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SUSTAINABLE FOREST ECOSYSTEM ASSESSMENT: PLANT DIVERSITY, BIOMASS, AND CARBON SEQUESTRATION POTENTIAL

SUMMARY

Understanding the dynamics of forest ecosystems is essential for achieving sustainability and climate-resilient development. This study aimed to assess plant diversity, biomass, and carbon sequestration potential within the dry evergreen and dry dipterocarp forests of Tat Ton National Park, northeastern Thailand. Field inventories were conducted across a 320-ha area encompassing 22 sampling plots, where 4,047 trees were measured with an average density of 12.65 trees ha^{-1}. Structural parameters and vegetation composition were analyzed to evaluate forest heterogeneity and carbon distribution. Results revealed rich species diversity and a wide variation in carbon storage, with total carbon stock estimated at 25,383.90 tC and an overall mean of 79.95 tC ha^{-1}, ranging from 59.72 to 110.24 tC ha^{-1} among plots. The coexistence of dry evergreen and dipterocarp ecosystems enhances ecological stability and strengthens the park's role as a substantial carbon sink. These findings underscore the ecological importance of

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conserving mixed forest landscapes through sustainable forest management. The study provides scientific evidence supporting climate adaptation, carbon-credit development, and Thailand's long-term pathway toward a Net Zero future.

Keywords: plant diversity, carbon sequestration, dry evergreen forest, dry dipterocarp forest, carbon credit, green economy

INTRODUCTION

Climate change has become one of the most important environmental problems affecting all regions of the world (Uttaruk and Laosuwan, 2020; Čadro *et al.,* 2024; Uttaruk and Laosuwan, 2026). Its development is driven mainly by the increase of greenhouse gases in the atmosphere, resulting in negative changes to Earth's climate system. These gases are released by human activity (such as industrial processes, use of motor vehicles, oil or gas burning and farming). Further, large scale deforestation and land use conversions have also contributed climate destabilization at local, regional and global scales (Prudil *et al.,* 2023; Dagiliūtė and Kazanavičiūtė, 2024). Of different GHG, CO_2 dominates with around 77% and is followed by CH_4 with approximately 14%, N_2O at about 8%. Less prevalent greenhouse gases, such as hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6), collectively account for approximately 1% of the global emissions (Tian *et al.,* 2019; Laosuwan *et al.,* 2023). Fossil fuel CO_2 emissions are expected to rise to an unprecedented level of 37.4 billion tons in 2024, an increase by 0.8% from the year before, according to Global Carbon Project (Thai PBS, 2025). That increase is evidence that the world remains nowhere near on track to deliver on its climate reduction pledges. The findings were released on (UNFCCC, 2024). While the peak of emissions might well arrive within this decade - propelled in particular by the swift spread of renewables as solar, wind or electric mobility – such solutions presently cater for just a small fraction of global energy need. As a result, fossil fuels remain the primary energy sources in the world (Carlsen, 2025).

Decreasing atmospheric CO_2 levels can be achieved by incorporating a combination of complementary methods, including enhancing the efficiency of clean production processes, promoting the use of low-carbon and renewable energy sources as well as attempting carbon capture and storage (CCS) technology (Saxena *et al.,* 2024). CO_2 is considered among these as one of the most powerful means to keep CO_2 out of the atmosphere (Kongkuah *et al.,* 2025). One of the most cost-effective and environmentally sound forms of sequestration is storing carbon in trees and wood products. Trees sequester CO_2 from the atmosphere through photosynthesis and store it as carbon in their biomass spread over above- (stem, branch, leaf) and below-ground (mostly root) organs (Albrecht and Kandji, 2003; Brockerhoff *et al.,* 2017; Nunes *et al.,* 2020; Uttaruk *et al.,* 2024a; Angkahad *et al.,* 2025; Laosuwan *et al.,* 2025a). The sequestered carbon is stored in the tree and remains until that tree is harvested; increased photosynthetic activity increases CO_2 uptake and accumulation (Plybour, *et al.,* 2025). To estimate the biomass, tree anatomical characteristics can be analyzed through allometric equations that express the mathematical relation between dimensions of a tree and its biomass volume (Pati *et al.,* 2022; Oumasst *et al.,* 2024) Strategies like afforestation (establishment of a forest where there was no forest), reforestation (replanting trees in areas that were cut down), restoration of forests, conversion of agricultural land to agroforestry and the planting or setting aside land for commercial purposes as a plantation help to expand the forest cover (Uttaruk *et al.,* 2024b). These practices increase the storage of carbon and decrease CO_2 emissions into atmosphere supporting equilibrium in the global carbon cycle, thus influencing climate stability (Bussotti and Pollastrini, 2025). However, the quantity of carbon sequestered in forests significantly differs depending on many factors such as forest type, species composition, stand density, terrain features and site-specific environmental conditions (Dixon *et al.,* 1994; Van Con *et al.,* 2013). Furthermore, carbon stocks are determined by species-specific traits, tree age, local climate conditions and soil characteristics (Spittlehouse and Stewart, 2003; Wattanasuksakul *et al.,* 2012; Chen *et al.,* 2022; Zhang *et al.,* 2023; Laosuwan *et al.,* 2025b) as well as silvicultural management events occurring in the forest ecosystem.

This research is based on the hypothesis that both dry evergreen and dry dipterocarp forests are characterized by high levels of plant species diversity, which determine the accumulation of aboveground biomass (AGB) and enhance the overall carbon storage capacity of these ecosystems. Species diversity is assumed to be positively correlated with the potential of forest ecosystems to sequester and maintain carbon, reflecting the intricate relationship between biodiversity and ecosystem functionality (Xu *et al.,* 2020) In other words, greater species richness is expected to promote higher AGB and more efficient carbon storage, thereby mitigating greenhouse gas emissions (Khan *et al.,* 2024).

Given this ecological significance, the main objective of the present study is to evaluate plant species diversity, aboveground biomass, and carbon stock across two dominant forest types—dry evergreen and dry dipterocarp forests—in Tat Ton National Park. These ecosystems serve as essential natural resources that contribute to climate change mitigation, biodiversity conservation, and ecological stability. The findings from this research are anticipated to provide valuable insights for ecosystem restoration, carbon accounting, and sustainable forest management strategies that support climate resilience and long-term environmental sustainability.

MATERIAL AND METHODS

Study Area

Tat Ton National Park (Figure 1) is located in Nafai Sub-district, Mueang District, Chaiyaphum Province, northeastern Thailand, covering approximately 320 ha. Established on December 31, 1980 as Thailand's 23rd national park, it lies within the Phu Laen Kha mountain range at elevations of 200–945 m a.s.l. The landscape features undulating plateaus and shallow valleys with lateritic and sandy-loam soils derived from sandstone, forming the headwaters of the Lam Pathao and Tat Ton creeks that support surrounding ecosystems and agriculture.

The park's vegetation is dominated by dry dipterocarp forest, with smaller portions of dry evergreen forest, distributed along distinct topographic and moisture gradients—dipterocarp forests occupying lower, drier slopes and evergreen forests occurring at higher, more humid elevations. The area has a tropical monsoon climate with three seasons: hot (April–May), rainy (June–October), and cool (November–March), with an average annual temperature of 27.6 °C and rainfall of 1,154 mm. These environmental conditions shape the park's vegetation composition, species diversity, and carbon sequestration potential, making it an ideal site for assessing plant diversity, above-ground biomass, and carbon storage within Thailand's characteristic dry forest ecosystems.

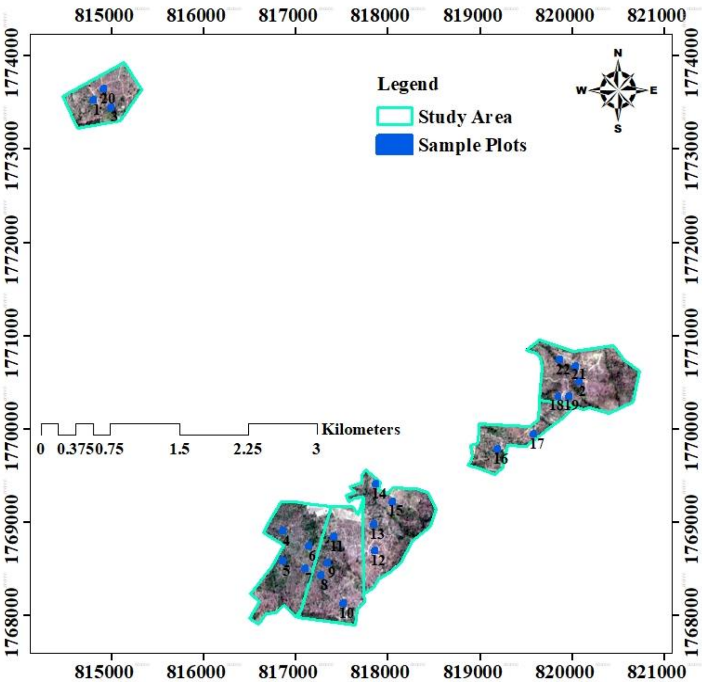

Figure 1. Study area and spatial distribution of the six main plots and twenty-two subplots in Tat Ton National Park, northeastern Thailand

Field Measurement and Data Analysis

A stratified random sampling approach was used to represent forest conditions across the 320-ha study area. Six main plots were selected in areas representing the dominant forest types of Tat Ton National Park, including dry evergreen forest (DEF) and dry dipterocarp forest (DDF). Each plot measured 40×40 m (0.16 ha), which follows common practice in forest carbon studies in

Thailand. The six plots were divided into 22 subplots distributed across the study area to improve spatial coverage. Subplot locations were selected using a random approach while considering field accessibility and vegetation differences. In each subplot, all trees with a diameter at breast height (DBH) greater than 4.5 cm were recorded. The distribution of sampling plots is shown in Figure 1.

For every recorded tree, species identification and classification were performed to describe the overall composition of the forest community. The Importance Value Index (IVI) was subsequently calculated to evaluate vegetation structure and species dominance. IVI combines key ecological parameters—density (D), frequency (F), and dominance (Do)—together with their relative values: relative density (RD), relative frequency (RF), and relative dominance (RDo). The formulas and calculation procedures for these variables are summarized in equation 1-7.

$$IVI = RDi + RFi + RDoi \quad (1)$$

Relative density (RDi)

$$RDi = \frac{Density\ of\ a\ species\ (Di)}{Total\ density\ of\ all\ species}\ x\ 100 \quad (2)$$

Density (Di)

$$Di = \frac{Total\ number\ of\ tree\ a\ species\ i}{Total\ sampled\ area} \quad (3)$$

Relative frequency (RFi)

$$RFi = \frac{Frequency\ value\ of\ a\ species\ i\ (Fi)}{Total\ frequency\ value\ of\ a\ species}\ x\ 100 \quad (4)$$

Frequency (Fi)

$$Fi = \frac{Number\ of\ plots\ where\ a\ species\ i\ occurs}{Total\ number\ of\ sampled\ plots} \quad (5)$$

Relative dominance ($RDoi$)

$$Fi = \frac{Number\ of\ plots\ where\ a\ species\ i\ occurs}{Total\ number\ of\ sampled\ plots}\ x\ 100 \quad (6)$$

Dominance (Doi)

$$Doi = \frac{Total\ basal\ area\ of\ a\ species\ i}{Total\ sampled\ area} \quad (7)$$

Furthermore, species diversity was quantified using the Shannon–Wiener diversity index (Shannon and Weaver, 1949), while species evenness was determined using Pielou’s evenness index (Pielou, 1975). Both indices were calculated following the formulas presented in equations (8) and (9)

$$H' = \sum_{i=1}^{s} (Pi)\ln(Pi) \quad (8)$$

The Shannon diversity index, denoted as H′, is calculated using Pi, which represents the proportion of the total population made up of species I, and S, the total number of species observed.

$$E = H' \ln S \tag{9}$$

H′ represents the Shannon diversity index, while S denotes the total count of distinct species.

We tested the relationship between biodiversity and carbon storage using Pearson correlation. Biodiversity was represented by species richness (number of species) and the Shannon–Wiener index (H′) for each sampling plot (n=22). Carbon storage was represented by carbon density (tC ha^{-1}). Correlation results are reported with r and p values.

The biomass of tree stems, branches, and leaves was calculated using the allometric equation (equation 10) for dry dipterocarp forests developed by Ogawa (Ogawa *et al.*, 1965). The carbon sequestration of individual species and the entire forest area was estimated based on the carbon proportion in woody biomass, which for dry dipterocarp forests is approximately 47% (IPCC, 2006).

$$\begin{aligned} Ws &= 0.0396\, D^2 H^{0.9326} \\ Wb &= 0.003487\, D^2 H^{1.0270} \\ Wl &= \left(28.0 / wtc + 0.025\right)^{-1} \\ Wt &= Ws + Wb + Wl \end{aligned} \tag{10}$$

In these equations, D denotes the diameter at breast height (cm), and H represents the total tree height (m). The variables Ws, Wb, and Wl correspond to the dry weights of the stem, branches, and leaves, respectively, expressed in kilograms (kg).

The below-ground biomass (BGB) was estimated from above-ground biomass (AGB) using a root-to-shoot ratio (R) of 0.26, following the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). This ratio represents the default value for tropical dry forests as specified in Volume 4, Chapter 4 (Forest Land). Accordingly, BGB was computed as BGB=AGB×0.26, and the total biomass (TB) was obtained by summing AGB and BGB. The carbon stock (C) was then derived by multiplying TB by a carbon fraction of 0.47, consistent with the IPCC default values.

RESULTS AND DISCUSSION

Plant Species Survey

A total of 4,047 individual trees were recorded across the 320-ha study area, corresponding to an average density of approximately 12.65 trees ha^{-1}. This structure reflects a diverse and well-balanced forest community characteristic of dry dipterocarp ecosystems in Tat Ton National Park, where both dominant and co-dominant species contribute to stand stability, ecological resilience, and the overall carbon accumulation potential of the forest.

Dominant species such as *Syzygium cumini*, *Pterocarpus macrocarpus*, and *Microcos paniculata* were widely distributed, suggesting strong adaptability to semi-arid soils and temperature fluctuations. In contrast, less abundant species tend to be ecological specialists that occupy narrower niches. Collectively, this structural and functional diversity enhances the forest's capacity for biomass accumulation, nutrient cycling, and carbon sequestration. The ten most abundant species are summarized in Table 1, representing the dominant taxa that shape the forest composition and maintain community balance.

Among the recorded species, *Syzygium cumini* (695 individuals) was clearly the most abundant, followed by *Pterocarpus macrocarpus* (304) and *Microcos paniculata* (269). Together, these three taxa represent nearly one-third of all trees recorded, confirming their ecological dominance and strong adaptability to the semi-arid conditions of the region. *Cratoxylum formosum* (169 individuals) and *Nephelium hypoleucum* (167) were also found frequently throughout the plots. Both species are well-known for their tolerance to dry, nutrient-poor soils and are common constituents of open deciduous formations, where they play important roles in canopy regeneration and understory shading.

The remaining five species—*Tectona grandis* (144), *Grewia eriocarpa* (139), *Peltophorum dasyrrhachis* (118), *Syzygium claviflorum* (97), and *Wrightia religiosa* (96)—were less abundant but still form integral parts of the forest community. These species contribute significantly to the heterogeneity and multi-layered structure of the stand, particularly by occupying different canopy levels and microhabitats. Their coexistence with dominant trees helps stabilize nutrient cycling and promotes species turnover, which are key ecological processes supporting long-term forest persistence.

Table 1. Dominant Tree Species and Number of Individuals in the Study Area

Rank	Species (1–5)	Number of Trees	Rank	Species (6–10)	Number of Trees
1	*Syzygium cumini* (L.) Skeels	695	6	*Tectona grandis* Linn.f.	144
2	*Pterocarpus macrocarpus* Kurz.	304	7	*Grewia eriocarpa* Juss.	139
3	*Microcos paniculata* L.	269	8	*Peltophorum dasyrrhachis* (Miq.) Kurz.	118
4	*Cratoxylum formosum* (Jacq.) Benth. & Hook.f. ex Dyer	169	9	*Syzygium claviflorum* (Roxb.) A.M.Cowan & Cowan	97
5	*Nephelium hypoleucum* Kurz.	167	10	*Wrightia religiosa* Benth.	96

Overall, the quantitative composition presented in Table 1 highlights that a small group of dominant species largely determines the forest structure, while a wide variety of less common taxa enriches species diversity and ensures ecological balance. This coexistence of dominant and subordinate species reflects the natural dynamics of dry dipterocarp forests, where both environmental stress and species adaptation shape the composition and stability of the ecosystem.

Plant Species Diversity

In Table 2, the details of tree species recorded in Tat Ton National Park are presented, providing a comprehensive overview of the various families, scientific names, total numbers of trees, and mean densities for each species. An examination of these data reveals clear patterns and notable variations, offering valuable insights into the forest composition and the structural distribution of trees in terms of abundance and density. The dominance of several species such as *Syzygium cumini*, *Pterocarpus macrocarpus*, and *Microcos paniculata* highlights their adaptability to local environmental conditions, particularly the dry dipterocarp forest type. Meanwhile, the presence of numerous species with lower densities reflects a diverse and balanced ecosystem, indicating stable regeneration processes and ecological resilience within the park's forest community.

Table 2. Tree Species Composition, Number of Individuals, and Density

Family Name	Scientific Name	Number of Trees	Density (tree ha^{-1})
ANACARDIACEAE	*Anacardium occidentale* L.	1	0.003
	Buchanania lanzan Spreng.	8	0.026
	Gluta usitata (Wall.) Ding Hou.	2	0.007
	Lannea coromandelica (Houtt.) Merr.	92	0.304
	Mangifera caloneura Kurz.	10	0.033
	Spondias pinnata (L.f.) Kurz	1	0.003
ANNONACEAE	*Diospyros ehretioides* Wall. ex G.Don	21	0.069
	Goniothalamus laoticus (Finet & Gagnep.) Ban	4	0.013
	Melodorum fruticosum Lour.	15	0.050
APOCYNACEAE	*Holarrhena pubescens* Wall. ex G.Don	10	0.033
	Wrightia pubescens R.Br.	99	0.327
BIGNONIACEAE	*Dolichandrone serrulata* (Wall. ex DC.) Seem.	8	0.026
	Fernandoa adenophylla (Wall. ex G.Don) Steenis	46	0.152
	Millingtonia hortensis L.f.	6	0.020
	Stereospermum neuranthum Kurz.	2	0.007
BURSERACEAE	*Canarium subulatum* Guill.	5	0.017
CELASTRACEAE	*Salacia chinensis* L.	8	0.026
CHRYSOBALANACEAE	*Parinari anamense* Hance	9	0.030
COMBRETACEAE	*Terminalia bellirica* (Gaertn.) Roxb.	1	0.003
	Terminalia corticosa Pierre ex Laness.	5	0.017
CONNARACEAE	*Ellipanthus tomentosus* Kurz.	60	0.198
CRYPTERONIACEAE	*Crypteronia paniculata* Blume	9	0.030

Family Name	Scientific Name	Number of Trees	Density (tree ha^{-1})
DILLENIACEAE	*Dillenia ovata* Wall. ex Hook.f. & Thomson	11	0.036
DIPTEROCARPACEAE	*Dipterocarpus alatus* Roxb.	12	0.040
	D. intricatus	1	0.003
	D. obtusifolius Teijsm. ex Miq.	18	0.060
	Shorea obtusa Wall. ex Blume	2	0.007
	Shorea roxburghii G.Don	9	0.030
	Shorea siamensis Miq.	2	0.007
	Vatica harmamdiana Pierre	4	0.013
EBENACEAE	*Diospyros ferrea* (Willd.) Bak.	6	0.020
	D. glandulosa Lace.	2	0.007
EUPHORBIACEAE	*Aporusa villosa* Lindl. Baill.	120	0.397
	Croton oblongifolius Roxb.	3	0.010
	Suregada multiflorum (A.Juss.) Baill.	27	0.089
FABACEAE	*Acacia catechu* (L.f.) Willd.	19	0.063
	Afzelia xylocarpa (Kurz) Craib	18	0.060
	Albizia lucidior (Steud.) I.C.Nielsen	16	0.053
	Cassia bakeriana Craib	68	0.225
	Dalbergia cochinchinensis Pierre	43	0.142
	Dalbergia oliveri Prain	12	0.040
	Peltophorum dasyrrhachis (Miq.) Kurz.	124	0.410
	Pterocarpus macrocarpus Kurz	304	1.015
	Senna siamea (Lam.) H.S.Irwin & Barneby	91	0.301
	Sindora siamensis Teijsm. ex Miq.	88	0.291
FAGACEAE	*Castanopsis cerebrina* (Hickel & A.Camus) Barnett	24	0.079
HYPERICACEAE	*Cratoxylum formosum* (Jacq.) Benth. & Hook.f. ex Dyer	189	0.625
IRVINGIACEAE	*Irvingia malayana* Oliv. ex A.W.Benn.	106	0.350
LAURACEAE	*Beilschmiedia roxburghiana* Nees	39	0.129
LYTHRACEAE	*Lagerstroemia floribunda* Jack	25	0.083
MORACEAE	*Ficus hispida* L.f.	126	0.417
MYRTACEAE	*Syzygium cumini* (L.) Skeels	695	2.261
SAPINDACEAE	*Nephelium hypoleucum* Kurz	234	0.774
TILIACEAE	*Grewia eriocarpa* Juss.	142	0.469
	Microcos paniculata L.	269	0.906
VERBENACEAE	*Tectona grandis* Linn.f.	144	0.476
Total		4,047	12.650

As shown in Table 2, the tree community in Tat Ton National Park includes a wide range of species and families, reflecting the structural complexity of both dry evergreen forest (DEF) and dry dipterocarp forest (DDF). The distribution of species among families indicates that several taxa contribute strongly to the overall stand structure. Species such as *Syzygium cumini*, *Pterocarpus macrocarpus*, and *Microcos paniculata* were among the most abundant, confirming their importance in the forest community.

Among the recorded families, Myrtaceae, Fabaceae, and Tiliaceae were well represented. *Syzygium cumini* showed the highest number of individuals and density, indicating its ecological dominance. Several Fabaceae species, including *Pterocarpus macrocarpus* and *Peltophorum dasyrrhachis*, also occurred in relatively high numbers. Other families, such as Irvingiaceae, Euphorbiaceae, and Moraceae, were less abundant but still contributed to species diversity and forest structure. In addition, dipterocarp species were present at lower densities, representing characteristic elements of this forest type.

A total of 4,047 individual trees were recorded across the 320-ha study area, with an average density of 12.65 trees ha^{-1}. The coexistence of DEF and DDF creates a structurally diverse landscape with varying canopy conditions and species composition. The data presented in Table 2 provide the basis for evaluating species importance using the Importance Value Index (IVI), which is discussed in the following section.

To further examine species dominance, the Importance Value Index (IVI) was calculated by combining relative density, relative frequency, and relative dominance. This index reflects the overall contribution of each species to the forest structure. Higher IVI values indicate more dominant species, while lower values represent less abundant taxa. The calculated IVI values are summarized in Table 3.

Table 3 presents the calculated Importance Value Index (IVI) for all tree species recorded in Tat Ton National Park, derived from relative density (RD), relative dominance (RDo), and relative frequency (RF). The IVI serves as a composite measure reflecting the ecological significance and structural contribution of each species within the forest community. The results reveal distinct patterns of dominance and coexistence among species typical of a dry dipterocarp forest ecosystem.

The analysis indicates that *Syzygium gratum* had the highest IVI (53.951), attributed primarily to its exceptionally high relative dominance (RDo=53.697). This suggests that although the species occurs in low numbers, it consists of large, mature individuals with substantial basal area, making it a key structural component in the canopy layer. In contrast, *Syzygium cumini* recorded the second highest IVI (20.385), driven mainly by its very high relative density (RD=16.901) and frequency (RF=3.484), confirming it as the most abundant and widely distributed species in the study plot. Together, these two *Syzygium species* define the upper canopy dynamics and play a crucial role in maintaining carbon storage and canopy closure.

Following them, *Microcos paniculata* (IVI=16.823) and *Pterocarpus macrocarpus* (IVI=12.837) showed balanced contributions across RD, RDo, and RF, suggesting they are structurally important and well-adapted to local soil and microclimatic conditions. Dalbergia oliveri (IVI=10.205) had a relatively moderate density but extremely high RDo (9.294), indicating a few large-diameter individuals dominating the basal area. Other co-dominant species such as *Nephelium hypoleucum* (IVI=8.651), *Irvingia malayana* (IVI=8.178), and *Cratoxylum formosum* (IVI=7.745) also contributed substantially to the stand's biomass and vertical structure, reflecting their ecological adaptability to dry and nutrient-poor soils.

Species including *Grewia eriocarpa* (IVI=7.170) and *Tectona grandis* (IVI=6.005) exhibited moderate IVI values, representing co-dominant taxa that help maintain canopy heterogeneity and support successional regeneration. The coexistence of dominant, co-dominant, and subordinate species across varying IVI ranges illustrates a balanced forest composition that enhances ecosystem resilience and stability.

Table 3. Importance Value Index (IVI) of Tree Species Recorded

Scientific Name	RD (%)	RDo (%)	RF (%)	IVI
Anacardium occidentale L.	0.025	1.636	0.205	1.865
Buchanania lanzan Spreng.	0.198	0.000	0.615	0.813
Gluta usitata (Wall.) Ding Hou.	0.049	0.064	0.205	0.318
Lannea coromandelica (Houtt.) Merr.	2.273	0.017	2.869	5.159
Mangifera caloneura Kurz.	0.247	0.000	1.025	1.272
Spondias pinnata (L.f.) Kurz	0.025	0.003	0.205	0.232
Diospyros ehretioides Wall. ex G.Don	0.519	0.002	0.615	1.135
Goniothalamus laoticus (Finet & Gagnep.) Ban	0.099	0.015	0.205	0.319
Melodorum fruticosum Lour.	0.371	0.116	0.820	1.306
Holarrhena pubescens Wall. ex G.Don	0.247	0.922	1.025	2.194
Wrightia pubescens R.Br.	2.446	0.025	3.484	5.955
Fernandoa adenophylla (Wall. ex G.Don) Steenis	1.137	0.011	0.820	1.967
Ellipanthus tomentosus Kurz.	1.483	0.429	2.459	4.370
Dipterocarpus obtusifolius Teijsm. ex Miq.	0.445	0.001	0.820	1.265
Aporusa villosa Lindl. Baill.	2.965	0.125	2.664	5.755
Suregada multiflorum (A.Juss.) Baill.	0.667	1.408	1.434	3.510
Afzelia xylocarpa (Kurz) Craib	0.445	1.478	0.820	2.743
Peltophorum dasyrrhachis (Miq.) Kurz.	3.064	0.008	2.459	5.531
Pterocarpus macrocarpus Kurz	7.586	0.948	4.303	12.837
Cratoxylum formosum (Jacq.) Benth. & Hook.f. ex Dyer	4.670	0.001	3.074	7.745
Irvingia malayana Oliv. ex A.W.Benn.	2.619	2.280	3.279	8.178
Ficus hispida L.f.	3.113	0.040	2.664	5.817
Syzygium cumini (L.) Skeels	16.901	0.000	3.484	20.385
Syzygium gratum (Wight) S.N.Mitra var. gratum	0.049	53.697	0.205	53.951
Nephelium hypoleucum Kurz	5.782	0.000	2.869	8.651
Grewia eriocarpa Juss.	3.509	2.022	1.639	7.170
Microcos paniculata L.	6.770	5.749	4.303	16.823
Tectona grandis Linn.f.	3.558	1.217	1.230	6.005

Figure 2 graphically summarizes these results, highlighting the Top 10 species by IVI. The bar chart clearly visualizes the sharp dominance gap between *Syzygium gratum* and the rest of the species, followed by a gradual decline among co-dominant taxa. This pattern typifies the "uneven dominance structure" characteristic of mature dry dipterocarp forests, where a small number of species exert strong structural control while numerous others contribute to ecological diversity and regeneration potential. Overall, the IVI distribution underscores that Tat Ton National Park supports a floristically diverse yet structurally hierarchical forest community, which underpins its high ecological stability, long-term productivity, and significant capacity for carbon sequestration.

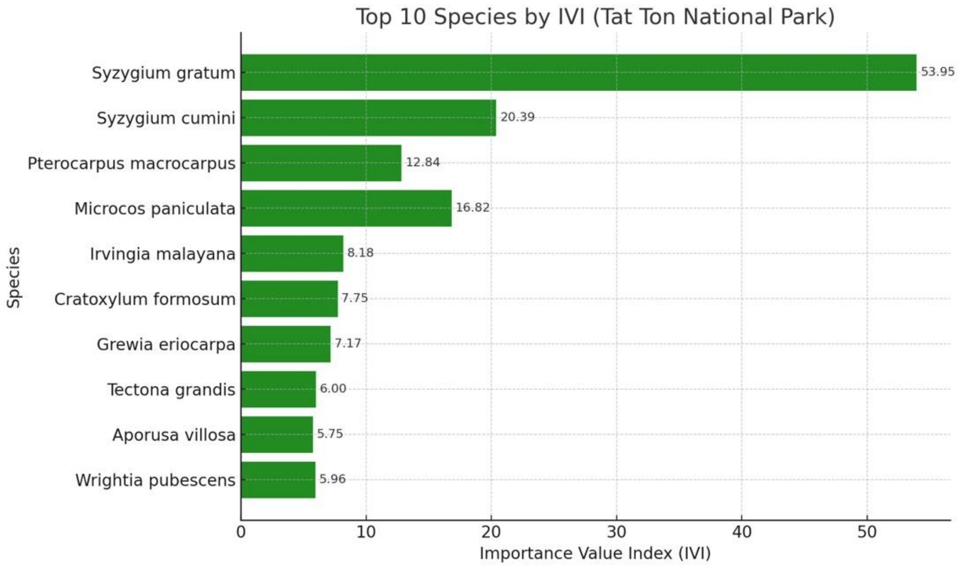

Figure 2. Top 10 species by IVI

Biomass and Carbon Stock

To summarize the overall findings from the field plots, the aboveground and belowground biomass as well as the corresponding carbon stock values from main plot 1–6 were aggregated to represent the total biomass and carbon sequestration potential within the study area. This integrated analysis provides a comprehensive overview of carbon distribution between above- and belowground components, allowing for an understanding of how different forest structures contribute to total carbon storage. The results demonstrate clear variations in carbon accumulation among plots due to differences in stand density, canopy coverage, and species composition. The combined biomass and carbon stock values for plots 1–6 are presented in Table 4.

Table 4 presents the total above- and below-ground carbon stock across six major forest plots covering 320 ha in the study area. Each record includes forest type, area, number of samples, and measured carbon content of above-ground biomass (AGB) and below-ground biomass (BGB), expressed in metric tons of carbon (tC). The calculations follow the IPCC (2006) methodology, where biomass was converted to carbon using a factor of 0.47, and BGB was estimated from AGB using a root-to-shoot ratio consistent with tropical dry forests.

Table 4. Total Aboveground and Belowground Biomass and Carbon Stock

Main Plot	Forest Type	Area (ha)	No. of Samples	AGB (tC)	BGB (tC)	Total (tC)	Average (tC/ha)
1	Dry evergreen and dry dipterocarp forest	35.20	3	2,018.88	545.10	2,563.98	72.82
2	Dry dipterocarp forest	62.40	4	4,197.23	1,133.25	5,260.41	84.30
3	Dry dipterocarp forest	62.40	4	3,805.16	1,027.39	4,832.55	77.37
4	Dry dipterocarp forest	62.40	4	2,935.82	792.67	3,728.49	59.72
5	Dry dipterocarp forest	32.00	2	2,777.64	749.96	3,527.61	110.24
6	Dry dipterocarp forest	64.00	5	4,399.40	1,187.84	5,587.24	87.30
Total Project	—	320.00	22	20,042.50	5,411.48	25,383.90	79.95

Overall, the 320 ha study area stores 25,383.90 tC, with an average of 79.95 tC ha^{-1}. Of this total, 20,042.50 tC occurs above ground and 5,411.48 tC below ground, giving an AGB:BGB ratio of about 79:21. All carbon values in this study are reported in metric tons of carbon (tC). When converted to CO_2 equivalents using the factor 44/12, the total is approximately 93,000 tCO2e (about 291 tCO2e ha^{-1}). These results indicate a high carbon storage potential in the forest ecosystem. Carbon density showed a positive relationship with species richness across the sampling plots ($r=0.77$, $p<0.001$, $n=22$). However, the relationship between carbon density and the Shannon diversity index (H′) was weak and not statistically significant ($r=0.29$, $p=0.18$, $n=22$).

Carbon density varies among the six main plots, ranging from 59.72 to 110.24 tC ha^{-1}, mainly due to differences in stand structure, canopy closure, and species composition. Plot 5 (32 ha) exhibits the highest carbon density (110.24 tC ha^{-1}) despite its smaller area, suggesting a mature canopy structure and dominance of high wood-density species, representing a high-carbon patch that should be prioritized for long-term conservation and monitoring. Plot 6 (64 ha) has the highest total carbon (5,587.24 tC) and accounts for about 22% of the project's total, making it the principal contributor to overall carbon sequestration; maintaining its ecological stability through fire prevention and minimizing disturbance is therefore essential. Plots 2 and 3 (62.4 ha each) contain moderate-to-high carbon densities (84.30 and 77.37 tC ha^{-1}, respectively), jointly contributing nearly 40% of the total carbon stock and representing stable, well-developed stands. Plot 1 (35.2 ha), representing a transitional zone between dry evergreen and dry dipterocarp forests, shows 72.82 tC ha^{-1}, slightly below the project mean, indicating a moderately developed canopy that could increase carbon storage through selective enrichment. In contrast, Plot 4 (62.4 ha) has the lowest mean (59.72 tC ha^{-1}), likely influenced by recurring fires or previous disturbances, suggesting that targeted restoration measures such as fuel-load reduction and gap enrichment planting would enhance biomass recovery.

From a sustainable forest management (SFM) perspective, these results highlight three functional zones within the study area: high-carbon hotspots such as Plot 5 that should be strictly protected to ensure long-term carbon stability; key leverage areas such as Plot 6 that determine the majority of project-scale carbon sequestration and thus require careful maintenance of ecological integrity; and restoration zones such as Plot 4, where ecological enhancement can generate substantial additional carbon benefits over time.

The carbon density observed in this study (59.72–110.24 tC ha^{-1}, mean 79.95 tC ha^{-1}) falls within the range reported for tropical dry forest ecosystems. Previous studies in Thailand have reported carbon densities of approximately 60–78 tC ha^{-1} for dry dipterocarp and dry evergreen forests, indicating comparable biomass accumulation patterns under similar climatic and soil conditions. In some cases, higher values exceeding 150 tC ha^{-1} have been observed in mature stands with greater basal area and stand age. These comparisons suggest that the forest ecosystems in Tat Ton National Park represent moderately developed carbon stocks typical of regional dry forest systems.

The positive relationship between carbon density and species richness found in this study is consistent with several studies indicating that higher tree diversity can enhance biomass accumulation through complementary resource use and structural complexity. However, the weak relationship observed with the Shannon diversity index also agrees with previous findings showing that biodiversity–carbon relationships may vary depending on forest structure, environmental conditions, and disturbance history. Some studies suggest that structural attributes such as basal area and canopy architecture may play a stronger role in determining carbon storage than species diversity alone.

Overall, the results confirm that mixed dry evergreen and dry dipterocarp forests can function as important carbon sinks while maintaining relatively high biodiversity, supporting the concept that conservation of heterogeneous forest landscapes contributes simultaneously to climate mitigation and ecosystem stability.

CONCLUSIONS

This study provides an assessment of forest ecosystems in Tat Ton National Park, focusing on plant diversity, above- and below-ground biomass, and carbon sequestration across two main forest types. A total of six main plots and twenty-two subplots recorded 142 species and 4,047 individual trees, indicating a highly diverse dry forest ecosystem. The combined total biomass and carbon stock reached 25,383.90 tC (≈93,000 tCO2e), highlighting the important role of these forests as long-term carbon sinks.

The results underscore that biodiversity and carbon storage are mutually reinforcing components of sustainable forest ecosystems. Forests with greater species diversity exhibited more stable biomass accumulation and higher carbon retention, confirming their essential role in climate-change mitigation and ecosystem resilience. These findings reinforce the importance of protecting and restoring mixed dry forest landscapes as a nature-based approach to enhance Thailand's carbon balance.

From a broader perspective, this assessment contributes valuable baseline data for carbon-credit development and sustainable forest management under the national Net Zero framework. By quantifying both ecological diversity and carbon sequestration potential, the study aligns with the principles of the Green Economy, offering scientific evidence to support the integration of biodiversity conservation into carbon market mechanisms such as T-VER and VERRA.

In conclusion, the forests of Tat Ton National Park not only preserve ecological integrity but also provide measurable climate benefits. Promoting their protection and sustainable utilization will enhance both environmental sustainability and socio-economic value, advancing Thailand's transition toward a low-carbon, Net Zero future. Moreover, integrating community-based forest monitoring, local participation, and continuous satellite-based carbon assessment could ensure long-term transparency and accountability in carbon credit projects. This holistic approach will bridge science, policy, and practice, turning Tat Ton National Park into a living model of sustainable forest governance and contributing to the achievement of the UN Sustainable Development Goals (SDGs), particularly Goals 13 (Climate Action) and 15 (Life on Land).

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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