ecological stability and protecting habitat integrity. However, since its classification as a school site reservation, the DMFR has been under public pressure to facilitate the construction of ASCOT infrastructures and other human needs (Angara 2022). Such land-use change altered the forest structure, reduced potential biomass stocks and jeopardized the forest's long-term capacity to act as a carbon sink. This event drove the author to initiate this study to determine the current carbon stock of the DMFR and as a response also to the global demand of the World Health Organization (WHO) to all countries, through the United Nations Framework Convention on Climate Change (UNFCCC), to assess

their contributions to carbon offset and evaluate approaches that control carbon dioxide accumulation in the atmosphere.

Data gathering and assessment

Two modified belt-transect lines and 13 quadrats were established as baseline plots for tree identification and estimation of the carbon sequestered. The first transect (T1) measured 2,000 m in length, while the second transect (T2) measured 1,000 m long. T2 is shorter than T1 because of the narrower configuration in the southern portion of the study area. T2 was added to ensure a representative sampling distribution within the forest reservation.

The first transect has 9 quadrats established at the very start of the transect line, with grid coordinates of 121° 34' 37.405" E and 15° 44' 26.930" N. The remaining quadrats of T1 were systematically distributed at 250 m intervals up to its endpoint. T2 has only 4 quadrats started at Quadrat 10, with grid coordinates of 121° 35' 0.339" E and 15° 44' 42.109" N, and then followed by the rest.

The 20 m x 20 m plot sample size and 250 m intervals applied in the study were adapted from the standard manual and guidelines on biodiversity assessment (DAO-BMB 2024), as this plot size provides the best balance in assessing tree species diversity and biomass in the tropical forest ecosystem of the Philippines.

The transects followed the existing trails for the purposes of convenience. However, the quadrats were placed at least 3 m away from the trails to minimize potential bias, as the trails were characterized by open

space resulting from soil compaction, disturbed vegetation and altered species distribution caused by human activities and animal movement. Placing the quadrats slightly away from these disturbances ensured more accurate data collection that reflects the natural conditions of the DMFR. This approach enhanced the study's reliability by providing a more precise assessment of carbon stocks free from trail-related factors. The established quadrats served as permanent monitoring stations for assessing and revalidating the existing tree assets and woody vegetation of the DMFR (Obemio et al. 2016).

Throughout the evaluation, a portable Global Positioning System (GPS) receiver was used to obtain the coordinates of each quadrat. Subsequently, the classification of trees within each quadrat was scientifically identified and revalidated. The circumference of the observed trees was measured using a tape measure and converted to diameter by dividing it by π (3.1416) a conventional conversion factor. The diameters of each species were summed to obtain cumulative values that represent the sum of individual measurements across all sampling units. This cumulative diameter will serve as a multiplier to calculate the carbon sequestered.

However, measurements were limited to trees with a DBH of ≥ 5 cm measured at 1.3 m above ground level. This method follows the forestry and biodiversity assessment standard protocols (Chave et al. 2005). Trees with a DBH of < 5 cm were excluded due to their high mortality rates and negligible contribution to forest biomass and structure. Trees with unique morphological features were assessed following the framework developed by Husch et al. (2003). Likewise, the expertise of a dendrologist is vital in revalidating trees with uncertain identities before carbon stock calculation.

The authenticity of taxonomic classification, conservation status and endemism of identified flora was evaluated by comparing them in the existing online databases of the International Union for Conservation of Nature Red List of Threatened Species (IUCN 2023), the updated national list of threatened Philippine plants (DAO 2017) and the Philippine digital flora database of Leonardo L. Co. (Pelser et al. 2011).

Data Analysis

Species richness and abundance were analysed using field-collected data. Species richness was determined by counting the number of species within each quadrat, while abundance was measured by the number of individual trees per species found within the same area. On the other hand, the species diversity was interpreted and calculated following the Shannon-Weiner diversity index formula utilized by Chetry et al. (2025), wherein:

$$H' = - \sum_{i=1}^s P_i \ln P_i$$

H' = Shannon-Weiner diversity index

$\sum$ = summation over all species in the country

P_i = proportion of individuals belonging to i

$\ln$ = natural logarithm

The following formula was adapted according to Dave et al. (2025)

$$p_i = n_i / N$$

n_i = number of individuals of species i

N = total number of individuals of all species

Interpretation reminder of H' :

< 1.0 : Low diversity

$1.0 - 3.0$: Moderate diversity

> 3.0 : High diversity

In the calculation of carbon sequestration, a series of local allometric equations using the DBH of various tree species as a reference was employed. The first step is to calculate the potential Above Ground Biomass (AGB) using the equation developed by Banatiela et al. (2007). The formula applied is

$$Y \text{ (kg)} = 0.342 (\text{dbh})^{2.073}$$

Y = the above-ground biomass in kg.

dbh = the measured diameter at 1.3 m above the ground in cm.

The second step is the calculation of carbon stock using the foundational empirical basis equation by Brown (1997), which was adapted and developed in the Philippines by Lasco and Pulhin (2003) after supporting the national use of 0.45 for Philippine tropical forest conditions. The formula applied is

$$C \text{ (kg)} = \text{AGB} * 45\%$$

C = carbon stock

AGB = computed above-ground tree biomass

45% = carbon content of tree biomass

The 45% figure indicates that the tree contains 0.45 kg of carbon per 1 kg of dry biomass. The kilogram (kg) unit was converted to tons of carbon per hectare (tC/ha) by dividing the computed carbon value by 1,000 a common conversion factor in the country. This proportion is commonly employed in carbon stock assessments of tropical forests of the Philippines. Further, the Intergovernmental Panel on Climate Change (IPCC 2006) standards allow a 47% tolerance for tropical forests' Carbon Fraction (CF) values. However, the Philippines is prepared to employ 45% because local researchers discovered that the average carbon content of tropical hardwoods is about 43%–47%, not 50% (Lasco & Pulhin 2003).

Table 1 – Tree species composition, relative proportion (π_i) and Shannon–Wiener diversity index (H') values of trees in the DMFR.

No.	Species	Family	Population (ni)	π_i	$\ln(\pi_i)$	$-\pi_i \ln(\pi_i)$	Status
1	<i>Mangifera altissima</i> Blanco	Anacardiaceae	16	0.036	-3.323	0.120	NT
2	<i>Mangifera indica</i> L.	Anacardiaceae	1	0.002	-6.096	0.014	LC
3	<i>Xylopia brasiliensis</i> Spreng.	Annonaceae	3	0.007	-4.997	0.034	U
4	<i>Alstonia macrophylla</i> Wall. ex G.Don	Apocynaceae	6	0.014	-4.304	0.058	U
5	<i>Vitex</i> spp.	Apocynaceae	4	0.009	-4.710	0.042	U
6	<i>Ilex cumingiana</i> Rolfe	Aquifoliaceae	5	0.011	-4.486	0.051	U
7	<i>Celtis philippensis</i> Blanco	Araliaceae	8	0.018	-4.016	0.072	U
8	<i>Acanthophoenix rubra</i> (Bory) H.Wendl.	Arecaceae	1	0.002	-6.096	0.014	U
9	<i>Cordyline australis</i> (G.Forst.) Endl.	Asparagaceae	4	0.009	-4.710	0.042	LC
10	<i>Canarium odontophyllum</i> Miq.	Burseraceae	3	0.007	-4.997	0.034	T
11	<i>Celtis paniculata</i> (Endl.) Planch.	Cannabaceae	1	0.002	-6.096	0.014	U
12	<i>Tristaniaopsis decorticata</i> (Merr.)	Cannabaceae	1	0.002	-6.096	0.014	U
13	<i>Casuarina equisetifolia</i> L.	Casuarinaceae	2	0.005	-5.403	0.024	LC
14	<i>Gmelina arborea</i> Roxb. ex Sm.	Clusiaceae	7	0.016	-4.150	0.065	LC
15	<i>Syzygium simile</i> (Merr.) Merr.	Combretaceae	17	0.038	-3.263	0.125	DD
16	<i>Dillenia luzoniensis</i> Merr.	Dilleniaceae	2	0.005	-5.403	0.024	CE
17	<i>Hopea philippinensis</i> Dyer	Dipterocarpaceae	1	0.002	-6.096	0.014	E
18	<i>Parashorea malaanonan</i> (Blanco) Merr.	Dipterocarpaceae	7	0.016	-4.150	0.065	V
19	<i>Pterocarpus rotundifolius</i>	Dipterocarpaceae	1	0.002	-6.096	0.014	U
20	<i>Shorea gisok</i> Foxw.	Dipterocarpaceae	11	0.025	-3.698	0.092	E
21	<i>Lagerstroemia speciosa</i> (L.) Pers.	Euphorbiaceae	8	0.018	-4.016	0.072	LC
22	<i>Macaranga grandifolia</i> (Blanco) Merr.	Euphorbiaceae	2	0.005	-5.403	0.024	U
23	<i>Azela rhomboidea</i> Fern. – Vill.	Fabaceae	2	0.005	-5.403	0.024	V
24	<i>Beilschmiedia tawa</i> (A.Cunn.) Kirk	Fabaceae	1	0.002	-6.096	0.014	U
25	<i>Polyscias nodosa</i> (Blume) Seem.	Fabaceae	1	0.002	-6.096	0.014	U
26	<i>Lithocarpus solerianus</i> (Vidal) Rehder	Fabaceae	8	0.018	-4.016	0.072	U
27	<i>Anthocleista grandiflora</i> Gilg	Gentianaceae	6	0.014	-4.304	0.058	U
28	<i>Calophyllum obliquinervium</i> Merr.	Guttiferae	1	0.002	-6.096	0.014	U
29	<i>Cratogeomys sumatranum</i> (Jack) Blume	Hypericaceae	2	0.005	-5.403	0.024	U
30	<i>Lagerstroemia piriiformis</i> Blume	Lythraceae	33**	0.074	-2.599	0.193	U
31	<i>Shorea polysperma</i>	Malvaceae	12	0.027	-3.611	0.098	E
32	<i>Sterculia foetida</i> L.	Malvaceae	2	0.005	-5.403	0.024	LC
33	<i>Artocarpus blancoi</i> (Elmer) Merr.	Meliaceae	22****	0.050	-3.005	0.149	V
34	<i>Artocarpus odoratissimus</i> Blanco	Meliaceae	51*	0.115	-2.164	0.249	LC
35	<i>Dysoxylum alliaceum</i> (Blume) Blume.	Meliaceae	10	0.023	-3.793	0.085	U
36	<i>Ficus ampelos</i> Burm.f.	Meliaceae	3	0.007	-4.997	0.034	U
37	<i>Ficus variegata</i> Blume	Meliaceae	12	0.027	-3.611	0.098	LC
38	<i>Pterocarpus indicus</i> Willd.	Meliaceae	5	0.011	-4.486	0.051	V
39	<i>Sterculia rubiginosa</i> Vent.	Meliaceae	5	0.011	-4.486	0.051	U
40	<i>Ficus balete</i> Merr.	Moraceae	1	0.002	-6.096	0.014	U
41	<i>Myristica philippensis</i> Lam.	Myristicaceae	3	0.007	-4.997	0.034	V
42	<i>Acacia auriculiformis</i> A.Cunn. ex Benth.	Myrtaceae	2	0.005	-5.403	0.024	LC
43	<i>Swietenia macrophylla</i> King	Myrtaceae	16	0.036	-3.323	0.120	LC
44	<i>Syzygium garciae</i> (Merr.) Merr.	Myrtaceae	8	0.018	-4.016	0.072	U
45	<i>Syzygium leucoxylon</i> Korth.	Myrtaceae	26***	0.059	-2.838	0.166	LC
46	<i>Terminalia catappa</i> L.	Myrtaceae	1	0.002	-6.096	0.014	LC
47	<i>Wrightia pubescens</i> (Blanco) Ngan	Myrtaceae	6	0.014	-4.304	0.058	U
48	<i>Xanthostemon philippinensis</i> Merr.	Myrtaceae	20*****	0.045	-3.100	0.140	E
49	<i>Pandanus exaltatus</i>	Pandanaceae	12	0.027	-3.611	0.098	U
50	<i>Drypetes grandifolia</i> (C.B.Rob.)	Putranjivaceae	14	0.032	-3.457	0.109	U
51	<i>Hypobathrum racemosum</i> (Roxb.)	Rubiaceae	9	0.020	-3.899	0.079	U
52	<i>Morinda citrifolia</i> L.	Rubiaceae	2	0.005	-5.403	0.024	LC
53	<i>Melicope vieillardii</i> (Baill.) Guillaumin	Rutaceae	1	0.002	-6.096	0.014	U
54	<i>Palaquium dubardii</i> Elmer	Sapotaceae	3	0.007	-4.997	0.034	V
55	<i>Palaquium luzoniense</i> (Fern–Vill.) Vidal	Sapotaceae	5	0.011	-4.486	0.051	V
56	<i>Palaquium merrillii</i> Dubard	Sapotaceae	19	0.043	-3.151	0.135	V
57	<i>Prasoxylon alliaceum</i> (Blume) M.Roem.	Verbenaceae	9	0.020	-3.899	0.079	U
TOTAL			31	444			
Shannon Diversity Index (H')						3.543	

, *, ***** = Top 5 species with highest population and diversity index

U=unknown, LC=Least Concern, V=Vulnerable, E=endangered, DD=data deficit, NT=near threatened, T=threatened, CE=critically endangered.

n_i =number of individuals of species

π_i (π) = proportional abundance of species i in the community. It is calculated as $\pi_i = n_i/N$, where n_i is the number of individuals of that species (e.g. 16 for *Mangifera altissima*), and N is the total number of individuals across all species which is 444. In the table, $\pi_i = 0.036$ means that this species makes up about 3.6% of the total population.

$\ln(\pi_i)$ = natural logarithm (base e) of π_i . This transforms the proportion into a logarithmic scale, which is used to measure evenness or rarity in diversity calculations. In the table, $\ln(\pi_i) = -3.323$, indicating that this is a relatively rare species (negative value since $\pi_i < 1$).

$-\pi_i \ln(\pi_i)$ = negative product of π_i and $\ln(\pi_i)$ and represents each species' contribution to the overall Shannon diversity index. This term penalizes uneven distributions (e.g., dominant vs. rare species). In the table, $-\pi_i \ln(\pi_i) = 0.120$, a small value suggesting a low contribution from this rare species.

Table 2 – Composition, relative abundance and contribution to Shannon–Wiener diversity of tree species in the DMFR.

Abundance Category	Population Class (ni)	Richness (Community)	Evenness
Low	1–5	31	0.32
Moderate	6–19	17	0.6
High	≥ 20	9	0.88

Given that the study was conducted locally, the author used the local allometric equations published by Banaticla et al. (2007) and Lasco and Pulhin (2003) in estimating the above-ground biomass and carbon stocks of the DMFR, as the empirical data were collected in the Philippines. This equation is suitable to use as it provides greater accuracy and relevance than the Asian setting used by Pragasan (2022) and other global models, which may not reflect the local growth conditions of tree species in the Philippines. These equations enhance the credibility of the DMFR's carbon stock estimates, which align with national forestry research standards and provide reliable data for ecological assessment and carbon accounting in Philippine forests.

Results

Tree inventory assessment

Table 1 shows the species taxonomic composition, relative abundance and parameters used in calculating the Shannon–Wiener diversity index (H') of trees inventoried in the 13 sampling quadrats established in the Dibudalan Mountain Forest Reserve. A total of 444 individual trees, representing 57 species from 31 families were recorded. The five most abundant species (marked with asterisks) registered the highest relative abundance values and the most significant numerical contributions to H' .

The total Shannon–Wiener diversity index was computed as 3.543. This H' index was calculated based on the proportional contributions of each species, from low to high relative abundance, in the sample plots.

Table 2 presents the composition, relative abundance and contribution to Shannon–Wiener diversity of tree species in the DMFR. As the number of tree species in the DMFR increased, so did the evenness of the species. Species with low abundance (1–5 individuals) exhibited low evenness ($E = 0.32$), while possessing the maximum species richness (31 species), suggesting an unequal distribution of individuals across several rare species. Moderate-abundance species (6–19 individuals) exhibited moderate evenness ($E = 0.60$), but extremely abundant species (≥ 20 individuals) showed high evenness ($E = 0.88$), indicating a more equitable distribution of individuals among a limited number of dominating species.

Baseline carbon sequestration

Table 3 presents the estimated value of above-ground biomass (AGB) and carbon stock based on

DBH measurements. A total of 57 tree species were examined, and each showed significant variation in both AGB and carbon storage. The total carbon stock of all sampled trees is 250.949 tC/ha.

The five tree species with the highest cumulative carbon stock that collectively contribute to the total carbon stock are *Lagerstroemia piriformis* (57.931 tC/ha), *Xanthostemon philippinensis* (45.473 tC/ha), *Wrightia pubescens* (32.362 tC/ha), *Artocarpus odoratissimus* (29.402 tC/ha) and *Palaquium merrillii* (12.386 tC/ha). These plants typically have bigger DBH, which was used to measure carbon stock.

On the other hand, trees with the lowest carbon stock contribution were *Pandanus exaltatus* (0.004 tC/ha), *Pterocarpus indicus* (0.006 tC/ha), *Morinda citrifolia* (0.015 tC/ha), *Tristaniaopsis decorticata* (0.015 tC/ha) and *Mangifera indica* (0.017 tC/ha). These types of trees are characterized by smaller DBH, resulting in lower biomass accumulation.

The data show a positive relationship between tree size (DBH) and carbon stock, wherein the largest trees contribute most to the forest's carbon pool. A strong positive relationship means that large-diameter trees contribute disproportionately to the total forest carbon stocks and serve as the primary reservoirs of carbon within the forest ecosystem. This observation on the positive relationship between DBH and carbon stock aligns with the study results of Hasan et al. (2025), who argued that carbon stock increases as DBH increases. Whereas medium-sized trees, such as *Casuarina equisetifolia* (0.222 tC/ha), *Gmelina arborea* (0.365 tC/ha) and *Swietenia macrophylla* (0.197 tC/ha), contributed moderately to the total carbon stored, species with smaller DBH contributed little to the total carbon volume.

Total carbon stock varied considerably across the 13 quadrats (Figure 2), ranging from 3.67 to 78.39 tC/ha. Quadrats 2, 4 and 3 recorded the highest carbon stocks, with values of (78.39 tC/ha), (70.30 tC/ha) and (59.14 tC/ha) respectively. Moderate carbon stocks were observed in Quadrats 1, 5, 6, 7, 8 and 9, ranging from 25.32 to 54.28 tC/ha. In contrast, Quadrats 10 to 13 exhibited notably low carbon stocks, averaging only ≤ 6 tC/ha, indicating

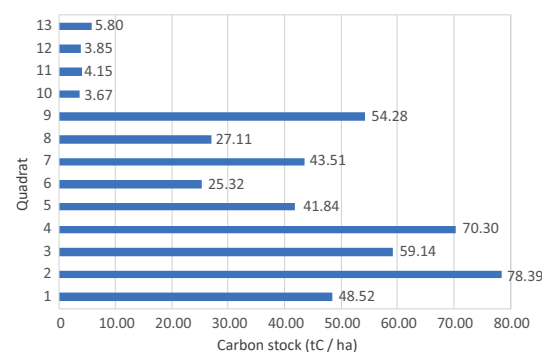


Figure 2 – Total carbon stock (tC/ha) recorded per quadrat in the study area.

Table 3 – Carbon stocks and Above-ground Biomass (AGB) Estimates of tree species based on DBH (diameter at breast height) measurements.

Species	DBH	AGB (kg/sp.)	Carbon Stock (kg)	Carbon Stock (tC/ha)
<i>Acacia auriculiformis</i> A.Cunn. ex Benth.	11.94	58.398	26.279	0.026
<i>Acanthophoenix rubra</i> (Bory) H.Wendl.	10.5	44.803	20.162	0.020
<i>Afzelia rhomboidea</i> Fern.-Vill.	38.2	650.991	292.946	0.293
<i>Alstonia macrophylla</i> Wall. ex G.Don	21.49	197.505	88.877	0.089
<i>Anthocleista grandiflora</i> Gilg	21.49	197.505	88.877	0.089
<i>Artocarpus blancoi</i> (Elmer) Merr.	179.05	16,011.658	7,205.246	7.205
<i>Artocarpus odoratissimus</i> Blanco	352.85	65,338.538	29,402.342	29.402 v
<i>Beilschmiedia tawa</i> (A.Cunn.) Kirk	14.8	91.214	41.046	0.041
<i>Calophyllum obliquinervium</i> Merr.	14.32	85.220	38.349	0.038
<i>Canarium odontophyllum</i> Miq.	16.71	117.307	52.788	0.053
<i>Casuarina equisetifolia</i> L.	33.42	493.580	222.111	0.222
<i>Celtis paniculata</i> (Endl.) Planch.	9.55	36.771	16.547	0.017
<i>Celtis philippensis</i> Blanco	10.03	40.685	18.308	0.018
<i>Cordyline australis</i> (G.Forst.) Endl.	19.1	154.718	69.623	0.070
<i>Cratoxylum sumatranum</i> (Jack) Blume	11.94	58.398	26.279	0.026
<i>Dillenia luzoniensis</i> Merr.	16.71	117.307	52.788	0.053
<i>Drypetes grandifolia</i> (C.B.Rob.)	147.06	10,647.193	4,791.237	4.791
<i>Dysoxylum alliaceum</i> (Blume) Blume.	176.18	15,485.141	6,968.313	6.968
<i>Ficus ampelos</i> Burm.f.	16.23	110.465	49.709	0.050
<i>Ficus baletae</i> Merr.	14.32	85.220	38.349	0.038
<i>Ficus variegata</i> Blume	84.03	3,337.469	1,501.861	1.502
<i>Gmelina arborea</i> Roxb. ex Sm.	42.49	811.998	365.399	0.365
<i>Hopea philippinensis</i> Dyer	22.44	216.137	97.261	0.097
<i>Hypobathrum racemosum</i> (Roxb.)	102.65	5,053.758	2,274.191	2.274
<i>Ilex cumingiana</i> Rolfe	11.94	58.398	26.279	0.026
<i>Lagerstroemia piriformis</i>	489.4	128,736.017	57,931.208	57.931 i
<i>Lagerstroemia speciosa</i> (L.) Pers.	41.06	756.284	340.328	0.340
<i>Lithocarpus solerianus</i> (Vidal) Rehder	142.76	10,012.346	4,505.556	4.506
<i>Macaranga grandifolia</i> (Blanco) Merr.	15.76	103.836	46.726	0.047
<i>Mangifera altissima</i> Blanco	177.62	15,747.260	7,086.267	7.086
<i>Mangifera indica</i> L.	9.55	36.771	16.547	0.017****
<i>Melicope vieillardii</i> (Baill.) Guillaumin	48.22	1,055.426	474.942	0.475
<i>Morinda citrifolia</i> L.	9.07	33.062	14.878	0.015****
<i>Myristica philippensis</i> Lam.	17.19	124.361	55.962	0.056
<i>Palaquium dubardii</i> Elmer	17.19	124.361	55.962	0.056
<i>Palaquium luzoniense</i> (Fern-Vill.) Vidal	26.74	310.787	139.854	0.140
<i>Palaquium merrillii</i> Dubard	232.52	27,524.347	12,385.956	12.386 vi
<i>Pandanus exaltatus</i>	4.77	8.739	3.933	0.004*
<i>Parashorea malaanonan</i> (Blanco) Merr.	196.72	19,460.385	8,757.173	8.757
<i>Polyscias nodosa</i> (Blume) Seem.	65.41	1,985.598	893.519	0.894
<i>Prasoxylum alliaceum</i> (Blume) M.Roem.	11.94	58.398	26.279	0.026
<i>Pterocarpus indicus</i> Willd	5.73	12.753	5.739	0.006**
<i>Pterocarpus rotundifolius</i>	72.57	2,462.812	1,108.265	1.108
<i>Shorea astylosa</i>	184.3	17,000.629	7,650.283	7.650
<i>Shorea polysperma</i>	13.85	79.437	35.746	0.036
<i>Sterculia foetida</i> L.	35.33	553.843	249.229	0.249
<i>Sterculia rubiginosa</i> Vent.	130.83	8,354.614	3,759.576	3.760
<i>Swietenia macrophylla</i> King	31.51	436.902	196.606	0.197
<i>Syzygium garciae</i> (Merr.) Merr.	218.68	24,235.034	10,905.765	10.906
<i>Syzygium leucoxylon</i> Korth.	102.18	5,005.152	2,252.318	2.252
<i>Syzygium simile</i> (Merr.) Merr.	12.41	63.345	28.505	0.029
<i>Terminalia catappa</i> L.	40.58	738.168	332.175	0.332
<i>Tristaniaopsis decorticata</i> (Merr.)	9.07	33.062	14.878	0.015***
<i>Vitex</i> spp	14.32	85.220	38.349	0.038
<i>Wrightia pubescens</i> (Blanco) Ngan	369.56	71,916.659	32,362.497	32.362 iii
<i>Xanthostemon philippinensis</i> Merr.	435.45	101,050.576	45,472.759	45.473 ii
<i>Xylopia brasiliensis</i> Spreng.	11.94	58.398	26.279	0.026
TOTAL				250.949

i, ii, iii, iv, v, vi = Species with higher carbon stocks (tC/ha).

*, **, *** = Top 5 species with the lowest carbon stock (tC/ha). Note that one * indicates the first species with the lowest carbon stock, two * indicates the second species with the lowest carbon stock, three * indicates the 3rd species with the lowest carbon stock and so on.

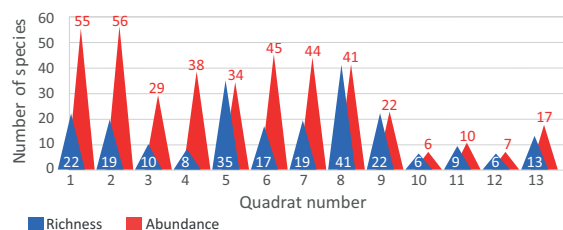


Figure 3 – Spatial variation in species richness and individual abundance across sample quadrats in the study area.

minimal biomass accumulation in these areas due to natural disasters, anthropogenic activities like illegal cutting of trees and traditional charcoal production. The discrepancies in carbon stock among the 13 quadrats are due to variances in vegetation structure, stand maturity, and species mix.

Species richness and abundance

Figure 3 showed noticeable spatial variation in species richness and abundance across quadrats. The highest species richness was recorded in Quadrats 8, 5, 1 and 9 (41, 34, 22 and 22 respectively), while the highest abundance index was observed in Quadrats 1 and 2 (55 and 56). Conversely, Quadrats 10–12 showed both low richness (6–9 species) and low abundance (6–10 individuals), reflecting disturbed vegetation structure.

The discrepancies among quadrats were due to the variances in vegetation and the presence of bigger trees that store more biomass. Quadrats exhibiting higher richness and abundance had moderate to high carbon stock values, indicating that structurally complex, species-diverse stands contribute more substantially to carbon storage. However, quadrats with low richness and abundance also showed low carbon stocks, signifying ecological degradation or environmental constraints on vegetation growth. This complex forest structure is largely driven by nutrient cycling within the soil, which contributes to the maintenance of a distinct microclimate that enhances biodiversity (Franklin & Spies 1991).

Conservation and endemism status

The 2023 IUCN Red List of Threatened Species revealed the endemism status of inventoried species. Figure 4 shows that most of the trees validated fell under the Unknown species (172) and Least Concern (126) categories. However, a substantial number of species were classified as Vulnerable (56) and Endangered (53). Fewer species were listed as Near Threatened (16), Data Deficient (17), Threatened (3) or Critically Endangered (1), indicating the importance of conservation of taxa within the study area.

Among the recorded species, *Shorea astylosa* and *Hopea philippinensis* Dyer are the most critically endangered, with severe population declines driven by historical overexploitation, extensive lowland forest loss, and limited natural regeneration, placing them at imminent risk of extinction. Their continued presence

suggests that the forest functions as a critical refuge and that any further degradation could result in local or total extinction of these species. Therefore, Dibudalan warrants a high conservation priority to protect its remaining biodiversity because it is not just a matter of storing carbon but also of keeping the whole web of life going.

The species composition of the DMFR was strongly dominated by endemic taxa, accounting for 312 species (Figure 5). Native non-endemic species numbered 84, while introduced species were relatively few (43). Only five species had unknown endemism status, highlighting the predominance of locally restricted flora at the site.

The abundance of endemic species indicates that the DMFR supports a highly unique biological community shaped by long-term ecological and evolutionary processes after the total logging operations (DENR 1998). The small percentage of introduced species suggests that the ecosystem has managed to withstand biological invasions. The fact that only a few species, such as *Vitex* spp., have unknown endemism status shows that Dibudalan has a high level of taxonomic work. Generally, the overwhelming dominance of endemic species emphasizes the DMFR's critical role as an endemism hub of irreplaceable biodiversity. These observations suggest that any further disturbance or habitat loss could result in disproportionate biodiversity impacts, including the potential loss of species, thereby emphasizing the importance of prioritizing the conservation and sustainable management of the area.

Discussion

The findings indicate that the Dibudalan Mountain Forest Reserve encompasses a diverse array of tree species. Table 1 demonstrates the importance of the DMFR as a safe habitat for many tree species. These various kinds of trees formed the ecological structure and composition of the forest, mostly with lower diversity indices.

The accumulated diversity index (H') value recorded illustrates that the DMFR is a highly diversified stand. The five species with the highest relative abundances and the most significant contributions to the Shannon–Wiener diversity index were *Artocarpus odoratissimus*, *Lagerstroemia piriformis*, *Syzygium leucocylon*, *Artocarpus blancoi* and *Xanthostemon philippinensis*. Among these, *Artocarpus odoratissimus* contributed the most to diversity ($H' = 0.249$), reflecting its structural dominance in the region. The dominance of these plant species is strongly influenced by their adaptability when it comes to thriving despite the edaphic stress associated with the ultramafic soils. According to Lazarus et al. (2011), ultramafic ecosystems demonstrate that soil chemistry controls plant distribution and dominance which restricts the set of metal-tolerant taxa that often account for the highest importance values in ultramafic forests. Furthermore, the ability of these stress-tolerant tree

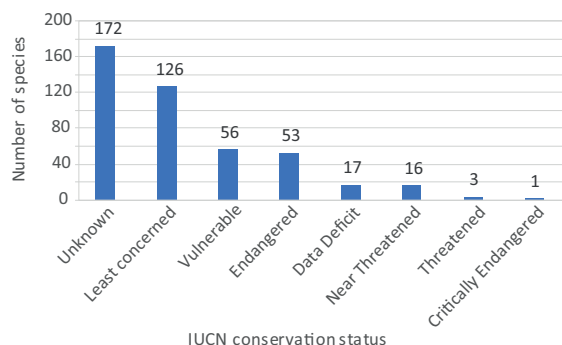


Figure 4 – Frequency distribution of recorded species according to IUCN conservation status.

species to withstand environmental stresses enables them to persist and outcompete less-adapted species, making them the key components of the forest community, particularly at elevations of at least 239 m asl or 784 ft (Figure 1). These findings were supported by the studies of Fernando et al. (2008), Lasco et al. (2001) and Whitmore (1998), which affirm that stress-tolerant taxa are distributed across the elevations of 0 – 1,219.2 m asl in lowland and lower montane secondary forests. Similar patterns of study have been observed in the ultramafic forests of the Philippines and across Southeast Asia, showing that only a minority of species thrive under such harsh soil conditions (Proctor 2003; Brady et al. 2005).

The presence of a few mature species with larger diameters is clear evidence of the DMFR's disturbance from previous natural catastrophes (extreme typhoons and lightning) and anthropogenic activities, such as illegal timber poaching and kaingin making, leading to intentional forest fires. These natural disturbances and anthropogenic activities have affected the succession process, resulting in the Dibudalan Mountain Forest being characterized as a secondary growth forest. Another factor that exacerbated the mountain's deterioration is the construction of ASCOT buildings and other infrastructures, as well as the illegal cutting of premium species by neighbouring residents for economic purposes. Such events aided stress-tolerant species in growing and competing with others while limiting the growth of late-successional and disturbance-sensitive taxa. As a result, many small-diameter trees (less than 5 cm DBH) of stress-tolerant species swiftly regenerated, thereby increasing the overall number of species while preserving forest structure for carbon sequestration.

Compared to other mountains in the Philippines and Southeast Asia, the DMFR has higher species diversity. Similar values have been documented in the tropical mountain forests of Borneo and Sumatra, where their corresponding H' typically ranges from 3.0 to 4.0, as well as in the montane and protected forest landscapes of Mt Apo (Lasco et al. 2001; Slik et al. 2015).

The dominance of low-abundant species in terms of species richness leads to low evenness, while the

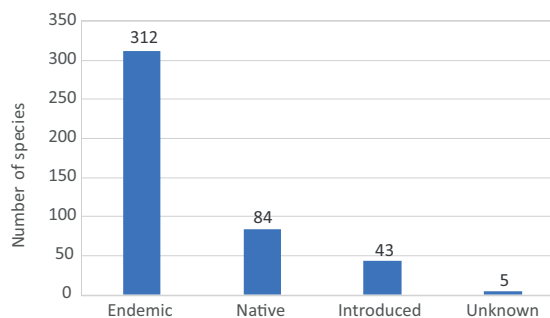


Figure 5 – Distribution of recorded species.

weakness of high-abundant mature species in terms of richness makes high evenness (Table 2). The observed increase in evenness with abundance suggests that the most common tree species in the DMFR are more evenly distributed. This helps the Dibudalan Forest stand stay stable. Odum (1971) explains in *The Fundamentals of Ecology* that ecosystems with a more even distribution of biomass and abundance among species tend to show greater stability and resistance to fluctuations, whereas systems dominated by only a few species are more vulnerable. Tilman (1996) further argues that greater species diversity and evenness can stabilize ecosystem processes by reducing fluctuations through compensatory dynamics among species. However, the poor evenness that accompanies the high richness of low-abundance species indicates that many uncommon or sparsely distributed species are present a typical feature of secondary and selectively disturbed mountain forests (Brown & Lugo 1990).

Table 3 presents a total carbon sequestered of 250.949 tC/h, demonstrating that a few mature trees of large-diameter species, such as *Lagerstroemia piriformis*, *Xanthostemon philippinensis* and *Wrightia pubescens*, are mainly contributors to carbon storage in the DMFR. This pattern was observed in both tropical and temperate forests, reflecting a common structural trend in which a few emergent and canopy species dominated the total carbon stocks despite high overall species diversity (Bhatia 2014; Brown 1997; Chave et al. 2014; Keith et al. 2009). The positive relationship between DBH and Carbon Stock emphasizes the ecological importance of conserving large-diameter trees, which store disproportionately high amounts of carbon and exhibit long residence times. In other words, a positive DBH–carbon stock relationship indicates that larger trees store more carbon and retain it for longer periods, making them vital for long-term carbon sequestration and forest stability. Along with the findings from Southeast Asian forests (Keith et al. 2009), European temperate forests (Fennessy & Beers 2023) and southeastern Australian mixed forests (Fedrigo et al. 2014), this research output reinforces the global relevance of protecting structurally dominant trees for climate regulation.

Smaller understory species, such as *Pandanus exaltatus* and *Pterocarpus indicus*, contribute less to total

carbon but play a crucial role in maintaining biodiversity and ecosystem resilience. This functional balance between carbon-dominant and diversity-supporting species is essential for preserving forest structure, habitat complexity, and ecological processes. The existence of large trees (Table 3) indicates the presence of old-growth forest remnants, which are becoming increasingly rare yet serve as long-lasting carbon repositories and help maintain ecological stability over time. These old, large trees are increasingly becoming rare due to damage from typhoons, which eventually leads to their death, and due to the illegal timber cutting by others selecting these mature trees for survival purposes. The DMFR's carbon stock of 250.95 tC/ha is within the upper range of values reported for tropical forests in the Philippines (Lasco et al. 2001; Corpuz et al. 2015).

In essence, this study demonstrates that the DMFR's carbon storage is dominated by a few large, high-biomass species, underscoring their ecological and climate-regulatory importance. Effective forest management should therefore prioritize the conservation of these carbon-dense species while maintaining overall species diversity to ensure a long-term ecosystem resilience and sustained carbon sequestration.

Conclusions

A Shannon-Weiner diversity index (H') of 3.543 shows that the DMFR is a highly diversified stand supporting highly significant tree species. A few mature species such as *Lagerstroemia piriformis*, *Xanthostemon philippinensis*, *Wrightia pubescens* and *Artocarpus odoratissimus* contribute the most to the 250.95 tC/ha total carbon sequestered. Large-diameter trees serve as key carbon reservoirs, while smaller understory species maintain biodiversity and structural complexity. Carbon stocks vary across quadrats, reflecting differences in stand maturity and disturbance, with degraded areas showing reduced biomass. DMFR management should prioritize the protection of carbon-dense species, foster the recruitment of medium-sized trees and restore disturbed areas to integrate climate mitigation with biodiversity conservation, thereby ensuring the DMFR's long-term resilience and ecological integrity.

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