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ORIGINAL RESEARCH ARTICLE

Carbon storage in the aboveground biomass of the dipterocarp forest, University of Phayao, Phayao, Thailand

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Abstract: Forests play a crucial role in global carbon cycling by sequestering atmospheric carbon dioxide in their biomass, with dipterocarp forests recognized as one of the most important carbon sinks in tropical Asia. This study aims to determine carbon storage in the aboveground biomass of the dipterocarp forest at the University of Phayao, Phayao, Thailand, using an allometric equation, comparison of carbon sequestration across tree species, and social data analysis. Field data were collected across approximately 4,800 m^2 by establishing three sampling plots. The biomass area calculation was performed to evaluate carbon storage and analyze the elements and importance of plants (important value index [IVI]). The results identified 943 trees belonging to 18 families and 41 species across the three studied stations, with an estimated carbon storage of 49.02 t C/ha in the total area of the University of Phayao. In addition, the tree species with the highest IVI was *Dipterocarpus tuberculatus* Roxb. (77.40%), followed by *Shorea obtusa* Wall. ex Blume. (64.76%), *Pentacme siamensis* (Miq.) Kurz. (37.59%), and *Dipterocarpus obtusifolius* Teijsm. ex Miq. (23.04%). Species diversity was measured at 2.19, species richness at 6.86, and species evenness at 0.59. The relationship between physical factors and carbon storage was inversely correlated at a correlation coefficient of −0.33, indicating a moderate negative relationship. Overall, the findings highlight the ecological importance of the dipterocarp forest at the University of Phayao as both a reservoir of biodiversity and a significant contributor to carbon storage, emphasizing its role in climate change mitigation and sustainable forest management.

Keywords: Carbon storage; Biomass; Dipterocarp forest

1. Introduction

The dipterocarp forest, dominated by the family Dipterocarpaceae—one of the major tropical rainforest families—is among the mega-diverse terrestrial ecosystems and a significant terrestrial carbon reservoir.[1,2] The family comprises nearly 700 species across 16–22 genera.[3] Dipterocarp forests are widely distributed in Thailand, with their coverage varying by region; in some areas, they can account for approximately 50% of the total area. Regionally, *Dipterocarpus* species are native to Bangladesh, Brunei, Indonesia, Myanmar, Malaysia, Singapore, and Thailand.[4]

This forest type has enormous economic and ecological significance. Predominant species such as *Dipterocarpus turbinatus* provide critical habitat for many endangered animal species while also serving as a key resource for timber and construction materials.

Ecologically, dipterocarps are highly effective in carbon storage, playing a crucial role in regulating the balance between carbon absorption, loss, and storage in the atmosphere.[5,6] However, a significant portion of dipterocarp forests has currently been degraded and lost due to commercial and building activities, impacting the carbon balance in the atmosphere.

Global warming has become an increasingly global challenge, largely driven by the rising concentration of greenhouse gases in the atmosphere.[7,8] Normally, greenhouse gases, together with clouds, regulate Earth's temperature by trapping part of the sun's heat, thereby preventing extreme fluctuations between hot and cold. However, rapid population growth, intensified human activities, and expanding economic systems have led to a sharp increase in carbon dioxide emissions. Deforestation and forest degradation, in particular, are major contributors to atmospheric carbon dioxide accumulation, accelerating climate change and altering ecosystems worldwide.[9-11] Forests have an important role in regulating atmospheric carbon dioxide, as plants absorb carbon dioxide during photosynthesis and store it in different parts of trees in the form of biomass. However, ongoing deforestation and recurrent forest fires have greatly reduced forest cover, thereby diminishing global carbon storage capacity.[12-14]

This research examines carbon storage in the aboveground biomass (AGB) of the dipterocarp forest at the University of Phayao, Phayao, Thailand. The study area, covering approximately 7,328,000 m^2, is classified as a dry dipterocarp forest with relatively high biodiversity. Unlike many previous studies that focused on undisturbed forest areas, this site has educational buildings, commercial buildings, and dormitories. Its location in the middle of a forested lowland contributes to greater heat accumulation, resulting in a greater climatic impact compared to other areas. The soil is predominantly red, with low fertility and limited mineral content, while air pollution tends to accumulate more intensively than in other areas.

Previous research has often focused on the economic value of forest carbon stocks[15] or compared carbon storage across agroforestry systems, monocultures, and natural tropical forests,[16] providing new insights into how ecosystems function in disturbed places by combining functional data with carbon sequestration data.[17] In contrast, this study provides insights into carbon sequestration in a semi-urban forest context, where ecosystems are exposed to both natural and human-induced pressures. The university forest plays an important role in supporting surrounding communities, educational personnel, and students by supplying forest products, conserving wildlife, providing unpolluted environments, and regulating the local climate.

At present, the university forest area faces multiple threats. Natural disasters, particularly wildfires, and anthropogenic activities such as deforestation have reduced its carbon absorption capacity. Furthermore, the upper northern region of Thailand is experiencing PM 2.5 dust pollution, which diminishes photosynthetic efficiency by coating leaf surfaces, slowing plant growth, and reducing carbon uptake. Furthermore, airborne dust can degrade soil quality by reducing nutrient availability and harming beneficial soil organisms. Together, these pressures disrupt forest carbon sequestration, weaken ecosystem resilience, and threaten wildlife habitats.

At present, the primary role of carbon sequestration in trees is to mitigate global warming. Beyond their ecological function, carbon sequestration also has commercial applications, such as generating carbon credits for trading, offsetting greenhouse gas emissions, and improving air and soil quality. Therefore, this study focused on enhancing forest area, implementing systematic management and conservation strategies, and promoting tree planting in degraded forests. Collecting data on forest density, species diversity, and carbon content provides information for future studies, forest conservation, soil quality improvement, and reforestation efforts. Such data also support the development of stronger measures to control forest fires and logging, facilitate comparisons of tree populations and carbon content over time, and guide planning, monitoring, and implementation of effective solutions to address climate change.

2. Materials and methods

2.1. Materials

The equipment used in this study included wood stakes, ropes, hammers, a tape measure, clinometers (PM-5, CST, Thailand), papers, stationery, a camera (EOS 1500D Kit, Canon, Thailand), code tags for tree labeling, a hygro-thermometer (TH-02 Digicon, Mainscale, Thailand), a lux meter (TM-205, Tenmars, Taiwan), and a GPSMap device (GPSMAP 66s, Garmin, United States [US]).

2.2. Research methodology

2.2.1. Study area

The study area—the dipterocarp forest at the University of Phayao, Phayao—was divided into three study plots, each with a size of 1600 m^2, representing the overall plant community and vegetation structure of the area (Figure 1).

2.2.2. Data collection

This research employed field exploration methods in the dipterocarp forest at the University of Phayao. Geographic positions of the study plots were identified using satellite signals, and three sampling plots were established to represent the overall forest community. The study plots measured 40 × 40 m and 80 × 20 m, selected to match the appropriate area and the suitable size of plant species. Each tree within the plots was tagged with coded labels to facilitate data collection. For each individual, the scientific name, abundance, height, and diameter at breast height (DBH) were recorded. AGB and underground biomass carbon stocks were then estimated using the allometric equation developed by Cairns *et al*.[17]

2.2.3. Tree labeling

All trees with a DBH of more than 4.5 cm or a girth of more than 15 cm within the permanent sample plots were marked with aluminum tree ID tags to facilitate data collection. The details of the tree ID tags are shown in Figure 2.

2.2.4. Sample plots

The sample plots established at the three positions measured approximately 40 × 40 m and 80 × 20 m, forming one large plot. Each plot was further divided into 16 subplots of 10 × 10 m to facilitate tree data collection, along with additional 1 × 1 m subplots for detailed measurements (Figure 3).

2.2.5. Number of tree measurements

Sample plots of three sizes (1 × 1 m, 4 × 4 m, and 10 × 10 m) were established to record vegetation data. In 1 × 1 m plots, data were collected for all species <1.3 m in height. Information recorded included species name, number of individuals, total height, basal width at soil level, and representative samples. In 4 × 4 m plots, data were collected for saplings taller than 1.3 m with a DBH of <4.5 cm or a girth of <15 cm. Recorded data included the number of species, number of individuals, scientific name, total height, and DBH. In 10 × 10 m plots, data were collected for all trees taller than 1.3 m with a DBH of more than 4.5 cm or a girth of more than 15 cm. Information recorded included the number of species, number of individuals, scientific name, total height, and DBH. In addition, the diameter and girth of large trees were measured.

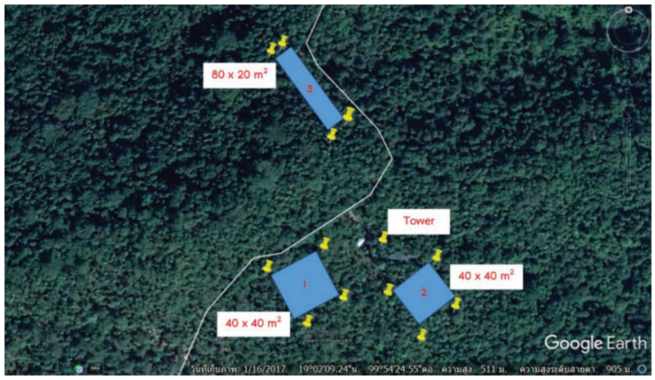

Figure 1. Study areas and sample plots at all three stations. Modified from maps data by Google (https://earth.google.com/web/@16.74063451,-99.25702377,36.61724128a,22771.438817d,35y,0h,0t,0r/data=CgRCAggBOgMKATBCAggASg0IARAA), retrieved on January 5, 2018.

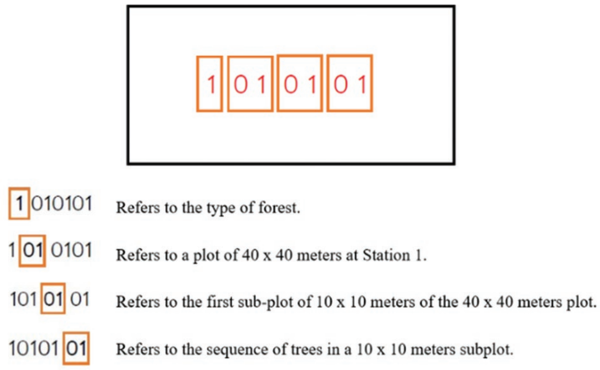

Figure 2. Details of code tags for tree labeling

Tree size was assessed primarily by DBH, measured at 1.3 m above the ground. DBH was measured using a diameter tape; when unavailable, girth was measured using a measuring tape and then converted to DBH later using the formula:

$$DBH = \frac{girth}{\pi}, \left(\pi = 22/7 \text{ or } 3.14 \right) \quad (1)$$

2.2.6. Growth of tree measurements

Tree growth was assessed using DBH and the height of trees. In natural forests, DBH measurements may require adjustments due to unique tree or site characteristics. To ensure accuracy and standardization, DBH measurements were classified into eight types:

(i) Normal trees: Measured at 1.30 m above ground on level terrain

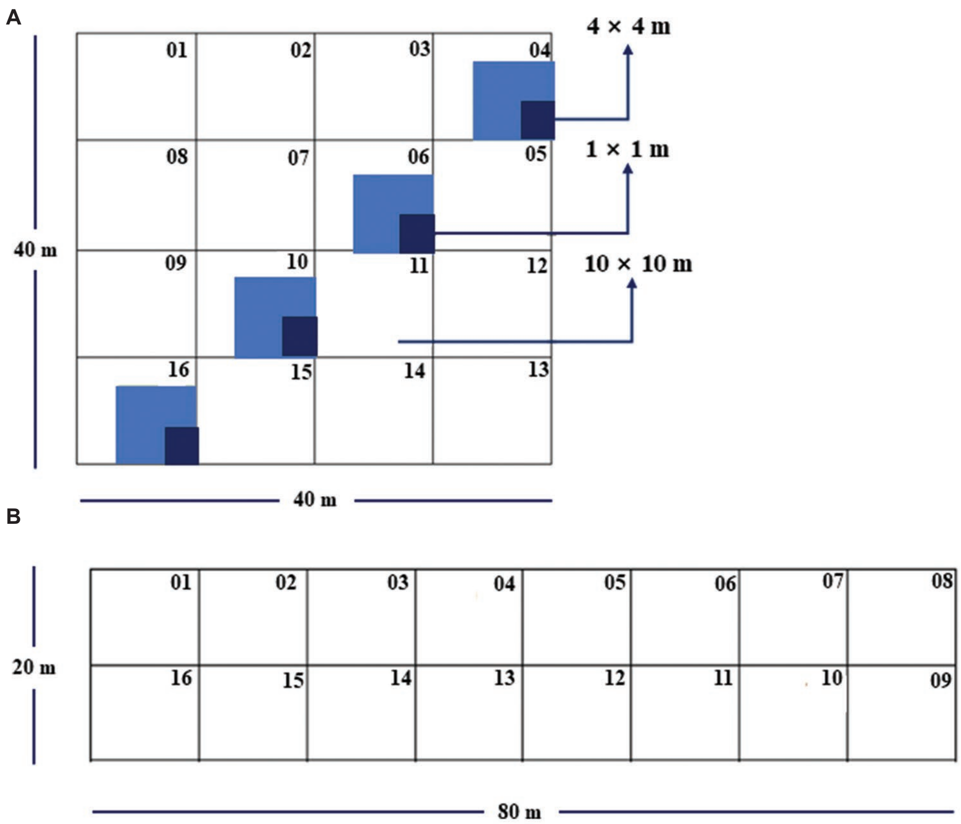

Figure 3. Sample plot determination. (A) A plot size of 40 × 40 m. (B) A plot size of 80 × 20 m.

(ii) Trunk-nodular trees: Measurements adjusted slightly above or below 1.30 m to avoid nodules
(iii) Buttressed trees: Measurements taken above the buttress, sometimes over 3.00 m, depending on tree form
(iv) Aerial roots: For species such as *Rhizophora mucronata*, measurements taken above root flares, typically at approximately 0.20 m
(v) Forked trees below 1.30 m: Measurement taken lower (1.00–1.20 m) to obtain only one value of the trunk
(vi) Forked trees at or near 1.30 m: Each trunk is measured separately if splitting occurs at or near breast height
(vii) Trees on slopes: DBH measured at 1.30 m on the uphill side of the slope
(viii) Leaning trees: DBH measured at 1.30 m from the leaning side of the trunk.

2.2.7. AGB calculation

The calculation of AGB in distinct types of natural forests was performed using allometric equations, which require total tree height and DBH as input variables (Table 1).

Allometric equations were used to calculate the biomass of trees in various natural forest types with a DBH of <4.5 cm and a height of more than 1.3 m:

$$W_S = 89.3059\ D^2H^{0.66513} \tag{2}$$

$$W_B = 15.3063\ D^2H^{0.58255} \tag{3}$$

$$W_L = 0.0140\ D^2H^{0.44363} \tag{4}$$

$$W_T = W_S + W_B + W_L \tag{5}$$

where W_S is the biomass of trunks (kg); W_B is the biomass of branches (kg); W_L is the biomass of leaves (kg); W_T is the total biomass of trunks, branches, and leaves (kg); D is the DBH (cm); and H is the tree height from the base to the top (m).

2.2.8. Carbon quantity estimation

Carbon storage in AGB is primarily contained in woody tissues. Once tree biomass was estimated using allometric equations, the carbon content can be derived. In general, carbon is assumed to account for approximately 47% of the total biomass, calculated according to the standard equation:

Table 1. Allometric equations used to calculate the biomass of trees in natural forest types with a diameter at breast height of more than 4.5 cm

Wild types	Equations
Dry evergreen forest Hill evergreen forest	W_S=0.0509 $(D^2H)^{0.919}$ W_B=0.00893 $(D^2H)^{0.977}$ W_L=0.0140 $(D^2H)^{0.669}$ W_T=W_S+W_B+W_L
Mixed deciduous forest Dipterocarp forest	W_S=0.0396 $(D^2H)^{0.933}$ W_B=0.00349 $(D^2H)^{1.03}$ W_L=$(28.0/(W_S+W_B+0.025))^{-1}$ W_T=W_S+W_B+W_L
Tropical rainforest	W_S=0.0396 $(D^2H)^{0.9326}$ W_B=0.006003 $(D^2H)^{1.0270}$ W_L=$(28.0/(W_S+W_B+0.025))^{-1}$ W_T=W_S+W_B+W_L
Pine forest (*Pinus merkusii*)	W_S=0.2141 $(D^2H)^{0.9814}$ W_B=0.00002 $(D^2H)^{1.4561}$ W_L=0.00072 $(D^2H)^{1.0138}$ W_T=W_S+W_B+W_L
Pine forest (*Pinus kesiya*)	W_S=0.02698 $(D^2H)^{0.946}$ W_B=0.00018 $(D^2H)^{1.455}$ W_L=0.00072 $(D^2H)^{1.094}$ W_T=W_S+W_B+W_L
Mangrove	W_S=0.05466 $(D^2H)^{0.945}$ W_B=0.01579 $(D^2H)^{0.9124}$ W_L=0.0678 $(D^2H)^{0.5806}$ W_T=W_S+W_B+W_L
Mangrove forest	W_S=0.0449 $(D^2H)^{0.9549}$ W_B=0.02412 $(D^2H)^{0.8649}$ W_L=0.09422 $(D^2H)^{0.5439}$ W_T=W_S+W_B+W_L
Long sheath bamboo	W_T=0.22187 $(D)^{2.2749}$
Fernleaf bamboo	W_T=0.49522 $(D^2)^{0.8726}$
Beechey bamboo	W_T=0.17446 $(D^2)^{1.0437}$
Silk-ball bamboo	W_T=0.2425 $(D^2)^{1.0751}$

$$\text{Carbon storage (C)} = \text{Aboveground biomass} \times 0.47 \quad (6)$$

The proportion of dry root weight per tree was used to estimate underground biomass from the AGB of each species:

$$\text{Dry root weight} = \text{Aboveground carbon} \times 0.27 \quad (7)$$

Carbon storage in forest areas can be calculated by multiplying the average carbon content per unit area by the total size of the forest area. The amount of carbon dioxide absorption was calculated using:

$$\text{Carbon dioxide absorption} = \text{Total forest carbon} \times 3.66 \quad (8)$$

While the amount of oxygen released was calculated using:

$$\text{Oxygen released} = \text{Total forest carbon} \times 2.66 \quad (9)$$

2.2.9. Sample drying

Biomass samples of at least 500 g were collected and analyzed in the laboratory. Fresh samples were weighed and then dried at 105°C for 48 h. The resulting dry weight was used to calculate the percentage of moisture content using the equation:

$$\text{Humidity}\ (\%) = \frac{(\text{fresh weight} - \text{dry weight})}{\text{dry weight}} \times 100 \quad (10)$$

2.2.10. Plant species composition and significance analysis

The important value index (IVI) was calculated according to the following formula:

$$\text{Relative IVI} = \text{RD} + \text{RF} + \text{RDo} \quad (11)$$

$$\text{Density}\ (\text{D}) = \frac{\text{The number of species A in a sample plot}}{\text{The number of all plots}} \quad (12)$$

$$\text{Relative density}\ (\text{RD},\ \%) = \frac{\text{Density of species A}}{\text{Sum of density of all species}} \times 100 \quad (13)$$

$$\text{Frequency}\ (\text{F}) = \frac{\text{Frequency of species A}}{\text{The number of all plots}} \times 100 \quad (14)$$

$$\text{Relative frequency}\ (\text{RF},\ \%) = \frac{\text{Frequency of species A}}{\text{Sum of density of all species}} \times 100 \quad (15)$$

$$\text{Dominance}\ (\text{Do}) = \frac{\text{Basal area of species A}\,(1.30\ \text{m})}{\text{Survey area}} \quad (16)$$

$$\text{Relative dominance}\ (\text{RDo},\ \%) = \frac{\text{Dominance of species A}}{\text{Sum of dominance of all species}} \times 100 \quad (17)$$

2.2.11. Social data analysis

The equation for calculating the Shannon index of species diversity is as follows:[18]

$$H' = \sum_{i=1}^{s} (P_i \ln P_i) \quad (18)$$

where H' is the Shannon index of species diversity, s is the number of species, and P_i is the proportion of the total number of individuals occurring in species i.

The species richness was calculated using the following equation:

$$R = \frac{S-1}{\ln(n)} \quad (19)$$

Where S is the number of species within a defined region and n is the total number of species.

The species evenness was calculated using the following equation:

$$E = \frac{H}{\ln(S)} \quad (20)$$

where H is the species diversity of Shannon-Weiner and S is the total number of species.

2.2.12. Analyzing the similarity index

The similarity index was calculated using the following equations:[19,20]

$$\text{Percentage of similarity}_{A-B}(\text{PS, \%}) = \frac{2W}{A+B} \times 100 \quad (21)$$

$$\text{Percentage of dissimilarity (PD, \%)} = 100 - \text{PS} \quad (22)$$

where W is the species found in both A and B points, A is the number of trees at point A, and B is the number of trees at point B.

2.3. Statistical analysis

The results were analyzed using SPSS version 26.0 (IBM, US). ANOVA and Duncan's multiple range test were used at a confidence level of 95% (p<0.05).

3. Results

3.1. Plant species

The survey of plant species in the University of Phayao area recorded 943 trees, representing 18 families and 41 species (Table 2).

3.2. Composition and importance index of plant species analyses

Analysis of Station 1 showed that *Shorea obtusa* Wall. ex Blume. reported a density of 7.50 plants/plots and a relative density of 33.90%, followed by *Dipterocarpus tuberculatus* Roxb. with a density of 5.50 plants/plots and a relative density of 24.86%. Meanwhile, both *S. obtusa* Wall. ex Blume. and *D. tuberculatus* Roxb. reported the highest frequency (100 plants/plots) and relative frequency (13.11%). In terms of dominance and relative dominance, *D. tuberculatus* Roxb., reported the highest values (0.77 plants/plots and 28.50%, respectively), followed by *S. obtusa* Wall. ex Blume. with 0.74 plants/plots and 27.48%, respectively. For the IVI, *S. obtusa* Wall. ex Blume. ranked first with an IVI of 74.49%, followed by *D. tuberculatus* Roxb. with 66.47% and *Pentacme siamensis* (Miq.) Kurz. with 34.40%, and the percentage of relative IVI being 24.83%, 22.16%, and 11.47%, respectively.

In Station 2, *S. obtusa* Wall. ex Blume. recorded the highest density (7.56 plants/plots) and relative density (33.80%), followed by *D. tuberculatus* Roxb. with 4.94 plants/plots and 22.07%, respectively. In terms of frequency and relative frequency, both *S. obtusa* Wall. ex Blume. and *P. siamensis* (Miq.) Kurz. recorded a frequency of 100 plants/plots and a relative frequency of 14.81%. In addition, *S. obtusa* Wall. ex Blume. recorded the highest dominance (0.75 plants/plots) and relative dominance (30.51%), followed by *D. tuberculatus* Roxb. with 0.64 plants/plots and 25.88%, respectively. For the IVI, *S. obtusa* Wall. ex Blume. recorded an IVI of 79.12%, followed by *D. tuberculatus* Roxb. (61.84%), *P. siamensis* (Miq.) Kurz. (51.60%), and *Dipterocarpus obtusifolius* Teijsm. ex Miq. (25.07%), and the percentage of relative IVI being 26.37%, 20.61%, 17.20%, and 8.36%, respectively.

In Station 3, *D. tuberculatus* Roxb. recorded the highest density (6.69 plants/plots) and relative density (46.32%). In terms of frequency and relative frequency, *D. tuberculatus* Roxb. recorded the highest frequency (100 plants/plots) and relative frequency (16.33%), followed *by S. obtusa* Wall. ex Blume. with (75 plants/plots) and 12.24%, respectively. In addition, *D. tuberculatus* Roxb. recorded a dominance of 1.07 plants/plots and a relative dominance of 50.49%, followed by *S. obtusa* Wall. ex Blume. with 0.19 plants/plots and 9.05%, respectively. For the IVI, *D. tuberculatus* Roxb. ranked first with an IVI of 113.14%, followed by *S. obtusa* Wall. ex Blume. (32.12%), *P. siamensis* (Miq.) Kurz. (23.76%), and *D. obtusifolius* Teijsm. ex Miq. (21.47%), and the percentage of relative IVI being 37.71%, 10.71%, 7.92%, and 7.16%, respectively.

Overall, across all three stations, the highest density was reported by *D. tuberculatus* Roxb., followed by *S. obtusa* Wall. ex Blume., *P. siamensis* (Miq.) Kurz., and *D. obtusifolius* Teijsm. ex Miq. In terms of frequency and relative frequency, *D. tuberculatus*

Table 2. Data on plant species identified in the survey plots across three stations of the dipterocarp forest at the University of Phayao

Family	Scientific name	Number	Station
Anacardiaceae	*Gluta* spp.	2	1
	Semecarpus cochinchinensis Engl.	2	1, 2
	Gluta usitata (Wall.) Ding Hou	20	1, 2, 3
	Gluta obovata Craib	4	1, 2, 3
	Buchanania latifolia Roxb.	3	1, 3
Bignoniaceae	*Fernandoa adenophylla* (Wall. ex G. Don) Steenis	1	3
Burseraceae	*Canarium subulatum* Guill.	12	1, 2, 3
Combretaceae	*Terminalia alata* Heyne ex Roth.	10	1, 2
Dipterocarpaceae	*Shorea obtusa* Wall. ex Blume.	266	1, 2, 3
	Dipterocarpus obtusifolius Teijsm. ex Miq.	53	1, 2, 3
	Dipterocarpus tuberculatus Roxb.	274	1, 2, 3
	Pentacme siamensis (Miq.) Kurz.	129	1, 2, 3
Dilleniaceae	*Dillenia aurea* Sm.	2	1, 3
Ebenaceae	*Diospyros ehretioides* Wall. ex G. Don	2	1, 2
Ericaceae	*Craibiodendron stellatum* W.W. Smith	37	1, 2, 3
Euphorbiaceae	*Aporosa villosa* (Wall. ex Lindl.) Baill.	17	1, 2, 3
	Bridelia retusa (L.) A. Juss.	1	2
Fagaceae	*Castanopsis* sp.	39	1, 2, 3
	Castanopsis argyrophylla King ex Hook.f.	6	1, 3
	Quercus kerrii Craib.	4	1,3
Lamiaceae	*Vitex pinnata* L.	1	3
Leguminosae-Mimosoideae	*Albizia odoratissima* (L.f.) Benth.	1	1
	Albizia chinensis (Osbeck) Merr.	2	3
Leguminosae-Papilionoideae	*Dalbergia cochinchinensis*	2	1
	Dalbergia cultrata Graham ex Benth.	12	1, 2, 3
	Dalbergia oliveri Gamble.	3	1, 2
	Pterocarpus sp.	2	2
	Pterocarpus macrocarpus Kurz	2	3
	Millettia brandisiana Kurz	1	3
	Dalbergia cultrate	1	2
Melastomataceae	*Memecylon scutellatum* (Lour.) Hook. and Arn. var. *scutellatum*	1	2
Myrtaceae	*Syzygium cumini* (L.) Skeels	5	1, 2, 3
	Syzygium claviflorum (Roxb.) A. M. Cowan and Cowan	5	3
	Syzygium oblatum (Roxb.) Wall. ex A. M. Cowan and Cowan	4	2
Rubiaceae	*Wendlandia tinctoria (Roxb.) DC.*	1	1
	Morinda coreia Buch.-Ham	3	1, 2
	Gardenia sootepensis Hutch.	3	1, 2
Rubiaceae	*Haldina cordifolia* (Roxb.) Ridsdale	1	2
Strychnaceae	*Strychnos nux-blanda* A.W. Hill	1	3
Tiliaceae	*Colona winitii* Craib.	1	2
Unknown	-	7	1, 2
Total		943	

Roxb. was the highest among all, followed by *S. obtusa* Wall. ex Blume. Moreover, *D. tuberculatus* Roxb. also recorded the highest dominance (0.83 plants/plots) and relative dominance (34.02%), followed by *S. obtusa* Wall. ex Blume. with 0.56 plants/plots and 23.14%, respectively. For the IVI, *D. tuberculatus* Roxb. ranked first with an IVI of 77.40%, followed by *S. obtusa* Wall. ex Blume. (64.76%), and the percentage of relative IVI being 25.80% and 21.59%, respectively.

3.3. Social data analysis

Station 1 reported the highest species diversity value of 2.14, while Stations 2 and 3 reported 1.96 and 2.10, respectively. This finding suggests that Station 1 has a higher species diversity in the study plot. Similarly, Station 1 reported the highest species richness index (4.60), indicating a correlation between the number of species and the number of trees. In terms of species evenness index, Station 1 reported more evenness of plant species than the other stations, with a value of 0.66. Overall, across all three stations, the species diversity index was 2.19, the species richness index was 6.86, and the species evenness index was 0.59 (Table 3).

Table 3. Social data analysis

Station	Parameter	Value
1	Species diversity	2.14
	Species richness	4.60
	Species evenness	0.66
2	Species diversity	1.96
	Species richness	4.59
	Species evenness	0.63
3	Species diversity	2.10
	Species richness	4.41
	Species evenness	0.65
All three stations	Species diversity	2.19
	Species richness	6.86
	Species evenness	0.59

3.4. Similarity index analysis

Stations 1 and 2 recorded a similarity index of 82.72% and a difference of 17.28%. Meanwhile, Stations 1 and 3 recorded a similarity index of 67.81% and a difference of 39.19%, while Stations 2 and 3 recorded a similarity index of 59.91% and a difference of 40.09% (Table 4).

Table 4. Similarity index analysis

Stations	Similarity	Percentage
1 and 2	Similarity	82.72
	Dissimilarity	17.28
1 and 3	Similarity	67.81
	Dissimilarity	32.19
2 and 3	Similarity	59.91
	Dissimilarity	40.09

3.5. Correlation analysis

In Station 1, the correlation between DBH and carbon storage was 0.63, indicating a relatively strong relationship. Similarly, the correlation between tree height and carbon storage was 0.59, also reflecting a moderately strong relationship. In Station 2, the correlation between DBH and carbon storage was higher at 0.75, representing a strong relationship, while the correlation between tree height and carbon storage was 0.47, indicating a moderate relationship. In Station 3, the correlation between DBH and carbon storage was the highest at 0.87, showing a very strong relationship, and the correlation between height and carbon storage was 0.85, also considered a strong relationship. Overall, the results suggest that both DBH and tree height are positively correlated with carbon storage across all three stations.

3.6. AGB study

Station 1 contained a total of 354 trees with a total biomass of 21,612.99 kg. This biomass was divided into trunks (13,780.65 kg), branches (2,650.31 kg), leaves (587.14 kg), and roots (4,594.89 kg). Trunks contributed the largest proportion (63.76%), followed by roots (21.26%), branches (12.26%), and leaves (2.72%). Within this station, *D. tuberculatus* Roxb. had the highest biomass (7,356.22 kg), followed by *S. obtusa* Wall. ex Blume. (4,792.19 kg), whereas *Gardenia sootepensis* Hutch. had the lowest biomass (9.07 kg). On a per tree basis, *Albizia odoratissima* (L.f.) Benth. exhibited the highest average biomass (164.44 kg), while *G. sootepensis* Hutch. had the lowest (4.54 kg).

Station 2 contained 358 trees and a total biomass of 19,331.77 kg, comprising trunks (12,328.79 kg), branches (2,367.87 kg), leaves (525.20 kg), and roots (4,109.90 kg). The trunk accounted for the highest proportion (63.77%), followed by roots (21.26%), branches (12.25%), and leaves (2.72%). The species with the highest biomass in this station was *D. tuberculatus* Roxb. (5,831.09 kg), while “Unknown 6” had the lowest (1.78 kg). On a per tree basis, *Pterocarpus* spp. Had the highest average biomass (388.97 kg), followed by *D. obtusifolius* Teijsm. ex Miq. (181.38 kg), with “Unknown 6” showing the lowest (1.78 kg).

Station 3 comprised 231 trees with a total biomass of 26,420.99 kg, distributed among trunks (16,706.60 kg), branches (3,379.75 kg), leaves (717.58 kg), and roots (5,617.06 kg). Trunks again formed the largest component (63.23%), followed by roots (21.26%), branches (12.79%), and leaves (2.72%). The highest species biomass was found in *D. tuberculatus* Roxb. (15,205.55 kg), followed by *D. obtusifolius* Teijsm. ex Miq. (2,491.53 kg), while *Dillenia aurea* Sm. recorded the lowest biomass (12.63 kg).

Overall, across all three stations, the total biomass was 67,365.74 kg, consisting of 42,816.04 kg in trunks (63.56%), 8,397.93 kg in branches (12.47%), 1,829.92 kg in leaves (2.72%), and 14,321.85 kg in roots (21.26%).

3.7. Carbon storage

Station 1 contained a total of 354 trees with a total carbon storage of 10,158.10 kg of carbon (kg C), a mean of 635.93 kg C, and a standard deviation of 150.85. This comprised 6,476.90 kg C in trunks (with a proportion of 63.76%), 1,245.65 kg C in branches (12.26%), 275.96 kg C in leaves (2.72%), and 2,159.60 kg C in roots (21.26%). Among species, *D. tuberculatus* Roxb. stored the greatest amount of carbon (3,457.47 kg C; 34.04% of the total), followed by *S. obtusa* Wall. ex Blume. (2.17%). The lowest value was recorded for *G. sootepensis* Hutch. (4.26 kg C). In terms of mean carbon storage per tree, *A. odoratissima* (L.f.) Benth. had the highest value (77.29 kg C), followed by *Semecarpus cochinchinensis* Engl. (71.21 kg C), whereas *G. sootepensis* Hutch. had the lowest average (2.13 kg C).

Station 2 contained a total of 358 trees with a total carbon storage of 9,085.93 kg C, a mean of 567.87 kg C, and a standard deviation of 190.32. This comprised 5,794.53 kg C in trunks (63.77% of total), 1,112.90 kg C in branches (12.79%), 246.85 kg C in leaves (2.72%), and 1,931.66 kg C in roots (21.26%). Among species, *D. tuberculatus* Roxb. had the highest carbon storage (2,740.61 kg C; 30.16% of total), followed by *S. obtusa* Wall. ex Blume. (2,296.79 kg C; 25.28%). The lowest value was recorded for “Unknown 6” (0.84 kg C). In terms of mean carbon storage per tree, *Pterocarpus* spp. had the highest value (182.82 kg C), followed by *D. obtusifolius* Teijsm. ex Miq. (85.25 kg C), whereas “Unknown 6” had the lowest average (0.84 kg C).

Station 3 contained a total of 231 trees with a total carbon storage of 12,417.86 kg C (or 65,960 kg C/ha), a mean of 776.12 kg C, and a standard deviation of 319.60. This comprised 7,852.10 kg C in trunks (63.23%), 1,588.48 kg C in branches (12.79%), 337.26 kg C in leaves (2.71%), and 2,640.02 kg C in roots (21.26%). Among species, *D. tuberculatus* Roxb. had the highest carbon storage (7,146.61 kg C; 57.55% in total), while *D. aurea* Sm. had the lowest (5.94 kg C). *D. obtusifolius* Teijsm. ex Miq. contributed 9.43% of the total carbon. In terms of mean carbon storage per tree, *Quercus kerrii* Craib. had the highest value (117.31 kg C), followed by *D. obtusifolius* Teijsm. ex Miq. (83.64 kg C), while *D. aurea* Sm. had the lowest (5.94 kg C).

Overall, across all three stations, the total carbon storage was 31,661.90 kg C, consisting of 20,123.54 kg C in trunks (63.55% of total), 3,947.03 kg C in branches (12.47%), 860.06 kg C in leaves (2.72%), and 6,731.27 kg C in roots (21.26%). The highest contributor was *D. tuberculatus* Roxb., accounting for 42.00% of the total carbon storage.

3.8. Biomass and carbon storage of saplings and undergrowth trees

The saplings had a total biomass of 3,195.48 kg and a total carbon storage of 1,501.88 kg C, while the undergrowth trees recorded 0.00831 kg and 0.00391 kg C, respectively (Table 5).

Based on the overall carbon storage results, the carbon storage in the forest area at the University of Phayao (4.16 km^2) was estimated to be 20,392.36 t C (49.02 t C/ha). This total comprised 11,708.25 t C in trunks (57.41% of total), 2,949.34 t C in branches (14.46%), 1,277.88 t C in leaves (6.27%), and 4,456.89 t C in roots (21.86%). Overall, the forest area had an estimated carbon absorption capacity of 105,149.10 t of carbon dioxide and could release 76,419.83 t of oxygen (Table 6). A statistical comparison using the Duncan method indicated that the carbon storage of Station 1 was not significantly different from that of Stations 2 and 3 (Table 7).

Table 5. The quantity of biomass and carbon storage of saplings and undergrowth trees

Parameters	Saplings	Undergrowth trees
Biomass		
Total (kg)	3,195.48	0.00831
Density (kg/ha)	6657.00	0.01731
Carbon storage		
Total (kg C)	1,501.88	0.00391
Density (kg C/ha)	3128.90	0.00815

Table 6. Overview of the results

Stations	Number (trees)	Number (species)	Total biomass (kg)	Carbon storage (kg C)
1	354	26	21,612.99	10,158.10
2	358	23	19,331.77	9,085.93
3	231	25	26,420.99	12,417.86
Total	943	-	67,365.74	31,661.90
Carbon storage of aboveground biomass per station (kg C)				10,553.97±0.98
Carbon storage of saplings per station (kg C)				500.63
Carbon storage of undergrowth trees per station (kg C)				0.00130
Carbon storage of the total forest area, 4.16 km^2 (t C/ha)				49.02
Carbon dioxide absorption of the total forest area (t)				105,149.10
Oxygen released from the total forest area (t)				76,419.83

Table 7. Statistical comparison using ANOVA and Duncan *post hoc* test

Stations	Number of plots	Mean carbon storage per plot (kg C)	SD	SE
1	16	635.93	150.85	37.71
2	16	567.87	196.32	49.08
3	16	776.12	319.60	79.90
Total	48	659.97	244.62	35.31
Duncan		Number of plots	Subset for alpha=0.05	
		1	2	
Station 1		16	635.93	635.93
Station 2		16	567.87	
Station 3		16		776.12
Significance			0.414	0.096

3.9. Analysis of physical factors

The carbon storage in 2018 was compared with that in 2015, based on a previous study conducted in the same dipterocarp forest. When analyzing the relationship between average physical factors and carbon storage across the three stations in 2015 and 2018, it was found that Station 1 in both years showed the closest fit to the trend line. The carbon storage values were 78 t C and 63.49 t C in 2015 and 2018, respectively, with corresponding average temperatures of 25.10°C and 26.22°C, average rainfall of 83.74 mm and 122.78 mm, and relative humidity levels of 64.02% and 81.43%. The analysis revealed that temperature, rainfall, and relative humidity were inversely correlated with carbon storage, with a correlation coefficient of −0.33, indicating a moderate negative relationship.

4. Discussion

In this study, the University of Phayao in Phayao district, Phayao province, Thailand, covers an area of approximately 1,027.27 acres (4.16 km^2). The research was conducted in three stations with a total area of 4,800 m^2, equivalent to 1,600 m^2 per station. Across the three stations, the dipterocarp forest contained 943 trees, belonging to 18 families and 41 species. *D. tuberculatus* Roxb. was identified as the dominant species in this area.

When compared to international studies, similar findings have been reported. For example, Darmawan *et al*.,[21] in Bukit Tigapuluh National Park, Indonesia, found that Dipterocarpaceae was the dominant family, represented by 32 species and 2,572 individuals in the dipterocarp forest. Similarly, Das *et al*.[6] reported 19 species from 16 families in the Trishna Wildlife Sanctuary, northeast India, where Dipterocarpaceae was dominant. Dipterocarpaceae also dominated the mixed dipterocarp forests of southwest Sri Lanka.[22] This consistency highlights that Dipterocarpaceae, a tropical and sub-tropical family, forms a significant component of lowland rainforests across Southeast Asia.[3,23,24]

Analysis of species composition and IVI across Stations 1, 2, and 3 showed that Dipterocarpaceae had the highest density, relative density, frequency, relative frequency, dominance, and relative dominance, particularly for *D. tuberculatus* Roxb. and *S. obtusa* Wall. ex Blume. The results of this study are consistent with previous studies. Thichan *et al*.[25] found that *S. obtusa* and *D. tuberculatus* had the highest densities in the dipterocarp forest of Huai Hong Khrai Royal Development Study Center, ranging from 1,688 to 3,606 trees/ha and 3,594 trees/ha, respectively.

Similarly, Harnelly *et al*.[26] found that the relative density of Dipterocarpaceae species across growth stages in primary forest and secondary forest ranged from 0.24 to 10.2%, dominated by *Shorea* spp. and *Dipterocarpus* spp. In terms of frequency, Kaewfoo *et al*.[27] noticed that *D. tuberculatus* had the highest frequency (97), followed by *S. obtusa* in Mae Ping National Park, northern Thailand. In addition, Susilowati *et al*.[28] reported *Shorea leprosula* as the dominant species in terms of relative frequency (19.67%). Studies of dominance also confirm these findings, with Das *et al*.[29] noting *D. turbinatus* as having the highest relative dominance (53.15%) in dipterocarp forests. Therefore, the IVI values recorded in this study closely align with those of previous.

Social data analysis, particularly the species diversity index, combines both species richness and species evenness to reflect the overall diversity of species. In some cases, two communities may share the same diversity index value even though one has low species richness but high evenness, while the other shows the opposite pattern. Species diversity is closely related to species dominance: as certain species become dominant, diversity tends to decline. Over time, species diversity may increase with species substitution but will stabilize when only a few dominant species persist, making it a useful indicator of community stability. The species richness index indicates the number of plant species found at each station and depends on the relationship between the total species recorded and the total number of individuals sampled. This value generally increases with sample size. On the other hand, the species evenness index reflects how evenly individuals are distributed among species. When all species have similar abundances, evenness is high; however, when some species are much more abundant than others, evenness decreases. In this study, the low species evenness observed highlights differences in the number of individuals among species.

Research on AGB using allometric equations is more suitable than other methods in this research, particularly the volume-based method, because it provides higher accuracy despite requiring more information. Allometric equations, which use DBH and tree height, are widely applied to estimate the biomass of trunks, branches, and leaves, from which carbon storage can be calculated and converted into carbon dioxide sequestration. The total biomass of trees across the three study stations in this study was 67,365.74 kg, and the total carbon storage was 31,661.90 kg C. Thus, with about 4.16 km^2 of remaining forest at the University of Phayao, the estimated total carbon storage in biomass was 49.02 t C/ha, equivalent to 105,149.10 t of carbon dioxide sequestration and 76,419.83 t of oxygen release. These findings are consistent with other dipterocarp studies. For example, Idris *et al*.[30] reported higher carbon stock (20.37 ± 0.52 kg/tree) in native dipterocarp species in lowland Gunung Ledang, Malaysia, which aligns with this study, where carbon stock ranged from 20 to 30 kg/tree. Similarly, Indrajaya and Mulyana[31] examined the Cigerendeng Research Forest, West Java (7.62 ha, 18 blocks of dipterocarps), and reported carbon storage of 156 t/ha in 2009 and 199 t/ha in 2015. In comparison, the University of Phayao had 49.02 t C/ha, which is lower due to differences in trunk size and tree density among sites.[32]

The study revealed that Station 3 had the highest value of carbon stock in biomass, with 12,417.86 kg C, exceeding that of Stations 1 and 2, which contained 10,158.10 kg C and 9,085.93 kg C, respectively. Although Station 3 had fewer trees, its larger tree diameters and sizes contributed to higher biomass and consequently greater carbon storage.[33] The carbon stock of trees is closely tied to biomass; trees with higher biomass provide higher carbon storage. Conversely, low carbon storage levels are influenced by forest management, forest conditions, and external factors such as deforestation, forest fires, and climate change.[34-36] For example, deforestation and climate change are critical global challenges that reduce forest carbon absorption and storage capacity.[34] Ediriweera *et al*.[22] reported that AGB decreased by 17% over 40 years due to windstorms, landslides, climate change, and El Niño and La Niña drought.

The analysis of physical factors showed that temperature, rainfall, and relative humidity negatively affect carbon storage. Specifically, higher temperatures sharply reduced carbon storage,[37] increased rainfall corresponded to a decrease in carbon storage,[38] and elevated relative humidity also limited carbon sequestration.[39]

Beyond natural forest dynamics, research highlights the application of carbon storage methods in broader land-use systems. Agroforestry, for example, allows multiple crops to be cultivated alongside sedge, enhancing carbon sequestration while improving ecosystems and soil health.[40] Community-based agriculture and diversified carbon sources from agroforestry, monoculture, and natural rainforests have also been shown to mitigate global warming.[16] Similarly, studies assessing changes in carbon storage caused by hydroelectric dam construction underscore the impacts of land-use change on carbon dynamics.[34]

In summary, the collection of forest carbon data plays an important role in addressing climate change. Accurate measurements not only provide insight into the impacts of deforestation, forest burning, and forest pollution but also inform conservation of forest resources, protection of biodiversity, and community benefits derived from sustainable forest management.

5. Conclusion

This study identified 943 trees belonging to 18 families and 41 species across three stations, with an estimated carbon storage of 49.02 t C/ha in the total area of the University of Phayao. The IVI was highest for *D. tuberculatus* Roxb. (77.40%), followed by *S. obtusa* Wall. ex Blume. (64.76%), *P. siamensis* (Miq.) Kurz. (37.59%), and *D. obtusifolius* Teijsm. ex Miq. (23.04%). The species diversity index was 2.19, species richness was 6.86, and species evenness was 0.59. Analysis of the relationship between physical factors and carbon storage showed a moderate negative correlation ($r = -0.33$). These findings highlight the ecological importance of dipterocarp species in maintaining forest biomass and carbon storage, while also emphasizing the influence of environmental factors on carbon dynamics.

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Conflict of interest

The authors declare that there is no conflict of interest.

Author contributions

Conceptualization: Sitthisak Pinmongkhonkul
Formal analysis: All authors
Investigation: All authors
Methodology: Sitthisak Pinmongkhonkul
Writing–original draft: All authors
Writing–review & editing: All authors

Availability of data

The data that support the findings of this study are available on request from the corresponding author.

References

1. Widiyatno W, Hidayati F, Hardiwinoto S, *et al*. Selection of dipterocarp species for enrichment planting in a secondary tropical rainforest. *Forest Sci Technol*. 2020;16(4):206-215. doi: 10.1080/21580103.2020.1831620
2. Luo W, Strijk JS, Barstow M, Wee AK. The role of protected areas in tropical tree conservation post-2020: A case study using threatened Dipterocarpaceae. *Biol Conserv*. 2022;272:109634. doi: 10.1016/j.biocon.2022.109634
3. Cvetković T, Hinsinger DD, Thomas DC, Wieringa JJ, Velautham E, Strijk JS. Phylogenomics and a revised tribal classification of subfamily Dipterocarpoideae (Dipterocarpaceae). *Taxon*. 2022;71(1):85-102. doi: 10.1002/tax.12648
4. Romadini NP, Indrioko S, Widiyatno W, Faridah E. Regeneration failure and seedling growth of *Dipterocarpus gracilis*, a vulnerable dipterocarp in a tropical monsoon forest in Central Java, Indonesia. *Biodivers J Biol Divers.* 2022;23(9):4928-4939. doi: 10.13057/biodiv/d230963
5. Asanok L, Taweesuk R, Kamyo T. Plant functional diversity is linked to carbon storage in deciduous dipterocarp forest edges in Northern Thailand. *Sustainability*. 2021;13(20):11416. doi: 10.3390/su132011416
6. Das S, Nama A, Deb S, Sahoo UK. Soil quality, carbon stock and climate change mitigation potential of Dipterocarp natural and planted forests of Tripura, Northeast India. *Vegetos*. 2023;36(3):1105-1118. doi: 10.1007/s42535-022-00515-y
7. Plybour C, Laosuwan T, Uttaruk Y, *et al*. An investigation of plant species diversity, above-ground biomass, and carbon stock: Insights from a dry dipterocarp forest case study. *Diversity*. 2025;17(6):428. doi: 10.3390/d17060428
8. Gabric AJ. The climate change crisis: A review of its causes and possible responses. *Atmosphere*. 2023;14(7):1081. doi: 10.3390/atmos14071081
9. Audi M, Ali A, Kassem M. Greenhouse gases: A review of losses and benefits. *Int J Energy Econ Policy.* 2020;10(1):403-418. doi: 10.32479/ijeep.8416
10. Prudil J, Pospíšilová L, Dryšlová T, *et al*. Assessment of carbon sequestration as affected by different management

practices using the RothC model. *Plant Soil Environ*. 2023;69(11):532-544.
doi: 10.17221/291/2023-PSE

11. Dagiliūtė R, Kazanavičiūtė V. Impact of land-use changes on climate change mitigation goals. The Case of Lithuania. *Land*. 2024;13(2):131.
doi: 10.3390/land13020131
12. Nunes LJ, Meireles CI, Pinto Gomes CJ, Almeida Ribeiro NM., Forest contribution to climate change mitigation: Management oriented to carbon capture and storage. *Climate*. 2020;8(2):21.
doi: 10.3390/cli8020021
13. Kabir M, Habiba UE, Khan W, *et al*. Climate change due to increasing concentration of carbon dioxide and its impacts on environment in 21st century; a mini review. *J King Saud Univ Sci*. 2023;35(5):102693.
doi: 10.1016/j.jksus.2023.102693
14. Begum RA, Raihan A, Said MNM. Dynamic impacts of economic growth and forested area on carbon dioxide emissions in Malaysia. *Sustainability*. 2020;12(22):9375.
doi: 10.3390/su12229375
15. Raihan A, Begum RA, Mohd Said MN, Pereira JJ. Assessment of carbon stock in forest biomass and emission reduction potential in Malaysia. *Forests*. 2021;12(10):1294.
doi: 10.3390/f12101294
16. Besar NA, Suardi H, Phua MH, James D, Mokhtar MB, Ahmed MF. Carbon stock and sequestration potential of an agroforestry system in Sabah, Malaysia. *Forests*. 2020;11(2):210.
doi: 10.3390/f11020210
17. Cairns MA, Brown S, Helmer EH, Baumgardner GA. Root biomass allocation in the world's upland forests. *Oecologia*. 1997;111:1-11.
doi: 10.1007/s004420050201
18. Shannon CE. A mathematical theory of communication. *Bell Syst Tech J*. 1949;27(3):379-423.
doi: 10.1002/j.1538-7305.1948.tb01338.x
19. Wolda H. Similarity indices, sample size, and diversity. *Oecologia*. 1981;50(3):296-302.
doi: 10.1007/BF00344966
20. Rahman IU, Hart R, Afzal A, *et al*. A new ethnobiological similarity index for the evaluation of novel use reports. *Appl Ecol Environ Res*. 2019;17(2):2765-2777.
doi: 10.15666/aeer/1702_27652777
21. Darmawan A, Warta Z, Molidena E, *et al*. Aboveground forest carbon stock in protected area: A case study of Bukit Tigapuluh National Park, Indonesia. *J Trop Biodivers Biotechnol*. 2022;7(1):64827.
doi: 10.22146/jtbb.64827
22. Ediriweera S, Bandara C, Lakkana T, *et al*. Old-growth mixed dipterocarp forests show variable losses and gains in aboveground biomass and standing carbon over forty years. *Forest Ecosyst*. 2024;11:100163.
doi: 10.1016/j.fecs.2023.100163
23. Khan MA, Spicer RA, Spicer TE, *et al*. *Dipterocarpus* (Dipterocarpaceae) leaves from the K-Pg of India: A cretaceous gondwana presence of the Dipterocarpaceae. *Plant Syst Evol*. 2020;306:1-18.
doi: 10.1007/s00606-020-01718-z
24. Malik N, Edwards D, Freckleton RP. Comparative analyses and phylogenetic dependence in traits and trends of the dipterocarpaceae. *Ecol Evol*. 2025;15(1):e70784.
doi: 10.1002/ece3.70784
25. Thichan T, Anongrak N, Khamyong S, Kachina P. Restoration of water storage potential in a degraded dry dipterocarp forest with enrichment planting of three needle pine (*Pinus kesiya* Royle ex Gordon), Northern Thailand. *Environ Nat Resour J*. 2021;19(1):10-23.
doi: 10.32526/ennrj/19/2020130
26. Harnelly E, Fitri I, Kusuma HI. Assessing dipterocarp diversity at soraya research station, leuser ecosystem. *J Penelitian Pendidikan*. 2025;11(4):1-9.
doi: 10.29303/jppipa.v11i4.10599
27. Kaewfoo M, Bunyavejchewin S, Marod D, *et al*. Termitaria enhance soil and forest diversity in deciduous dipterocarp forest, Northern Thailand. *J Trop Ecol*. 2024;40:e5.
doi: 10.1017/S0266467423000342
28. Susilowati A, Rachmat HH, Elfiati D, *et al*. Floristic composition and diversity at keruing (*Dipterocarpus* spp.) habitat in tangkahan, gunung leuser national park, indonesia. *Biodivers J Biol Divers*. 2021;22(10):4448-4456.
doi: 10.13057/biodiv/d221038
29. Das SC, Alam MS, Hossain MA. Diversity and structural composition of species in dipterocarp forests: A study from Fasiakhali Wildlife Sanctuary, Bangladesh. *J Forest Res*. 2018;29:1241-1249.
doi: 10.1007/s11676-017-0548-7
30. Idris A, Linatoc AC, Takai ZI. Carbon storage in relation to plant species of lowland dipterocarp vegetation of Gunung Ledang, Malaysia. *Dutse J Pure Appl Sci*. 2024;10(4c):158-165.
doi: 10.4314/dujopas.v10i4c.15
31. Indrajaya Y, Mulyana S. Carbon stored in tree biomass of Cigerendeng Research Forest, Ciamis, West Java. *IOP Conf Ser Earth Environ Sci*. 2020;487(1):012004.
doi: 10.1088/1755-1315/487/1/012004
32. Zhao M, Sun M, Xiong T, Tian S, Liu S. On the link between tree size and ecosystem carbon sequestration capacity across continental forests. *Ecosphere*. 2022;13(6):e4079.
doi: 10.1002/ecs2.4079
33. Ma SH, Eziz A, Tian D, *et al*. Size-and age-dependent increases in tree stem carbon concentration: Implications for forest carbon stock estimations. *J Plant Ecol*. 2020;13(2):233-240.
doi: 10.1093/jpe/rtaa005
34. Dullah H, Malek MA, Omar H, Mangi SA, Hanafiah MM.

Assessing changes of carbon stock in dipterocarp forest due to hydro-electric dam construction in Malaysia. *Environ Sci Pollut Res*. 2021;28:44264-44276. doi: 10.1007/s11356-021-13833-6

35. Case MJ, Johnson BG, Bartowitz KJ, Hudiburg TW. Forests of the future: Climate change impacts and implications for carbon storage in the Pacific Northwest, USA. *Forest Ecol Manag*. 2021;482:118886. doi: 10.1016/j.foreco.2020.118886
36. Bargali H, Pandey A, Bhatt D, Sundriyal RC. Loss of carbon stock in the forests of Uttarakhand due to unprecedented seasonal forest fires. *Front Forests Glob Change*. 2024;7:1352265. doi: 10.3389/ffgc.2024.1352265
37. Zhou R, Li W, Zhang Y, *et al*. Responses of the carbon storage and sequestration potential of forest vegetation to temperature increases in Yunnan Province, SW China. *Forests*. 2018;9(5):227. doi: 10.3390/f9050227
38. Li B, Gao G, Luo Y, Xu M, Liu G, Fu B. Carbon stock and sequestration of planted and natural forests along climate gradient in water-limited area: A synthesis in the China's Loess plateau. *Agric Forest Meteorol*. 2023;333:109419. doi: 10.1016/j.agrformet.2023.109419
39. Gong C, Tan Q, Liu G, Xu M. Forest thinning increases soil carbon stocks in China. *Forest Ecol Manag*. 2021;482:118812. doi: 10.1016/j.foreco.2020.118812
40. Duangthip N, Anongrak N, Kachina P, Khamyong S. Plant community structure and carbon storage in a dry Dipterocarp community forest with using *Dipterocarpus tuberculatus* Roxb. leaves as forest product, Northern Thailand. *Thai Forest Ecol Res J*. 2022;6(1):13-30.