

Species Diversity, Aboveground Biomass, and Carbon Storage of Watershed Forest in Phayao Province, Thailand

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ARTICLE INFO

Received: 28 Apr 2022
Received in revised: 22 Sep 2022
Accepted: 26 Sep 2022
Published online: 2 Nov 2022
DOI: 10.32526/enrj/21/202200121

Keywords:

Tree diversity/ Tree biomass/
Carbon sequestration/ Seasonal
tropical forest/ Phayao

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ABSTRACT

Restoration of watershed forest ecosystems can perform different disturbance regimes over remnant forests, which can ultimately affect plant diversity, soil formation, and carbon storage. To address an issue, this study assessed tree species diversity, aboveground biomass (AGB), and aboveground carbon (AGC) storage of the watershed forest in Phayao Province, Thailand. Data collection was conducted in 18 plots along nine watersheds along the topographic gradients. Tree height and diameter at breast height (DBH) were collected. AGB of vegetation was estimated by using the allometric equation. Likewise, AGC storage was evaluated from half of AGB. A total of 133 species belonging to 105 genera and 39 families were recorded from the watershed forests (1.8 ha). Mixed deciduous forest (MDF) and dry evergreen forest (DEF) exhibited high density and high diversity index, respectively. The highest value of total AGC storage was found in the MDF with 91.2 ton C/ha, following by DEF (78.3 ton C/ha) and dry dipterocarp forest (DDF) (60.5 ton C/ha). Detrended correspondence analysis (DCA) revealed that the occurrences of *Albizia saman*, *Hopea odorata*, *Lagerstroemia calyculata*, and *Acrocarpus fraxinifolius* related to AGB, AGC, slope, and tree canopy in the DEF. Intensity of slope influenced tree species occurrence in the watershed forest of Phayao.

1. INTRODUCTION

Tropical forests have the greatest biodiversity, which contribute up to 50% of the terrestrial primary production and 25% of global terrestrial carbon. Likewise, the highest biomass stock per hectare (ha) is in tropical forests, with values above 200 ton/ha. (FAO, 2020). Tropical forests are important as a global CO₂ sink (IPCC, 2001) with an estimate of 3.1-3.7×1,016 g of carbon (C) per year (equivalent to 11.4-13.6×1,016 g of CO₂) absorbed and converted into plant materials. (Solomon et al., 2007; Malhi and Grace, 2000). During the twentieth century, biodiversity has

been threatened by human activity and climate change which affects primary productivity, carbon sequestration, and species diversity (FAO, 2010). In particular, climate events, such as El Niño, have an impact on biodiversity and the ecosystem that is essential to human life (Sala et al., 2000). Thus, assessing aboveground biomass (AGB) as well as aboveground carbon (AGC) storage precisely helps in moderating the effect of climate change. Also, clarification of biomass and carbon storage of plant diversity could allow us to better understand the function of the forests and ecological services.

Citation: Pimongkhonkul S, Boonriam W, Madhyamapurush W, Iamchuen N, Chaiwongsaen P, Mann D, Riyamongkol P, Seetapan K, Hasin S. Species diversity, aboveground biomass, and carbon storage of watershed forest in Phayao Province, Thailand. Environ. Nat. Resour. J. 2023;21(1):47-57. (<https://doi.org/10.32526/enrj/21/202200121>)

In Thailand, forest cover was estimated to be 43.33% of the country's total area in 1973. Forest cover has declined significantly to 25.1% in 1999 due to expanding agricultural land (RFD, 2016). However, forest cover of Thailand has been approximately stable at 31.57-31.62% from 2014 to 2019 according to the current estimates of forest area by Royal Forest Department (RFD, 2020). Meanwhile, the other land use was about 46% and 22% for agriculture and non-agriculture, respectively. In the north, forests are mainly characterized by the presence of mixed deciduous forest (MDF) and dry dipterocarp forest (DDF) which account for 53.39% and 11.43%, respectively (RFD, 2007; Chaiyo et al., 2011). Deforestation and forest degradation have created serious problems in the forest ecosystem as well as soil and water management problems (Steininger et al., 2001). Erosion of soil due to land use patterns of shifting cultivators in Northern Thailand degrades the watershed area.

Watershed forest plays a significant role in forest hydrology, absorbing rainfall to maintain stream flows, underground waters, and reservoirs (Gilmour, 2014). The fluctuations of warming temperatures and variable precipitation are expected to affect the ecosystem of the watershed forest and also the water situation (Sintayehu, 2018). This issue is the challenge for monitoring forest productivity and function which can approach the conservation and management of natural resource values such as protecting local resources, enhancing biodiversity, and sustaining productive biomass. Previous studies have considered that the increase in plant species diversity will increase AGC storage (Poorter et al., 2015; Mensah et al., 2016). In addition, forest type influences the impact of 12% on AGC storage, which means the relationship between AGC and attributed factors varies across forest types (Jia et al., 2022). In order to support the improvement of the 2006 IPCC rules for national greenhouse gas inventories, Jha et al. (2020) predicted that the rate of AGB and AGC recovery was around 50% greater in 2019 than in the last 20 years for secondary Thai tropical forests.

The watershed forest of Phayao Lake (Kwan Phayao) is the origin of the Ing River Basin as a tributary of the Mekong River. Generally, the forests where the original source of the rivers to Kwan Phayao are mainly the MDF, DDF, dry evergreen forest (DEF), and moist evergreen forest (MEF) (Klaydach and Khunrattanasiri, 2012). However, the Ing Watershed has occurred as the main three-dimensional problem comprising the extreme drought in the dry season,

severe flooding in the rainy season, and water quality at the present. Thus, it is essential to observe the characteristics of the watershed forest in Phayao and the situation of the forest. This is one of the best approaches for evaluating forest management problems. Consequently, this study was conducted to determine the tree species diversity, AGB, and AGC storage in a watershed forest in Phayao Province, Thailand.

2. METHODOLOGY

2.1 Study area

The study was performed in a tropical seasonal forest in Phayao Province, Northern Thailand. The study sites were in most of Doi Luang National Park representing the watershed forest of Phayao Lake (Kwan Phayao) and Ing River (19°10'N, 99°80'E; about 500-700 m above sea level) which flows to the Mekong River. In this study, the watershed forest was divided into nine sub-watershed areas based on the main reservoir in each sub-district (Figure 1) as follows; 1) Mae Tam reservoir, Mae Tam Sub-district (P1), Mae Na Ruea reservoir, Mae Na Ruea Sub-district (P2), Ban Ton reservoir; Ban Ton-Ban Sang Sub-district (P3), Huai Thap Chang reservoir, San Pa Muang Sub-district (P4), Huai Luek reservoir, Ban Tom Sub-district (P5), Huai Mae Tum reservoir, Tha Cham Pe Sub-district (P6), Huai Mae Yian reservoir, Ban Mai Sub-district (P7), Mae Chawa reservoir, Mae Suk Sub-district (P8), and Mae Suk reservoir, Mae Suk Sub-district (P9). The total annual rainfall was 1,137 mm with the monthly rainfall less than 90 mm during the dry season from November to April. The mean annual temperature was 25.9°C (13.7-36.0°C). The total means of elevation and slope in the study plots (n=18) were 597±69.4 m (508-760 m) and 14.8±8.3% (2.15-32.4%), respectively.

2.2 Data collection on plant diversity, community structure, and topography

A total of 18 main plots (50 m × 20 m in each) were established in the watershed forest of Phayao. Twenty subplots (10 m × 10 m in each) were set up in each sub-watershed area (Figure 2). The surveyed data on plant diversity and community structure were recorded during the period from 2019 to 2020. All trees were identified, with measurement of diameter at breast height (DBH, ≥4.5 cm) at 1.3 m above ground, and height (m) measured by the principle of triangulation with a clinometer. The tree species were identified by using the identification of wild plants Vol. 1 and Vol. 2 (DNP, 2007a; DNP, 2007b).

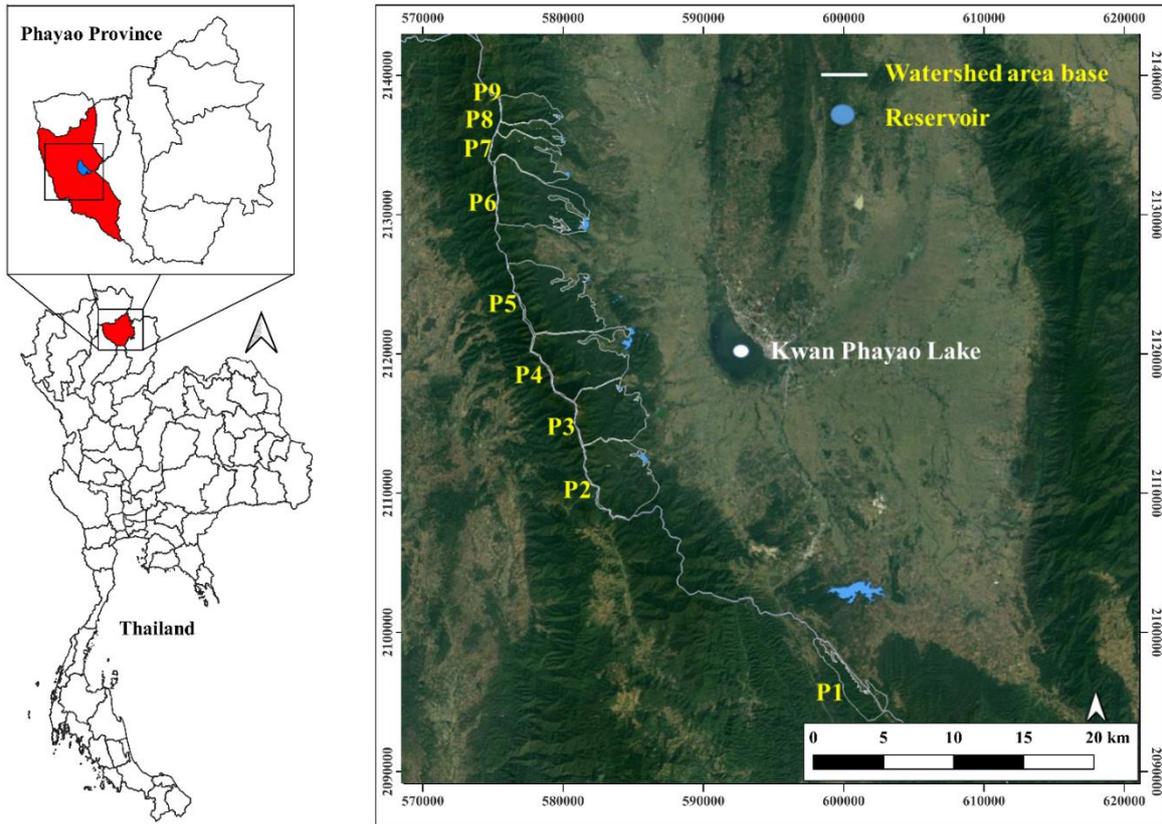


Figure 1. Study area in watershed forest of Phayao Lake (Kwan Phayao) and Ing River

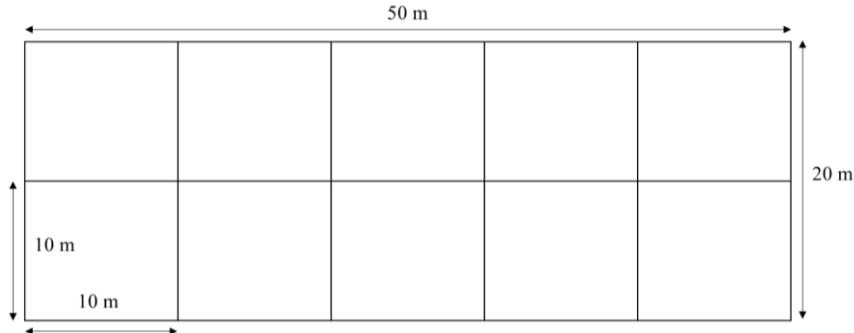


Figure 2. Experiment design of main plot (1,000 m²) with placement of 100 m² in each subplot

Species diversity and community structure of the trees were calculated using the Shannon-Wiener diversity index (H'), Margalef richness (R), and Equitability of Pielou (J') (Krebs, 1985). These statistical analyses were performed by using PAST statistics software ver. 3.0. The relative ecological importance of each tree species was expressed using

the Importance Value Index (IVI), which was calculated as Equation (1):

$$IVI = RDo + RD + RF \quad (1)$$

Where; RDo is Relative dominance, RD is Relative density, RF is Relative frequency, which was calculated as follow (2),(3),(4):

$$Rdo = (\text{total basal area of a species} / \text{total basal area of all species}) \times 100 \quad (2)$$

$$RD = (\text{number of individuals of a species} / \text{total number of individuals}) \times 100 \quad (3)$$

$$RF = (\text{frequency of a species} / \text{sum frequency of all species}) \times 100 \quad (4)$$

The tree density (D_i) in the plots was calculated by using the Equation (5) as follows:

$$D_i = (X_i/a_i) \quad (5)$$

Where; D_i is the tree density, X_i is the total number of species of trees (i), and a_i is the study area of the tree (i).

Site-specific elevation, slope, and soil loss were measured at each study site. The elevation of the study area was measured in meters above sea level (m.a.s.l.). Soil loss (A) was evaluated by using a model of Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) which implemented in ArcGIS 10.1 software supposes the multiplication of the five involved factors, at the level of each grid cell with 30 m spatial resolution, using Raster calculator tool (6):

$$A = R \times K \times L \times S \times C \times P \quad (6)$$

Where; R is the rainfall-runoff erosivity factor, K is a soil erodibility factor, L is the slope length factor, S is the slope gradient factor, C is a cover management factor, and P is a supporting practices factor.

2.3 ABG allometric equation and AGC storage

ABG in the watershed forests was calculated using the specific allometric equation as a function of tree height (H), and DBH (D), including the biomass of stem (W_s)(7), biomass of branch (W_b)(8), and biomass of leaf (W_l)(9). The sum of W_s , W_b , and W_l (W_{tc} is a total mass of stem and branch) is the total ABG in a tree. The ABG allometric equations were used to analyze for DDF and MDF in this study (Ogawa et al., 1965) as follows:

$$W_s = 0.0396 \times (D^2 \times H)^{0.9326} \quad (7)$$

$$W_b = 0.003487 \times (D^2 \times H)^{1.0270} \quad (8)$$

$$W_l = (28.0/W_{tc} + 0.025)^{-1} \quad (9)$$

Generally, ABG is considered for an average AGC of approximately 45 to 50% (by oven-dry mass) in all plant species (Schlesinger, 1991). According to various applications, as well as this study, the AGC of vegetation was calculated by multiplying the biomass

amounts with the average carbon contents (0.475) in the trees (Solomon et al., 2007).

2.4 Statistical analysis

Pearson's correlation test was used to examine relationships between AGB and tree sizes (i.e., DBH and height). Tree species were grouped based on the similarity of their attributes by using hierarchical clustering analysis. Based on the ordination analysis, detrended correspondence analysis (DCA) was used to elucidate the relationships between biological assemblages of tree species and environmental factors. All these statistical analyses were performed by using PC-ORD ver. 5.10.

3. RESULTS

3.1 Forest composition and species density

The forest in Phayao watershed had 1,464 tree individuals recorded representing 133 species from 105 genera and 39 families from the total area (1.8 ha). *Lagerstroemia calyculata* and *Gigantochloa albociliata* accounted for the highest number of individuals of wood and bamboo, respectively. The highest number of species was represented by Fabaceae with eight genera and 15 species, while the other families contributed from one to nine species (Supplementary data: Table S1). According to the topographic gradient, the highest number of tree individuals (205 individuals) was found in P2 consisting of 23 families, 35 genera, and 37 species, while the lowest was found in P1 (91 individuals) consisting of 17 families, 24 genera, and 26 species (Table 1). At each site, the forests were dominated by a number of family of Fabaceae, except for the P7. The average tree density was 813 individuals/ha in the watershed forest consisting of the highest and the lowest of the tree densities in P2 and P1, respectively.

3.2 Tree diversity value index and Importance Value Index (IVI)

The highest tree diversity value index was found in P9 with 3.75, 11.56, and 0.77 of Shannon-Wiener diversity index (H'), richness index, and equitability index, respectively. While the watershed forest in P5 showed the lowest of the biodiversity indices except for the richness indices by Margalef index (R) (Table 2). The range of species diversity index (H') was between 2.75 to 3.75.

Table 1. Species composition, density, total basal of stem, and its topography of watershed forest of Phayao Lake (Kwan Phayao), Thailand

Forest site	Elevation (m)	Slope (%)	Family	Genus	Species	Density (individual/ha)	Basal area of stem (m ² /ha)	USLE (ton/ha/year)
P1	575	20.80	17	24	26	455	26.39	0.65
P2	614	8.06	23	35	37	1,025	32.51	0.61
P3	556	7.69	22	36	38	940	31.05	0.68
P4	667	21.09	21	32	35	815	23.97	2.86
P5	512	7.82	25	34	38	875	28.89	4.76
P6	536	13.05	19	30	31	720	25.23	1.30
P7	701	24.32	24	40	42	1,005	26.40	1.26
P8	584	14.61	25	43	47	730	25.06	0.81
P9	537	16.77	30	53	59	755	28.70	0.69
Mean±SD	597±69.4	14.8±8.4	23±3.8	36±8.3	39±9.5	813±176.4	27.58±2.80	1.51±1.41

Table 2. Species richness and biodiversity index of trees in Phayao Watershed Forest

Forest site	Number of species	Density		Richness indices (Margalef index (R))	Shannon-Wiener diversity index (H')	Variances (H)	Equitability J. Index (E)
		Wood (tree/ha)	Bamboo (clump/ha)				
P1	26	450	5	5.54	2.96	0.007	0.61
P2	37	1,025	0	6.76	2.95	0.006	0.60
P3	38	940	0	7.06	3.19	0.005	0.65
P4	36	810	5	6.87	2.99	0.008	0.61
P5	38	580	295	7.16	2.75	0.011	0.56
P6	31	555	165	6.03	2.97	0.007	0.61
P7	42	980	25	7.73	3.36	0.004	0.69
P8	47	640	90	9.23	3.35	0.009	0.68
P9	59	685	70	11.56	3.75	0.006	0.77
Average±SD	39±9	741±206	73±100	7.55±1.83	3.14±0.30	0.010±0.002	0.64±0.06

The most important species of the watershed forests were indicated by the Importance Value Index (IVI) as shown in Figure 3. In each forest site, the most important species were *A. saman* (Fabaceae) (36.0%), *Terminalia corticosa* (Combretaceae) (38.6%), *Protium serratum* (Burseraceae) (43.9%), *Shorea siamensis* (Dipterocarpaceae) (45.3%), and *Quercus kerrii* (Fagaceae) (44.3%) in the P1, P2, P5, P6, and P7, respectively. The tree species *Xylia xylocarpa* (Fabaceae) was the most important species at 33.4% and 48.5% in both P3 and P4, respectively, while *L. calyculata* (Lythraceae) the highest important species at 36.2% and 21.9% in P8 and P9, respectively. Based on IVI, the forest sites were classified as DDF in P6 and P7, MDF in P2, P3, P4, and P5, and DEF in P1, P8, and P9. The basal area of tree stem was highest in the MDF at 29.11 m²/ha, followed by the DEF (26.72) and DDF (25.82).

Overall, this study found that the highest density was 1025 individuals/ha in P2 (MDF) at 614 m and 8.06% of the mean elevation and slope, respectively. This MDF had the most important

species of *T. corticosa* (Combretaceae) at 38.6%. In terms of diversity index, the tree biodiversity (diversity, richness, equilibrium indices) along the study areas was highest in P9 (DEF) at 537 m and 16.77% of the mean elevation and slope, respectively. Likewise, this DEF had the most important species of *L. calyculata* (Lythraceae) at 21.9%.

3.3 AGB and AGC storage

The total AGB of living trees (DBH≥4.5) was 1516.58 ton/ha. The highest and the lowest total AGB were estimated at 230 ton/ha in P3 (MDF) and 109 ton/ha in P6 (DDF), respectively (Figure 4). The average AGB (±SD) was 168.51±46.09 ton/ha with the mean per individual of 1.14±2.40 ton/tree/ha. Therefore, the total AGC storage in the watershed forest of this study was 720.58 ton C/ha with an average of 80.04±21.89 ton C/ha. Giving integrative result, there was no a significant different between the DDF (60.5±12.2 ton C/ha), MDF (91.2±21.4 ton C/ha), and DEF (78.3±22.8 ton C/ha) (p=0.299).

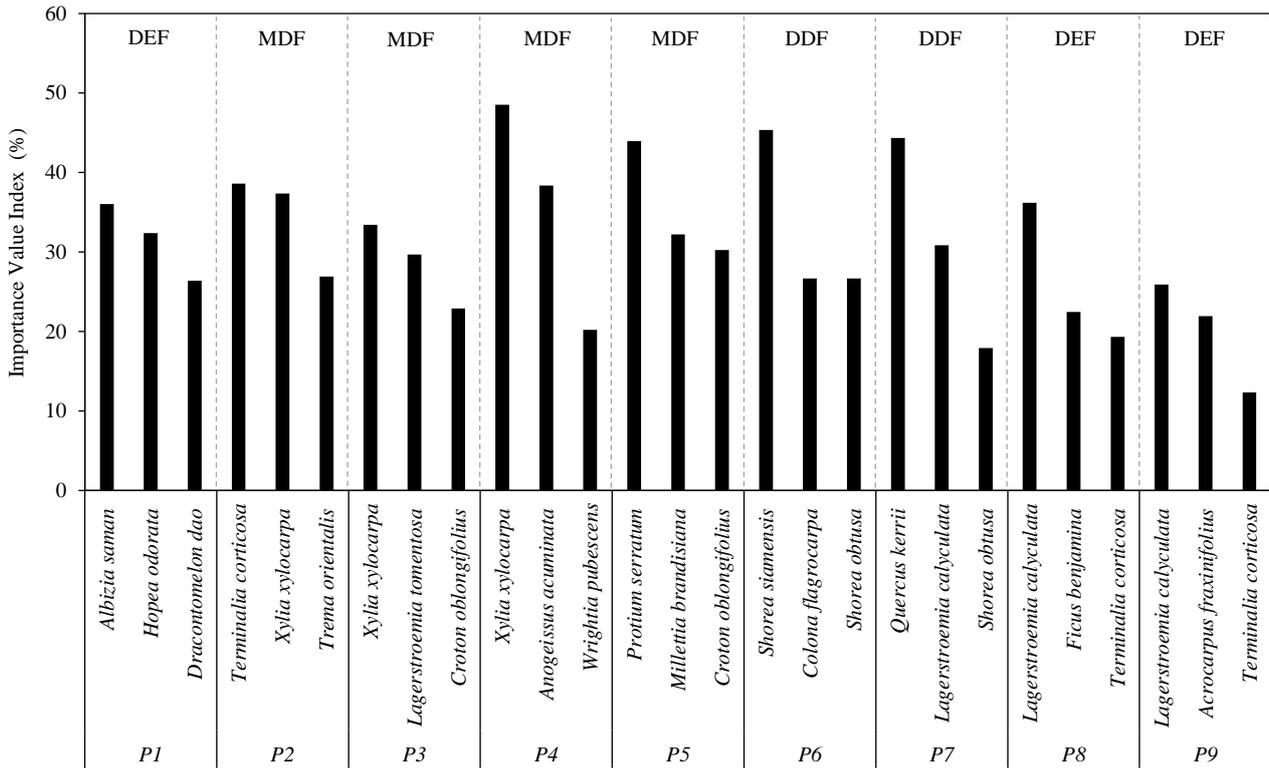


Figure 3. Importance value index (IVI) of dominant tree species (top three species of IVI value) in each forest type of Phayao Watershed Forest

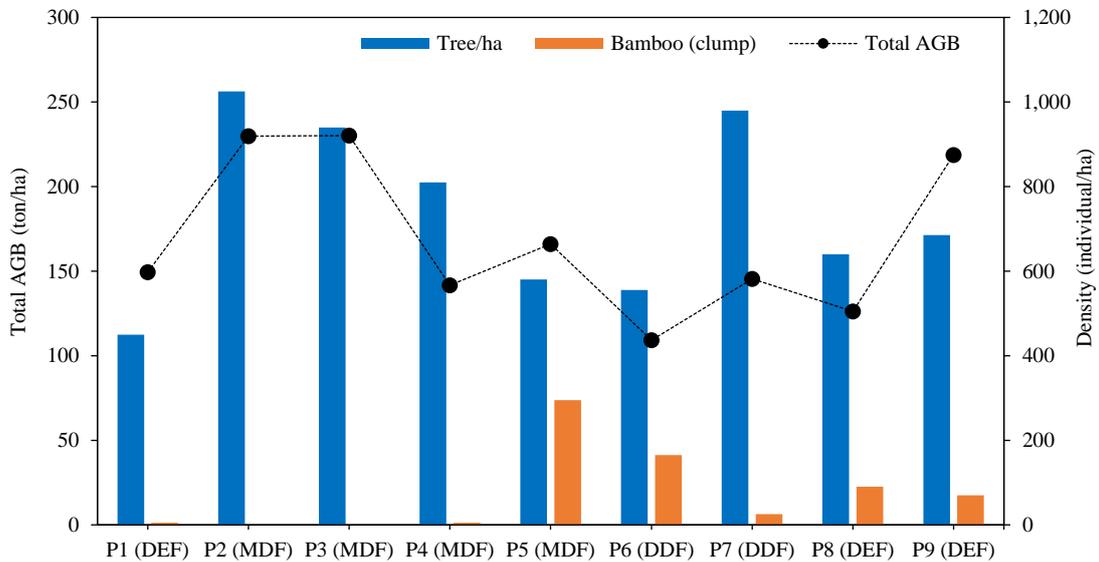


Figure 4. Total AGB and tree density of vegetation in Phayao Watershed Forest

In this study, the bigger trees were relatively high in AGB with the mean (\pm SD) of DBH and height was 17.7 ± 12.7 cm and 12.8 ± 6.7 cm, respectively. The linear regression analysis showed a significant positive relationship between AGB and both DBH ($p < 0.0001$) (regression equation: $Y = 0.1655x - 1.8056$, $R = 0.883$, $R^2 = 0.779$) and height ($p < 0.0001$) (regression equation: $Y = 0.2132x - 1.6081$, $R = 0.596$,

$R^2 = 0.356$) of the trees (Figure 5). Based on family, the highest and lowest mean of the AGB was Irvingiaceae at 6.18 ton/ha and Olacaceae at 0.02 ton/ha, respectively. Based on species, *Ficus benjamina* had the highest AGB in the forest with 29 ton/ha, while *Sterculia guttata* had the lowest AGB with 0.018 ton/ha.

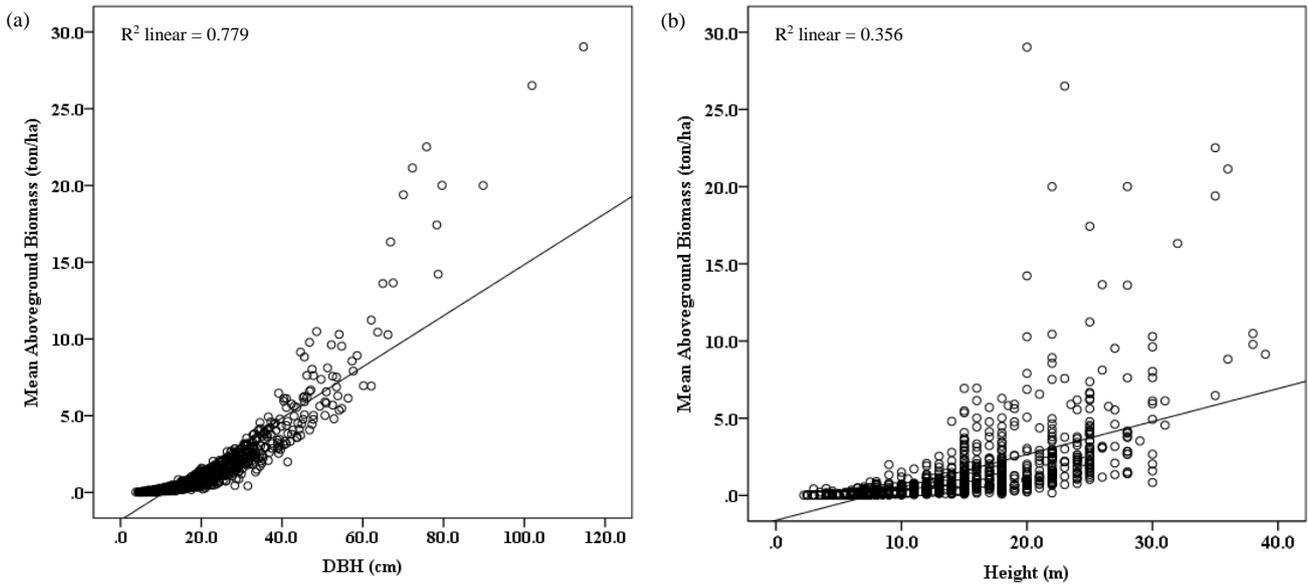


Figure 5. Relationship between aboveground biomass and tree size: DBH (a) and height (b)

3.4 Species distribution on environmental gradients

Based on cluster analysis, the similarity of tree species was grouped from each site using Sorensen (Bray-Curtis) distance technique with information remaining more than 60% as shown in Figure 6. Thus, the tree species in Phayao watershed forest can be divided into five groups as follows:

Group 1 (P1) was distinguished from the others with 100% of dissimilarity. This group was discriminated by composing of the dominant exotic *A. saman*, and native *H. odorata* at an altitude of 575 m and 21% of slope in DEF.

Group 2 (P2 and P5) were found at altitudes ranging from 512 to 614 m and 7.8-8.1% of slope in MDF. The dominant trees belonging to this group

were *Millettia brandisiana*, *Croton oblongifolius*, and *Dalbergia cultrata*.

Group 3 (P8 and P9) was found at altitudes ranging from 537 to 584 m and 14.6-16.8% of slope in DEF contributed by the dominance of *L. calyculata*, *T. corticosa*, and *Colona flagrocarpa*.

Group 4 (P6 and P7) was classified as DDF at altitudes of 536-701 m and 13.0-24.3% of slope. The group showed the information remaining almost 100%. It was composed of the dominant tree species *Shorea obtusa*, *S. siamensis*, and *L. calyculata*.

Group 5 (P3 and P4) was located at altitudes ranging from 556 to 667 m and 7.7-21.1% of slope in MDF. This group was dominated by *X. xylocarpa*, *C. oblongifolius*, and *L. calyculata*.

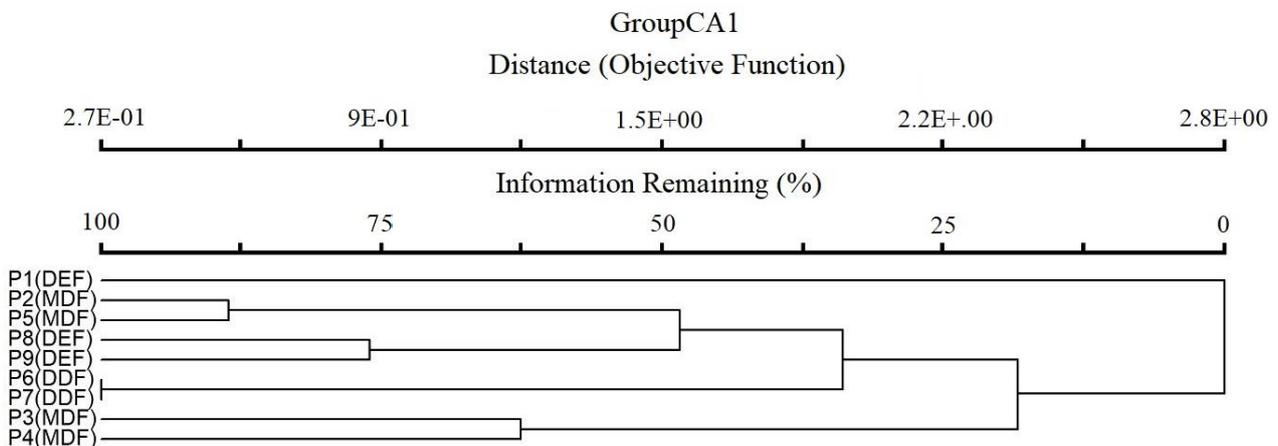


Figure 6. Dendrogram showing a hierarchical relationship among 133 tree species at nine sampling sites in the watershed forest of Phayao.

Correlation among 133 plant species, nine study sites (with vegetation coverage i.e., DDF, MDF, DEF), tree parameters and ecological variables of study sites were illustrated through DCA (Figure 7). In constrained DCA ordination, the maximum explanatory variation was accounted for PC1 axis, in which the maximum explanatory variation was accounted for Axis 1 (0.86) and lower variation on the Axis 2 (0.61). The maximum strength of plant community was represented by specific tree parameters (i.e., tree density and height). The influence of tree parameters and ecological variables

(i.e., AGB, slope and tree canopy) were the most representative drive of plant community structure into two community groups along the ecological gradients and tree parameters in watershed forest areas, in which the first group is DEF and MDF, and the second group is DDF. Interestingly, the DCA revealed unique tree species (i.e., *A. saman*, *H. odorata*, *L. calyculata*, and *A. fraxinifolius*) in the DEF, in which its occurrences are related to AGB, slope, and tree canopy. While most tree species in MDF are related to their height and density. Therefore, the slope of the area influenced tree species distribution in the watershed forest.

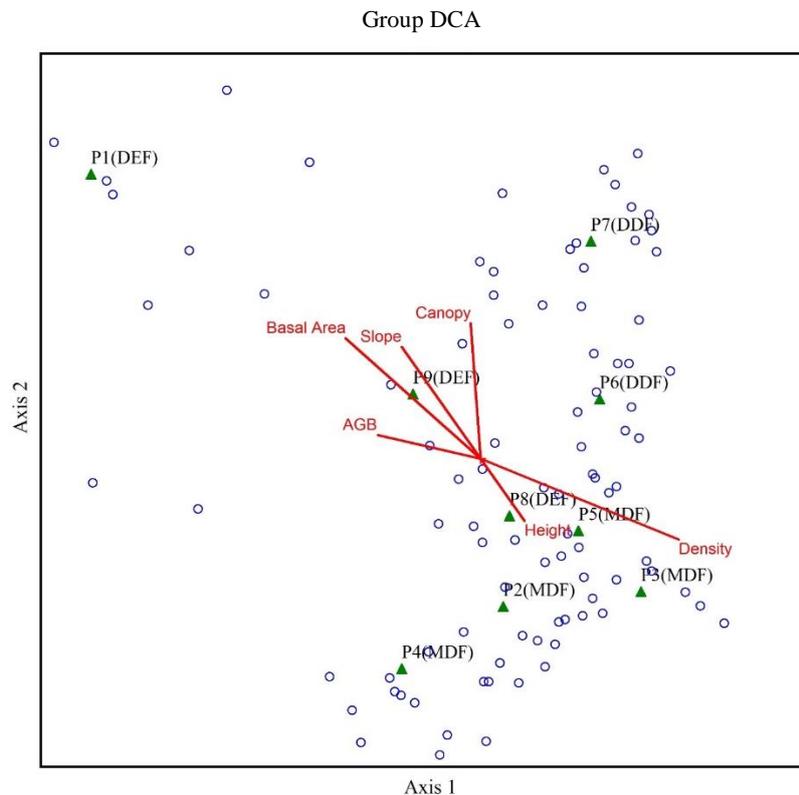


Figure 7. DCA analysis of plant communities in the study area (P1-P9) and environment factors at Phayao Watershed Forest

4. DISCUSSION

Our result showed that the forest types along the watershed area of Phayao Lake (Kwan Phayao) and Ing River can be roughly classified as DEF, MDF, and DDF based on the watershed area. The watershed forest consisted predominantly of Fabaceae (233 individuals), Lythraceae (107 individuals), Euphorbiaceae (98 individuals), Combretaceae (93 individuals), and Dipterocarpaceae (88 individuals) in the study sites. High biodiversity index was found in DEF (P9). The highest density was shown in the MDF (P2 and P3) and DEF (P7), respectively. The highest individual (295 clumps/ha) of Gramineae was found

in P5 (MDF). Many previous studies have reported that the important species as well as the dominant species of tree were different in the same forest type of the tropical seasonal forest due to the vegetation structure and composition, topographical gradient, altitude, and disturbance (Marod et al., 1999; Khamyong, 2009; Chaiyo et al., 2012; Liu et al., 2014; Sungpalee et al., 2015). As stated by Liu et al. (2014), the species diversity and composition changed along the topographical gradient as well as the distinction in DEF of group 1 (P1). As in this result, tree diversity was changed by the slope area according to the ordination. However, it was also clear that the spatial

distribution of trees was strongly impacted by elevation in mountain ecosystem, northern Thailand (Marod et al., 2019).

According to forest type based on IVI, this study found that the dominant species in DDF were *S. siamensis*, *Q. kerrii*, and *S. obtusa*, mixing with *L. calyculata* and *C. flagrocarpa*. Lamotte et al. (1998) reported that the dominant species were *S. obtusa*, *S. talura*, *Dipterocarpus intricatus*, *Q. kerrii*, *Mitragyna brunonis*, *X. xylocarpa*, *Morinda coreia*, and *Lannea coromandelica* in DDF of northeastern, Thailand. Also, tree species *S. obtusa*, *S. siamensis*, *L. coromandelica*, and *D. Obtusifolius* were important contributors in DDF of western Thailand (Chaiyo et al., 2011). While in DDF in the north of Thailand, the dominant tree species were reported to be *D. obtusifolius*, *D. tuberculatus*, *S. obtusa*, and *S. siamensis* in Doi Suthep-Pui National Park (Khamyong et al., 2018), as well as in the Huai Hong Khrai Royal Development Study Center, and Mae Tha Community Forest, Chiang Mai (Phongkhamphanh et al., 2015).

In the case of MDF, it is well-known that tree species *Tectona grandis* (Teak) is commonly dominant in some other locations in Thailand (Seanchanthong, 2005; Podong et al., 2013; Khamyong et al., 2018). However, *T. grandis* did not appear in some areas (Marod et al., 1999; Phonchaluen, 2009; Chaiyo et al., 2011), that is related to our result, only one individual *T. grandis* was found in P3 (MDF). Our results showed that the MDFs contained mixed stands of important tree species belonging to families such as Fabaceae (*X. xylocarpa* and *M. brandisiana*), Combretaceae (*T. corticosa*), Burseraceae (*P. serratum*), Euphorbiaceae (*C. oblongifolius*), Cannabaceae (*Trema orientalis*), Lythraceae (*Lagerstroemia tomentosa*), and Gramineae (*G. albociliata*).

In the case of DEF, this forest type was composed of dominant tree species *L. calyculata* (Lythraceae), *A. saman* (Fabaceae), *H. odorata* (Dipterocarpaceae), *F. benjamina* (Moraceae), and *A. fraxinifolius* (Fabaceae). Similarly, other reports of DEF had mixed stands of Dipterocarpaceae in Doi Suthep-Pui National Park (Khamyong et al., 2018) as well as in DEF at the Sakaerat Biosphere Reserve, northeastern, Thailand. (Lamotte et al., 1998).

Generally, AGB and AGC storage in the trees increases relatively with increasing density and tree size, and this was seen in the results of this study. Although this study showed a high total AGB of 230 ton/ha in the MDF, it was lower than MDF (311

ton/ha) in Chiang Mai, northern Thailand. In addition, the total average AGB (168.5 ton/ha) of this forest was lower than the total AGB (372.7 ton/ha) in a tropical forest at Doi Inthanon National Park, Chiang Mai, Thailand (Sungpalee et al., 2015). However, this average was higher than in the other sites (MDF) of northern Thailand as follows; Ogawa et al. (1961) showed a total of 49.60 ton/ha in Chiang Mai and 57.50 ton/ha in Lampang, while Kaewkrom et al. (2011) reported that the AGB was 104.59 and 50.95 ton/ha in a primary and secondary MDF in Phetchabun, respectively.

In the DDF, the total AGB ranged from 109 to 145 ton/ha, which was similar to the total AGB of 142.95 ton/ha in northeast Thailand (Senpaseuth et al., 2009). However, the mean AGB (186.4 ton/ha) in DDF at Chaiyaphum, northeast Thailand was higher than this study (Ounkerd et al., 2015). In contrast, there was a much lower AGB of 81.9 (20-40% of slope) and 23.8 ton/ha (<20% of slope) in DDF of western Thailand than this study with 13-24% of slope (Chaiyo et al., 2011).

In the DEF, the total AGB ranged from 129 to 219 ton/ha. This was higher than the AGB in DEF at Thong Pha Phum District, Kanchanaburi Province (140.58 ton/ha) (Terakunpisut et al., 2007), and the north of Thailand (126 ton/ha) (Ogawa et al., 1965). However, the mean of the AGB in this DEF was lower than the mean of DEF (331.75 ton/ha) in Nong Khai Province, northeast, Thailand (Senpaseuth et al., 2009). A result from Sungpalee et al. (2015) reported that a lower tropical montane forest in Doi Inthanon National Park, Chiang Mai, showed a greater AGB value for the middle elevation than at the low and high elevation, while the mean AGB did not significantly differ among the slope aspect and inclination.

Based on DCA, slope area was significantly associated with species distribution, AGB, and AGC storage. According to the results, the relationship between AGB and tree density was negative, while the relationship was positive with tree basal area and canopy cover. On the other hand, Jia et al. (2022) showed that the relationship between stand density and AGC was positive, while the influence of individual tree size variation on AGC storage was negative. However, the occurrences of tree species (1.7-6.6 m²/ha of basal area), especially *A. saman*, *H. odorata*, *L. calyculata*, and *A. fraxinifolius* were related to AGB and AGC storage in Phayao Watershed Forest. Future studies should further investigate the plant species distribution in enlarged scale areas and

spatial factors by using remote sensing in the assessment of AGB and AGC storage covering different forest types.

5. CONCLUSION

Overall, 133 tree species were found in the Phayao Watershed Forest. The study shows the species occurrences are practically related to AGB, AGC, slope, and tree canopy in DEF. Although the AGB and AGC were not related to tree density and height in MDF, there were related to the stand basal area and canopy cover in DEF comprising the highest tree diversity. Therefore, horizontal size variation in tree species could influence the enhancement of AGB as well as AGC storage. Based on the distribution gradient of the tree community, the distribution of tree species in the watershed forest was impacted by slope intensity. This study found that species-specific habitat is essential for improvements and can be applied to watershed forest management in the future. Nevertheless, the study suggests that spatial distribution data (e.g., soil characteristics and streamflow) is necessary for evaluating tree assemblages and diversity patterns.

ACKNOWLEDGEMENTS

This study was financially supported by National Research Council of Thailand (NRCT). The demonstration and laboratory of this work was mainly supported by the Unit of Excellence for Water Management Research (FF64-UoE006), School of Science, University of Phayao. We are thankful to the staff of Doi Luang National Park for their advice and support in the fieldwork. We thank Dr. Trin Seramethakun for his main assistance in identifying tree species.

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