BIODIVERSITAS
Volume 27, Number 3, March 2026
Pages: 14

ISSN: 1412-033X
E-ISSN: 2085-4722
https://doi.org/10.13057/biodiv/d270341

Ecological and social values of the community forest managed for rural livelihoods in Sa Kaeo Province, Eastern Thailand

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Manuscript received: 8 December 2025. Revision accepted: 31 March 2026.

Abstract. *Yodsa-Nga P, Teeratinan J, Pangklom S, Waiboonya P, Moungsrimuangdee B. 2026. Ecological and social values of the community forest managed for rural livelihoods in Sa Kaeo Province, Eastern Thailand. Biodiversitas 27 (3): d270341. https://doi.org/10.13057/biodiv/d270341.* Community forests are essential in Thailand for supporting local livelihoods and conserving the environment. This research investigates the ecological and social values of the Ban Nong Ma-U Community Forest in Sa Kaeo Province, Eastern Thailand. Ecological characteristics of woody species were assessed in 54 systematically established sampling plots, each measuring 20 × 20 m. Species composition and diversity were evaluated using the importance value index (IVI) and the Shannon-Wiener index (H′). Biomass of woody species was calculated using allometric equations, and carbon stocks were estimated accordingly. Social values were determined through ethnobotanical indices derived from interviews with 94 residents of Nong Ma-U Village regarding the use of non-timber forest products (NTFPs). In total, 68 species were identified in the sample plots, representing 54 genera and 30 families. Fabaceae was the dominant family, comprising 11 species. *Dipterocarpus tuberculatus* was the most prevalent tree species, while *Suregada multiflora* and *Sindora siamensis* ranked highest among sapling and seedling species based on IVI. The H′ ranged from 2.48 to 2.96 across tree, sapling, and seedling stages. Tree and sapling biomass were 59.49 and 0.75 ton ha^{-1}, respectively, while carbon stocks for trees and saplings were 27.96 and 0.35 ton C ha^{-1}. A total of 97 NTFPs were recorded, primarily wild plants used for human consumption. *Curcuma parviflora*, *Amorphophallus macrophyllum*, *Cratoxylum formosum*, *Azadirachta indica*, *Amorphophallus paeoniifolius*, *Curcuma alismatifolia*, and *Phoenix loureiroi* were identified as the most culturally significant NTFP species based on high values of the cultural importance index (CI) and relative importance index (RI). The results indicate that the Ban Nong Ma-U Community Forest provides significant ecological and social benefits to local communities. These benefits include meeting local needs, reliance on NTFPs, carbon sequestration, and the maintenance of local traditions. The implementation of a comprehensive conservation and utilization framework is expected to sustain the resources of Ban Nong Ma-U Community Forest and enhance local livelihoods.

Keywords: Biomass, carbon stock, community forestry, ethnobotany, non-timber forest products, species diversity

INTRODUCTION

Forests provide benefits for human livelihoods both directly and indirectly. From an ecological perspective, they have a significant role in preventing soil erosion, regulating hydrological processes, preserving soil and water resources, and serving as the primary habitat for many species (Jenkins and Schaap 2018; Wang et al. 2023). Furthermore, forests have an essential role in climate change mitigation by acting as a carbon sink where carbon is stored in various components such as living trees, dead wood, litter, and soils. On the other hand, forests can be carbon sources when they release substantial amounts of stored carbon into the atmosphere due to human activities, including deforestation, wildfires, and logging (Mills et al. 2023).

From an economic view, forests provide timber and non-timber forest products (NTFPs), especially for rural people, as sources of food, fibers, medicines, construction materials, fuels, and income revenue (Wimolsakcharoen 2020). Creating jobs and revenue streams are two of the economic benefits of forests (Hansmann 2024). Forests are recognized and highly valued for their socio-cultural dimensions. The cultural values of forests and their importance in maintaining people's customs and identities are among their social advantages. Additionally, forests improve human health, well-being and quality of life by providing natural areas for relaxation, stress relief, and physical exercise in the context of tourism and nature experiences.

In the tropics, community forestry has been promoted for the sustainable management and utilization of forest resources as well as forest restoration (Pokhrel and Gautam 2024; Budiharta and Holl 2025). Thailand has also promoted and officially launched the community forestry model in the form of a Community Forest under the Community Forest Act of 2019 (B.E. 2562). This legislation allows various groups of people other than the government sector to participate in decision-making on forest management and strengthens the rights and access of communities to manage and use forests. To date, 11,984 community forests have been formally registered, spanning approximately 1.07 million hectares over the country of Thailand (RECOFTC 2025). Prior research has distinctly demonstrated the contribution of Thailand's community forests in terms of ecosystem services to local livelihoods, including biodiversity conservation

(Agarwal et al. 2022), carbon sequestration and storage (Kanhom et al. 2019), and the utilization of NTFPs for sustenance and income (Thammanu et al. 2021a).

In eastern Thailand, the livelihood and income generation of rural communities are closely linked to the resources provided by community forests. These forests supply a diverse array of plant and animal products for both subsistence and commercial purposes. Certain products, such as wild mushrooms and wild honey, possess significant commercial value and contribute substantially to household income. Despite this importance, comprehensive studies examining the characteristics of vegetation communities and their utilization within community forests remain limited. Specifically, there has been little integration of species structure, carbon stock assessment, and ethnobotanical analysis in this region.

Ban Nong Ma-U Community Forest in Sa Kaeo Province, Eastern Thailand, serves as a model of community-led forest management that links conservation with rural development through formal tenure rights over the forest, alongside traditional practices. Nowadays, the residents of Nong Ma-U village, who live in the vicinity of the forest, can decide the protection and management plan and collect the NTFPs for their sustainable subsistence and livelihoods. To ensure this, quantitative measures of ecological and cultural diversity, along with the relative importance of NTFPs to the local community, are required to support the sustainable use and conservation of forest resources. Therefore, we conducted a study to (i) investigate the ecological values of forest vegetation based on their composition, diversity, biomass accumulation, and carbon stock in Ban Nong Ma-U Community Forest, and (ii) identify the social values of NTFPs used by the local villagers in this community forest. This scientific documentation offers baseline information on vegetation and NTFPs to support sustainable management and conservation in the community forest. It helps to enhance ecological and socioeconomic values through integrated, participatory approaches. The focus is on improving forest structure and productivity, which can promote sustainable resource use and enhance local livelihoods and well-being through NTFP use.

MATERIALS AND METHODS

Study area

The research was conducted in Ban Nong Ma-U Community Forest, located in Wattana Nakhon District, Sa Kaeo Province, Eastern Thailand (Figure 1). The site has a tropical climate, with the wet season occurring from July to October and the dry season from November to March. The mean annual air temperature is 28°C, and total annual rainfall is 1,400 mm. Ban Nong Ma-U Community Forest encompasses 70 ha and is situated at an elevation of 80 to 100 m asl. Historically, the forest has suffered degradation due to illegal logging, wildfires, and the lack of sustainable policies for the utilization of NTFPs. In response, the forest was officially designated as a Community Forest under the Community Forest Act of 2019. This legal status was intended to safeguard and manage forest resources to support the sustainable livelihoods of local communities. Currently, management is conducted by 400 households from Nong Ma-U village, with residents authorized to collect NTFPs as outlined in the management plan. The village exhibits diverse NTFP uses, as documented in the plan. Nevertheless, the community's substantial dependence on the forest for daily NTFP collection, species protection, and conservation continues to pose challenges in evaluating its ecological and social values.

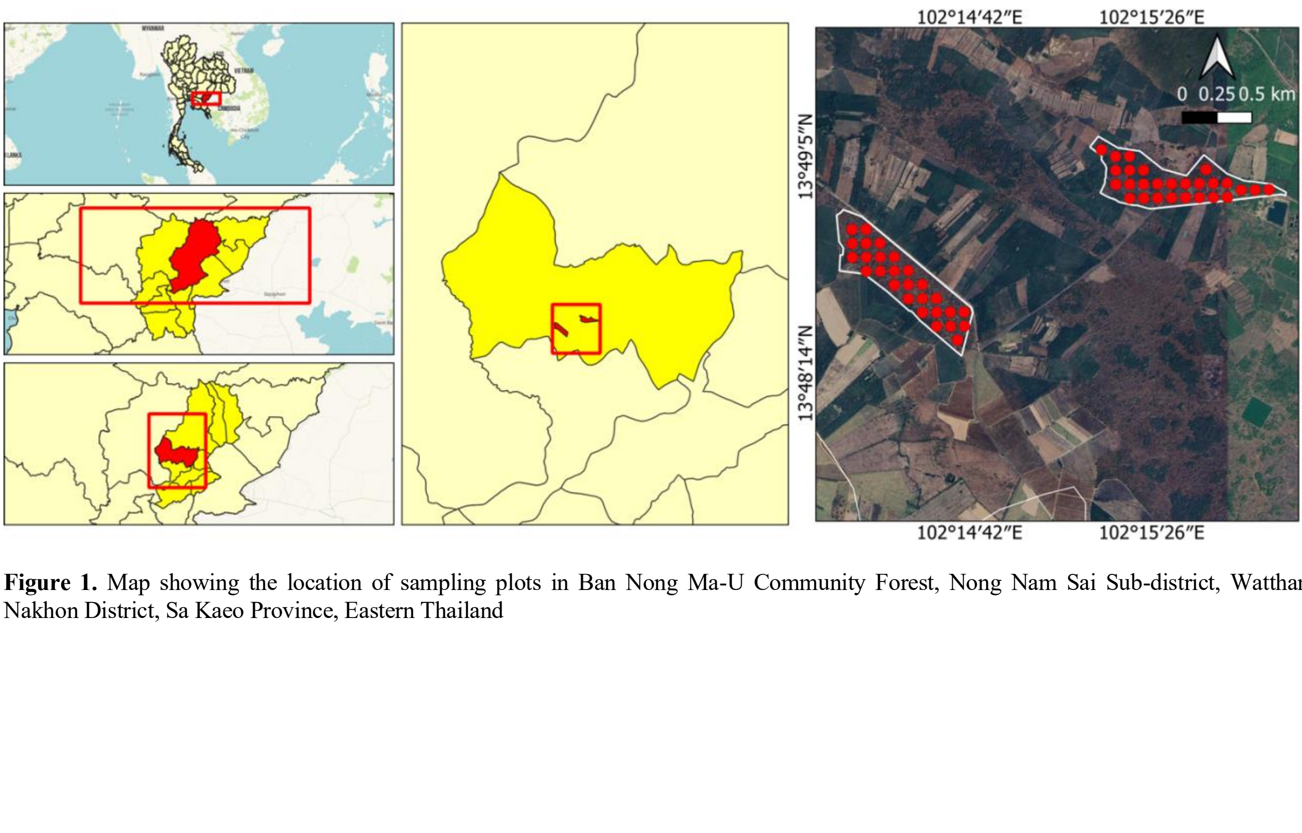

Figure 1. Map showing the location of sampling plots in Ban Nong Ma-U Community Forest, Nong Nam Sai Sub-district, Watthana Nakhon District, Sa Kaeo Province, Eastern Thailand

Data collection

Plot sampling and inventory

A total of 54 sampling plots were systematically established across the community forest at fixed 100-m intervals to ensure representation of site heterogeneity (Figure 1). For every 20 m × 20 m plot (total sampled area 2.160 ha), all individuals that were categorized as trees and had a diameter at breast height (DBH) ≥4.5 cm and a height ≥1.30 m were identified and documented. In addition, saplings (DBH <4.5 cm and height ≥1.30 m) and seedlings (DBH <4.5 cm and height <1.30 m) were recorded within each 20 m × 20 m plot, using a single 4 m × 4 m subplot (total sampled area 0.086 ha) and a single 1 m × 1 m subplot (total sampled area 0.005 ha), respectively. This study included woody species encompassing both tree and shrub lifeforms. For each stem, DBH was measured at 1.30 m above ground level, using a diameter tape. Total height was then determined with a laser rangefinder camera (Nikon, Forestry Pro II). For stems with buttresses, DBH was measured 10-30 cm above the buttress. For irregular stems, measurements followed the guidelines provided by Wiriyabancha (2020).

NTFPs survey and interview

An ethnobotanical study was conducted to assess the knowledge of NTFPs among the members of Ban Nong Ma-U Community Forest, which comprised the residents of Nong Ma-U village. To compile a comprehensive list of NTFP names and uses recognized through the free-listing method (Martin 1995), data were initially collected from three key informants. These local experts, selected via purposive sampling, possessed extensive traditional knowledge and cultural familiarity with wild products. Group interviews were conducted using semi-structured questionnaires during transect walks in the community forest. This approach enabled the observation of all NTFP species, the documentation of cultural details such as local names, utilized plant parts, and preparation methods, as well as the collection of voucher specimens for species identification. All NTFPs reported by the key informants were mainly classified into plants, mushrooms, and animals. Subsequently, we designed structured questionnaires to conduct in-depth interviews with 94 informants, all of whom were NTFP collectors from Nong Ma-U village. Participants were eligible if they were over 18 years of age, had resided in the area for more than five years, and had participated in at least one NTFP collection trip per year. Participation in the study was voluntary, with informed consent obtained from all respondents and procedures approved by the Srinakharinwirot University Ethical Committee (SWUEC-672267). The taxonomic identification of all species was determined by referring to available sources (Pooma and Suddee 2014; Chandarsrikul et al. 2008) and being checked by the specialist in plants and mushrooms from the Royal Forest Department of Thailand. Herbarium specimens are available in the herbarium of the College of Creative Agriculture for Society, Srinakharinwirot University.

Data analysis

Species composition and diversity

Plants were classified according to their species, genera, and families. The ecological elements of the Ban Nong Ma-U Community Forest were determined via a quantitative analysis using Microsoft Excel. Trends in species density, growth, and regeneration were obtained by analyzing DBH and height classes. Moreover, the ecological qualities of woody species in the community forest were analyzed by employing several indicators as follows:

Relative frequency:

$$RF = \frac{\text{Frequency of a species}}{\text{Total frequency of all species}} \times 100 \quad [1]$$

Relative density:

$$RD = \frac{\text{Density of the species}}{\text{Total density of all species}} \times 100 \quad [2]$$

Relative dominance:

$$RDo = \frac{\text{Total basal area of the species}}{\text{Total basal area of all species}} \times 100 \quad [3]$$

Importance value index (IVI)

For trees and saplings: IVI = RF + RD + RDo [4]

For seedlings IVI = RF + RD [5]

The diversity indicators, including the Shannon-Wiener Index (H′), Simpson Index, and Evenness Index, were computed in accordance with Shannon and Weaver (1949), He and Hu (2005), and Magurran (2007), respectively. The formulas are as follows:

Shannon-Wiener Index (H′):

$$H' = \sum_{i=1}^{s} (pi \; ln \; pi) \quad [6]$$

Where, H′ is the diversity index, p_i is the proportion of each species in the sample, and ln p_i is the natural logarithm of this proportion.

Simpson Index (D):

$$D = 1 - \left[\frac{\Sigma \, ni(ni-1)}{N(N-1)}\right] \quad [7]$$

Where, D is the diversity index ranges between 0 and 1, ni is the number of individuals in species i, and N is the total number of individuals.

Evenness Index (E): $E = \frac{H'}{ln(S)}$ [8]

Where, E is the species evenness index, H′ is the Shannon-Wiener Index, S is the number of species, and *ln* is the natural logarithm.

Biomass and carbon stock

We estimated the biomass of woody species found in Ban Nong Ma-U Community Forest using an allometric equation widely used for deciduous forests in Thailand. In this study, biomass refers to the sum of above-ground biomass (AGB) and below-ground biomass (BGB) calculated according to the equations developed by previous researchers:

For trees (Ogawa et al. 1965):

$Ws = 0.0396(D^2 H)^{0.9326}$ [9]
$Wb = 0.003487(D^2H)^{1.0270}$ [10]
$Wl = 1/(28.0/Wtc+0.025)$ [11]
$Wr = 0.0264(D^2H)^{0.775}$ [12]

For saplings (Issaree 1982):
$Ws = 0.0893059(D^2H)^{0.66513}$ [13]
$Wb = 0.0153063(D^2H)^{0.58255}$ [14]
$Wl = 0.000014(D^2H)^{0.44363}$ [15]

For saplings (IPCC 2006):

$Wr = 0.28Wt$ [16]

For total biomass:
$AGB = Ws+Wb+Wl$ [17]
$BGB = Wr$ [18]

Where, Ws is the stem biomass (kg), Wb is the branch biomass (kg), Wl is the leaf biomass (kg), Wr is the root biomass (kg), Wtc is the sum of Ws and Wb, Wt is the sum of Ws, Wb, and Wl (kg), D is the diameter at breast height (cm), and H is the total height (m).

Then, biomass was converted into carbon stock based on the formula developed by IPCC (2006), which notes that the carbon content of living biomass is about 47% by dry weight. Thus, the carbon stock was estimated using the following formula:

$\text{Carbon stock} = \text{Biomass} \times 0.47$ [19]

NTFPs social values

We grouped the NTFPs in this study into nine use-categories following Cook (1995), as listed in Table 5. We used ethnobotanical indices to assess the social value of NTFPs collected from the Ban Nong Ma-U Community Forest. Cultural importance index (CI) and relative frequency of citation (RFC) developed by Tardío and Santayana (2008), relative importance index (RI) developed by Pardo-de-Santayana (2003), and cultural value index (CV) developed by Reyes-Garcia et al. (2006) were computed using Microsoft Excel according to the following formulas:

$$CI = \sum_{u=u_1}^{u_{NC}} \sum_{i=i_1}^{i_N} UR_{ui}/N, \quad [20]$$

Where, CI is the cultural importance index, NC is the total number of use-categories (u1, u2, …uNC), N is the total number of informants, and UR is the use-report, defined as the number of informants who mention each use-category for a given species.

$$RFC = \frac{FC}{N} \quad [21]$$

Where, RFC is the relative frequency of citation, FC is the frequency of citation, defined as the number of informants who mention the use of a given species, and N is the total number of informants.

$$RI = \frac{[(FC/\max(FC)) + (\frac{NU}{\max(NU)})]}{2} \quad [22]$$

Where, RI is the relative importance index, FC is the frequency of citation, and NU is the number of uses.

$$CV = \frac{NU}{NC} \times \frac{FC}{N} \times \sum_{u=u_1}^{u_{NC}} \sum_{i=i_1}^{i_N} UR_{ui}/N, \quad [23]$$

Where, CV is the cultural value index, NU is the number of uses, NC is the total number of use-categories, N is the total number of informants, and UR is the use-report.

All ecological and social indices calculated as previously described will be interpreted. Specifically, the CI, which reflects both the diversity of use and the frequency among informants, was primarily employed to identify culturally significant NTFP species.

RESULTS AND DISCUSSION

Socio-demographics of respondents

A composite of the respondent data is shown in Table 1. A total of 68 women and 26 men were interviewed in this study. Women predominated at 72.34%, while men accounted for only 27.66%. Most of the informants belonged to the age group 51-70 (60.64%), followed by 71-90 (20.21%), and 30-50 (19.15%). The educational background was mainly in primary school (69.15%). The occupation was primarily off-farm at 59.57% (mostly in general workers). The majority of households (54.26%) had incomes under THB5,000 per month, indicating that most respondents were below the poverty line (poor) in Thailand. The members of the household mostly consisted of between one and three persons (58.51%). The vast majority were native (77.66%) and lived very close to the community forest, within 0-3 km (92.55%).

The study identified that a significant proportion of NTFP collectors were women and older adults with limited formal education and modest household incomes, underscoring the vital role of community forests in supporting rural livelihoods. These findings are consistent with previous research indicating that women are often the predominant informants due to their responsibilities in food preparation and household material management (Mechaala et al. 2022) and that older community members frequently possess extensive knowledge of the use of forest products (Chashike et al. 2025). Additionally, NTFP collection provides essential support to individuals with limited educational attainment and financial resources (Noinarai et al. 2020).

Species composition and diversity

A total of 1,159 trees, 82 saplings, and 82 seedlings were recorded across the 54 sampling plots in Ban Nong Ma-U Community Forest. This corresponded to densities of 536.56, 949.06, and 17,083.31 stems ha^{-1} for trees, saplings, and seedlings, respectively. A total of 68 species, representing 54 genera and 30 families, were identified among all individuals. In addition, 64 species and 30 families were identified at the tree stage, 24 species and 17 families at the sapling stage, and 20 species and 12 families at the seedling stage. The distribution of woody species among families was uneven (Figure 2). Six families with four or more species accounted for the greatest number of species (34 species, 50% of the total species richness); the remaining 24 families were represented by one to three species, accounting for 34 species (50% of the total species richness). The Fabaceae family was the most abundant, comprising 11 species, followed by Dipterocarpaceae with six species, Rubiaceae with five species, Anacardiaceae, Combretaceae, and Phyllanthaceae with four species, Hypericaceae, Lamiaceae, and Sapindaceae with three species, and the others with one or two species (Figure 2).

The distribution of trees and saplings in different DBH and height classes is shown in Figure 3. The DBH size class between 10 and 20 cm was the most abundant, comprising 47.48% of the total. This was followed by the size class under 10 cm at 31.99%, the 20-30 cm class at 16.68%, the 30-40 cm class at 2.82%, the 40-50 cm class at 0.57%, and the 50-60 cm class at 0.16% (Figure 3.A). Overall, the DBH of all individuals ranged from 0.64 to 59.55 cm with a mean of 14.25±0.22 cm. The height ranged from 1.30 to 24.00 m, with a mean of 11.44±0.11 m. The highest population was found in the 10-15 m height range (49.23%), followed by the 15-20 m range (22.88%), and the 5-10 m range (20.23%). The remaining population accounted for heights lower than 5 m and those in the 20-25 m range (7.66%) (Figure 3.B). DBH size classes of the four most dominant species, namely, *Dipterocarpus tuberculatus*, *Shorea obtusa*, *Xylia xylocarpa*, and *Sindora siamensis*, are also represented in Figure 4. The greatest abundance of these species was found in the DBH class of 10-20 cm. The size-class distribution of these species generally exhibited a bell-shaped pattern (Figures 4.A-4.D), with a high abundance of intermediate-sized stems and fewer small or large ones. This distribution likely results from disturbances such as selective logging, fires, or non-timber forest product (NTFP) collection, which preferentially remove small and large stems. These activities are particularly common in areas dominated by young, small vegetation. Consequently, removing these size classes may hinder regeneration processes. Comparable declines in the density of larger trees have been reported in the deciduous dipterocarp forests of Northern Thailand (Thammanu et al. 2021b) and the Central Highlands Region of Vietnam (Thanh Tuan et al. 2021). Nevertheless, analysis of seedling, sapling, and mature tree densities in the present study demonstrates that, despite these disturbances, the community maintains strong reproductive and recruitment potential in the Ban Nong Ma-U Community Forest. This outcome aligns with the area's history of harvesting, conservation, protection, and restoration efforts, as well as the implementation of the Community Forest Act.

Table 1. Socio-demographics data of respondents in Nong Ma-U village, Sa Kaeo Province, Eastern Thailand

Socio-demographics	Percentage
Gender	
Male	27.66
Female	72.34
Age (year)	
30-50	19.15
51-70	60.64
71-90	20.21
Educational level	
Uneducated	9.58
Primary school	69.15
Secondary school	27.27
Occupation	
Farmer	40.43
Off-farmer	59.57
Income (bath/month)	
<5,000	54.26
5,000-10,000	23.40
10,001-20,000	18.09
20,001-30,000	3.19
>30,000	1.06
Household size	
1-3 persons	58.51
4-6 persons	37.23
>7 persons	4.26
Hometown	
Native	77.66
Migration	22.34
Distance from home to Community Forest	
0-3 km	92.55
>3 km	7.45

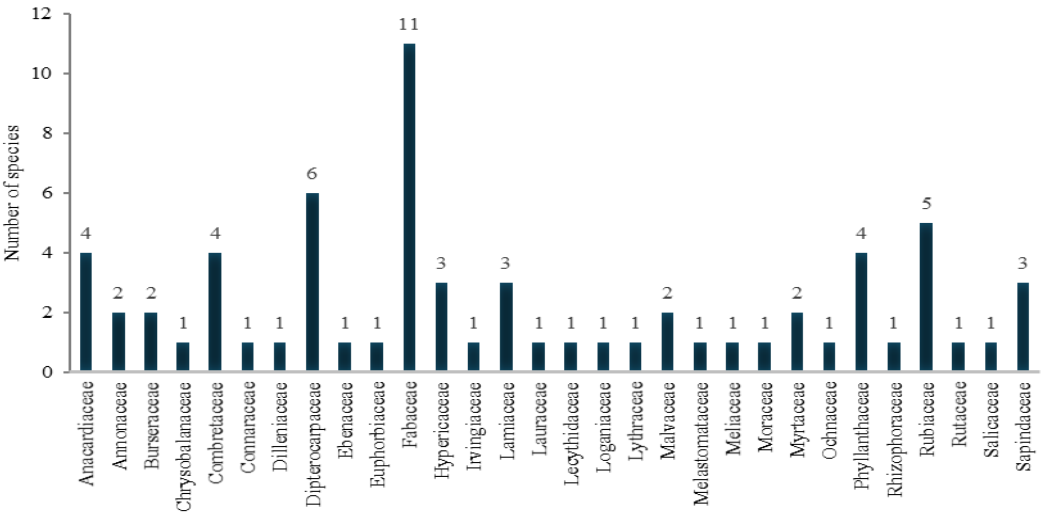

Figure 2. Distribution of families and their species in Ban Nong Ma-U Community Forest

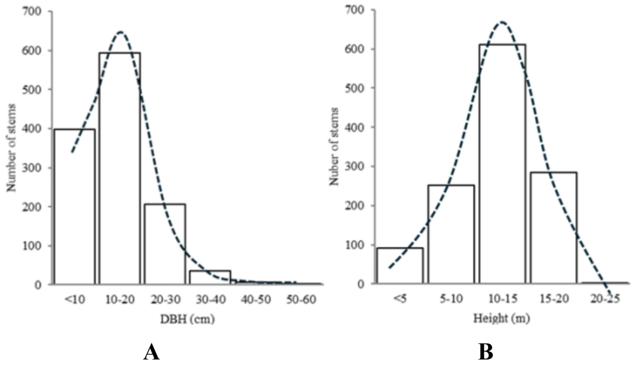

Figure 3. Distribution of DBH and height classes of woody species in Ban Nong Ma-U Community Forest, including all trees and saplings with height ≥1.30 m. A. DBH classes; B. Height classes

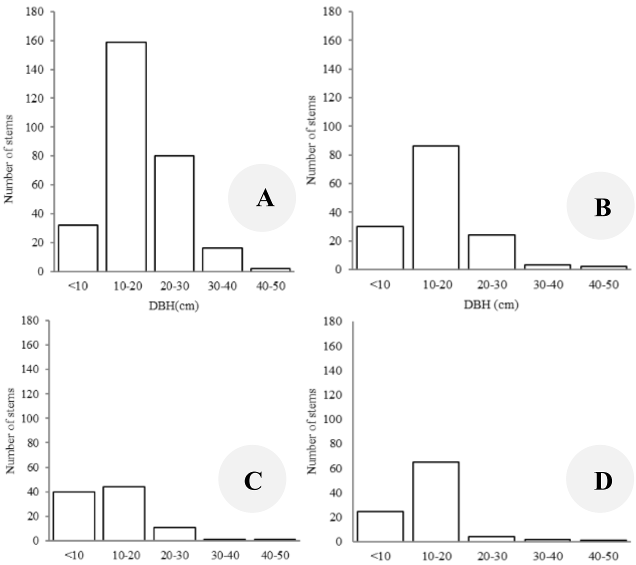

Figure 4. Distribution of DBH size classes in the most abundant species (DBH ≥4.5 cm, height ≥1.30 m). A. *Dipterocarpus tuberculatus*, B. *Shorea obtusa*, C. *Xylia xylocarpa*, D. *Sindora siamensis*

The importance value index (IVI) of woody tree species at various growth stages in the Ban Nong Ma-U Community Forest was assessed and presented in Table 2. The five most dominant tree species accounted for more than half of the IVI, totaling 156.57. The *D. tuberculatus* trees had the highest IVI value of 66.17, followed by *S. obtusa* (33.42), *X. xylocarpa* (22.57), *S. siamensis* (21.07), and *Syzygium ripicola* (13.34). In the saplings stage, *Suregada multiflora* showed the maximum IVI value of 55.00, followed by *X. xylocarpa* (41.78), *Memecylon scutellatum* (27.63), *Microcos tomentosa* (27.54), *Phyllanthus emblica* (23.24), and the remaining 19 species with low IVI (accounting for IVI of 124.81). *S. siamensis* had demonstrated the highest score of important value among other seedling species, followed by *Anthoshorea roxburghii*, *X. xylocarpa*, *M. scutellatum*, *S. obtusa*, and 15 other species. These critical values, based on a composite score of relative frequency and density, were 34.18, 24.84, 24.46, 19.13, 13.03, and 84.36 (accounting for 15 species), respectively (Table 2). According to IVI, these few species were considered the most ecologically significant trees, saplings, and seedlings in Ban Nong Ma-U Community Forest due to their high relative frequency, density, and basal area. It means they play crucial roles in the ecosystem. In contrast, many species show low IVI values, suggesting they are less abundant and have less impact on the study's vegetation community. The analysis of IVI is an important parameter that indicates the relative ecological importance of a given woody species at a particular site, where dominant or rare species are identified, and priority species needed for management and conservation practices are determined (Kent and Coker 1992).

Diversity indices of woody species at different growth stages are presented in Table 3. The Shannon-Wiener index (H′) ranged from 2.48 to 2.96. The tree stage showed the highest value of 2.96, while the sapling and seedling stages had values of 2.66 and 2.48, respectively. The Evenness index ranged from 0.71 to 0.84 across all growth stages. The lowest Evenness index of diversity was recorded during the tree growth stage. The Simpson index of the sapling stage was higher than that of the tree and seedling stages. These values were 0.91, 0.90, and 0.89, respectively. In general, the Shannon diversity index lies between 1.5 and 3.5, though in exceptional cases it can exceed 4.5. Our findings are similar to other reports found in the other dipterocarp forests, such as Aye et al. (2014) at Popa Mountain Park, Myanmar, with H′ of 2.96; Ekasari et al. (2024) at Dramaga research forest, Bogor, Indonesia, with H′ between 2.24 and 2.96; and Thammanu et al. (2021c) at Ban Mae Chiang Rai Lum Community Forest, Northern Thailand, with H′ of 2.44. However, the values are considered to be lower than in other tropical forests, such as in Kota Damansara Forest Reserve, Selangor, Malaysia, with H′ of 3.43 (Ruziman et al. 2022); and in Doi Suthep-Pui National Park, Chiang Mai Province, Thailand, with H′ of 3.18 (Khamyong et al. 2018).

In this study, Fabaceae, Dipterocarpaceae, and Rubiaceae are the predominant families that typically exhibit in dry regions of dipterocarp forests, including the north and northeast of Thailand. The dominance of Dipterocarpaceae and Fabaceae in these forests highlights their adaptations to harsh conditions, such as extended dry seasons and frequent fires (Eiadthong 2008). The evidence found in the forests of Nature Study Center in Kantharawichai District, Maha Sarakham Province, represents the dominance of tree species belonging to the Fabaceae family (Plybour et al. 2025) and Dipterocarpaceae species widely distributed in the deciduous dipterocarp forest in Doi Suthep-Pui National Park, Chiang Mai Province (Marod et al. 2019), as well as Rubiaceae species dominate most forests in Ban Mae Chiang Rai Lum Community Forest, Lampang Province (Thammanu et al. 2021c). Besides, Dipterocarpaceae and Fabaceae play an important role in providing forest products, as many valuable timber species belong to these families (Whitmore 1984). Our findings show that most of the dominant species found in Ban Nong Ma-U Community Forest, such as *D. tuberculatus*, *S. obtusa, X. xylocarpa*, *S.*

siamensis, and *Pterocarpus macrocarpus*, are notably recognized as economically valuable trees in Thailand. They are well known for producing high-quality timbers that are famous for construction and furniture applications due to their strength and durability, and are highly valued in Thailand and Southeast Asia (Shiva and Jantan 1998; Fambayun et al. 2021). Our findings indicate that Dipterocarpaceae and Fabaceae in the Ban Nong Ma-U Community Forest generally exhibit high species richness and abundance, whereas several other families show low species richness and abundance, including Annonaceae, Ebenaceae, Malvaceae, Moraceae, Rutaceae, and Sapindaceae. Variation in families and species composition reveals a diverse ecosystem, and this differentiation is due to differences in ecological niches and adaptive strategies among families and their species in this environment (Plybour et al. 2025). At the species level, some dominant species threaten their development, as indicated by IVI values, which show that sapling and seedling stages are much lower than the tree stage, such as in *D. tuberculatus*, *S. siamensis*, and *P. macrocarpus*. These species are ecologically important and serve as representative native trees in deciduous dipterocarp forests. Notably, the population trends of *D. tuberculatus* and *P. macrocarpus* are declining globally, according to the IUCN Red List category (IUCN 2025). Therefore, it is imperative to develop a management plan for these species to conserve their regeneration and habitat in the Ban Nong Ma-U Community Forest.

Table 3. Diversity indices of woody species in Ban Nong Ma-U Community Forest

Diversity indices	Trees	Saplings	Seedlings
Shannon-Wiener index	2.96	2.66	2.48
Simpson index	0.90	0.91	0.89
Evenness index	0.71	0.84	0.83

Table 2. Relative frequency (RF), Relative density (RD), Relative dominance (RDo), and Importance value index (IVI) of species in Ban Nong Ma-U Community Forest

Stage	No.	Family	Scientific name	RF	RD	RDo	IVI
Trees	1	Dipterocarpaceae	*Dipterocarpus tuberculatus* Roxb.	9.04	24.94	32.19	66.17
	2	Dipterocarpaceae	*Shorea obtusa* Wall. ex Blume	8.01	12.51	12.90	33.42
	3	Fabaceae	*Xylia xylocarpa* (Roxb.) W.Theob.	7.75	8.37	6.45	22.57
	4	Fabaceae	*Sindora siamensis* Teijsm. ex Miq.	5.68	8.37	7.01	21.07
	5	Myrtaceae	*Syzygium ripicola* (Craib) Merr. & L.M.Perry	5.17	4.40	3.77	13.34
	6	Dipterocarpaceae	*Anthoshorea roxburghii* (G.Don) P.S.Ashton & J.Heck.	4.39	3.36	5.52	13.27
	7	Fabaceae	*Pterocarpus macrocarpus* Kurz	5.17	3.54	3.32	12.02
	8	Combretaceae	*Terminalia elliptica* Willd.	4.91	3.71	3.04	11.65
	9	Combretaceae	*Terminalia glaucifolia* Craib	4.13	3.11	3.03	10.27
	10	Dipterocarpaceae	*Dipterocarpus intricatus* Dyer	2.84	2.59	3.95	9.38
	11-64		Others	42.91	25.10	18.82	86.84
Saplings	1	Euphorbiaceae	*Suregada multiflora* (A.Juss.) Baill.	13.73	21.95	19.32	55.00
	2	Fabaceae	*Xylia xylocarpa* (Roxb.) W.Theob.	13.73	8.54	19.52	41.78
	3	Melastomataceae	*Memecylon scutellatum* (Lour.) Hook. & Arn.	9.80	12.20	5.63	27.63
	4	Malvaceae	*Microcos tomentosa* Sm.	5.88	12.20	9.47	27.54
	5	Phyllanthaceae	*Phyllanthus emblica* L.	7.84	8.54	6.86	23.24
	6	Myrtaceae	*Syzygium ripicola* (Craib) Merr. & L.M.Perry	3.92	3.66	6.78	14.36
	7	Ebenaceae	*Diospyros defectrix* H.R.Fletcher	5.88	4.88	3.29	14.05
	8	Annonaceae	*Xylopia pierrei* Hance	5.88	3.66	2.09	11.63
	9	Dipterocarpaceae	*Shorea obtusa* Wall.	1.96	1.22	6.21	9.39
	10	Sapindaceae	*Allophylus cobbe* (L.) Forsyth f.	1.96	3.66	3.48	9.10
	11-24		Others	29.42	19.51	17.36	66.28
Seedlings	1	Fabaceae	*Sindora siamensis* Teijsm. ex Miq.	8.57	25.61	-	34.18
	2	Dipterocarpaceae	*Anthoshorea roxburghii* (G.Don) P.S.Ashton & J.Heck.	11.43	13.41	-	24.84
	3	Fabaceae	*Xylia xylocarpa* (Roxb.) W.Theob.	17.14	7.32	-	24.46
	4	Melastomataceae	*Memecylon scutellatum* (Lour.) Hook. & Arn.	5.71	13.41	-	19.13
	5	Dipterocarpaceae	*Shorea obtusa* Wall.	5.71	7.32	-	13.03
	6	Euphorbiaceae	*Suregada multiflora* (A.Juss.) Baill.	5.71	6.10	-	11.81
	7	Malvaceae	*Microcos tomentosa* Sm.	5.71	2.44	-	8.15
	8	Combretaceae	*Terminalia glaucifolia* Craib	5.71	2.44	-	8.15
	9	Lauraceae	*Litsea glutinosa* (Lour.) C.B.Rob.	2.86	3.66	-	6.52
	10	Lecythidaceae	*Careya arborea* Roxb.	2.86	2.44	-	5.30
	11-20		Others	28.59	15.85	-	44.43

Note: Others refers to all remaining species not listed individually. A hyphen (-) indicates that RDo is not computed

Biomass and carbon stock

The estimated AGB, BGB, and total biomass of trees and saplings at the community forest is demonstrated in Table 4. Total tree biomass was 59.49 ton ha^{-1}, contributed by AGB biomass of 52.01 ton ha^{-1} and BGB biomass of 7.48 ton ha^{-1}. The top five tree species that contributed most to total biomass were *D. tuberculatus* (18.85 ton ha^{-1}, 31.69%), *S. obtusa* (7.44 ton ha^{-1}, 12.51%), *S. siamensis* (4.39 ton ha^{-1}, 7.38%), *X. xylocarpa* (3.70 ton ha^{-1}, 6.22%), and *A. roxburghii* (3.63 ton ha^{-1}, 6.10%), while the remaining 59 species that contributed lesser biomass accounted for 21.48 ton ha^{-1} (36.10%). All sapling species accumulated the total biomass at 0.75 ton ha^{-1}, with AGB and BGB biomass of 0.58 and 0.16 ton ha^{-1}, respectively. The top five species contributed most to total biomass were *S. multiflora* (0.17 ton ha^{-1}, 22.67%), *M. tomentosa* (0.10 ton ha^{-1}, 13.33%), *X. xylocarpa* (0.10 ton ha^{-1}, 13.33%), *S. ripicola* (0.07 ton ha^{-1}, 9.33%), and *P. emblica* (0.04 ton ha^{-1}, 5.33%), and the remaining 19 species accounted for 0.27 ton ha^{-1} (36.01%).

The carbon stocks are listed in Table 4. Total carbon stocks in trees and saplings were 27.96 and 0.35 ton C ha^{-1}, respectively. Overall, the above-ground carbon stock found in this study was lower than that of other deciduous dipterocarp forests; for example, Kanhom et al. (2019) reported 25.64 ton C ha^{-1} of AGB at Ban Nong Mek Forest, Sa Kaeo; Thammanu et al. (2021c) reported 30.35 ton C ha^{-1} at Ban Mae Chiang Rai Lum Community Forest, Lampang; and Plybour et al. (2025) reported 67.92 ton C ha^{-1} at Nature Study Center, Northeastern Thailand. Additionally, prior studies revealed that trees in deciduous forests with DBH >20 cm accumulate more biomass than those with DBH <20 cm (Terakunpisut et al. 2007; Pibumrung et al. 2008). In the present study, 79.77% of stems in Ban Nong Ma-U Community Forest exhibited a DBH of less than 20 cm, which contributed to a low basal area and volume, as well as a reduced capacity to accumulate biomass and carbon stocks compared to stems with larger DBHs. The use of similar methods and size thresholds strengthens the robustness of these comparisons, enabling direct evaluation with similarly designed studies. In Thailand, the majority of community forests experienced timber harvesting. Following the implementation of community management, these forests underwent secondary succession as a direct consequence (Kabir and Webb 2006; Podong and Krivutthinun 2018). Past disturbances, such as wildfires, grazing, and NTFP hunting, may also limit biomass and carbon accumulation in the Ban Nong Ma-U community forest.

NTFP diversity and its social values

NTFPs collected and utilized at Ban Nong Ma-U Community Forest were categorized into three major groups: plants, mushrooms, and animals. Wild plants exhibited a higher diversity of species used by the local people at Ban Nong Ma-U villages, with 86 species, more than mushrooms, with five species, and animals, with six species. The distribution of plant families and their species is illustrated in Figure 5. The Fabaceae family was the most utilized, with seven species producing NTFPs, followed by Poaceae with six species, Zingiberaceae with five species, Araceae, Dioscoreaceae, Malvaceae, and Phyllanthaceae with four species, and the remaining families with members ranging from one to three species.

Table 4. Biomass and carbon stock of woody species in Ban Nong Ma-U Community Forest

Stage	No.	Scientific name	Biomass (ton ha^{-1})			Carbon stock (ton C ha^{-1})		
			AGB	BGB	Total	AGB	BGB	Total
Trees	1	*Dipterocarpus tuberculatus* Roxb.	16.53	2.32	18.85	7.77	1.09	8.86
	2	*Shorea obtusa* Wall. ex Blume	6.49	0.94	7.44	3.05	0.44	3.50
	3	*Sindora siamensis* Teijsm. ex Miq.	3.82	0.57	4.39	1.80	0.27	2.06
	4	*Xylia xylocarpa* (Roxb.) W.Theob.	3.21	0.49	3.70	1.51	0.23	1.74
	5	*Anthoshorea roxburghii* (G.Don) P.S.Ashton & J.Heck.	3.21	0.42	3.63	1.51	0.20	1.71
	6	*Dipterocarpus intricatus* Dyer	2.07	0.26	2.33	0.97	0.12	1.09
	7	*Pterocarpus macrocarpus* Kurz	1.91	0.28	2.19	0.90	0.13	1.03
	8	*Terminalia glaucifolia* Craib	1.67	0.24	1.92	0.79	0.11	0.90
	9	*Terminalia elliptica* Willd.	1.60	0.22	1.81	0.75	0.10	0.85
	10	*Syzygium ripicola* (Craib) Merr. & L.M.Perry	1.50	0.23	1.73	0.71	0.11	0.81
	11-64	Others	10.00	1.50	11.50	4.70	0.71	5.41
Total			52.01	7.48	59.49	24.44	3.51	27.96
Saplings	1	*Suregada multiflora* (A.Juss.) Baill.	0.14	0.04	0.17	0.06	0.02	0.08
	2	*Microcos tomentosa* Sm.	0.08	0.02	0.10	0.04	0.01	0.05
	3	*Xylia xylocarpa* (Roxb.) W.Theob.	0.08	0.02	0.10	0.04	0.01	0.05
	4	*Syzygium ripicola* (Craib) Merr. & L.M.Perry	0.06	0.02	0.07	0.03	0.01	0.03
	5	*Phyllanthus emblica* L.	0.03	0.01	0.04	0.01	0.00	0.02
	6	*Memecylon scutellatum* (Lour.) Hook. & Arn.	0.03	0.01	0.03	0.01	0.00	0.02
	7	*Shorea obtusa* Wall.	0.02	0.01	0.03	0.01	0.00	0.01
	8	*Allophylus cobbe* (L.) Forsyth f.	0.02	0.01	0.03	0.01	0.00	0.01
	9	*Antidesma acidum* Retz.	0.02	0.00	0.02	0.01	0.00	0.01
	10	*Diospyros defectrix* H.R.Fletcher	0.02	0.00	0.02	0.01	0.00	0.01
	11-24	Others	0.10	0.03	0.13	0.05	0.01	0.06
Total			0.58	0.16	0.75	0.27	0.08	0.35

The number of use-reports (UR) was grouped into nine categories, as shown in Table 5. Maximum use of plants was reported for human food (1,196 citations, 76.28%), followed by materials (157 citations, 10.01%), medicines (109 citations, 6.95%), social uses (48 citations, 3.06%), and fuels (8 citations, 0.51%). Moreover, the study revealed the number of plant species across the use-categories of NTFP-producing species (Table 6). The total of 86 species contributed to the human food use with 57 species, medicinal use with 27 species, materials use with 16 species, social uses with 7 species, fuel and animal uses with five species each, food additive use with three species, environmental use with one species, and invertebrate poison use with 2 species. The highest UR for human food aligns with the greatest number of species producing NTFPs, as shown in Tables 5 and 6. Furthermore, numerous plants and plant-derived products collected from forests are frequently utilized as human food and for medicinal purposes (Table 6). This pattern of NTFPs' use is common in rural communities in the North and Northeastern regions; for example, Georgiadis (2021) reported that the major wild plants are used as human food at Mae Klang Luang village, Doi Inthnon, Chiang Mai, and Saisor et al. (2021) showed that the most plant species at Kosum Phisai, Maha Sarakham, were used for human food, with Fabaceae being the most commonly used family, similar to our findings in this study. Based on life forms, trees contributed the most to NTFPs with 27 species, followed by herbs with 13 species, climbers with 11 species, and shrub/shrubby trees with 10 species, and the rest of the life forms had at least one to five species (Table 6).

Table 5. Use-reports (UR) of plants at different use-categories in Ban Nong Ma-U Community Forest

Use-categories	Number of UR	Percentage
Human Food (HF)	1,196	76.28
Medicines (MD)	109	6.95
Materials (MT)	157	10.01
Social Uses (SU)	48	3.06
Fuels (FU)	8	0.51
Animal Food (AF)	26	1.66
Food Additives (FA)	17	1.08
Environmental Uses (EU)	3	0.19
Invertebrate Poisons (IP)	4	0.26
Total	1,568	100.00

Table 6. Number of plant species producing NTFPs at different use-categories in Ban Nong Ma-U Community Forest

Life forms	Number of species	Number of species producing NTFPs								
		HF	MD	MT	SU	FU	AF	FA	EU	IP
Tree	27	19	4	5	1	1	1	1		
Herb	13	9	8	2	2	1			1	1
Shrub/shrubby tree	10	6	4	2		3	2			1
Climber	11	8	4	1						
Shrubby tree	5	4	2	1	1			1		
Bamboo	3	3	1	1			1			
Shrub	4	1	2	1	1			1		
Gras	3		1	2	1					
Herbaceous climber	4	4								
Palm	1	1		1						
Climbing palm	1	1								
Exotic herb	1		1							
Parasitic shrub	1				1					
Scandent shrub	1						1			
Woody climber	1	1								
Total	86	57	27	16	7	5	5	3	1	2

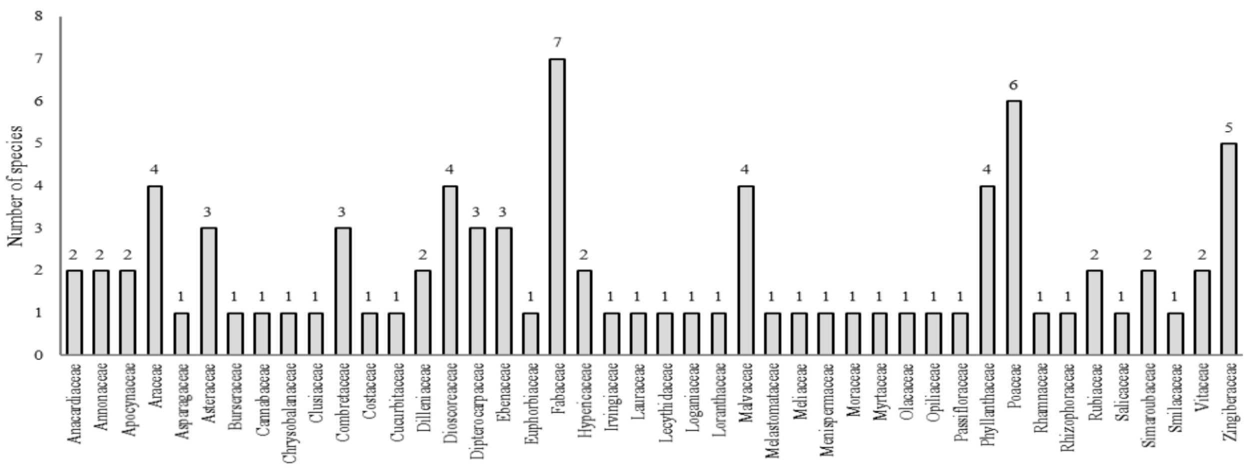

Figure 5. Families and their species of plants used as NTFPs in Ban Nong Ma-U Community Forest

Table 7. Ethnobotanical values of plants used in Ban Nong Ma-U Community Forest

Scientific name	FC	UR	NU	CI	RFC	RI	CV
Curcuma parviflora Wall.	74	74	1	0.79	0.79	0.70	0.07
Amorphophallus macrophyllum (Gagnep. ex Serebryanyi) Hett. & Claudel	70	70	1	0.74	0.74	0.67	0.06
Cratoxylum formosum (Jack) Benth. & Hook.f. ex Dyer	66	69	2	0.73	0.70	0.80	0.11
Azadirachta indica A.Juss.	54	54	2	0.57	0.57	0.72	0.07
Amorphophallus paeoniifolius (Dennst.) Nicolson	47	49	2	0.52	0.50	0.67	0.06
Phoenix loureiroi Kunth	42	48	2	0.51	0.45	0.63	0.05
Albizia lebbeck (L.) Benth.	48	48	1	0.51	0.51	0.51	0.03
Uvaria rufa (Dunal) Blume	46	46	1	0.49	0.49	0.50	0.03
Adenia viridiflora Craib	45	45	1	0.48	0.48	0.49	0.03
Bambusa bambos (L.) Voss	40	45	2	0.48	0.43	0.62	0.05
Dioscorea filiformis Blume	40	40	1	0.43	0.43	0.45	0.02
Smilax perfoliata Lour.	34	36	2	0.38	0.36	0.58	0.03
Zingiber zerumbet (L.) Roscoe ex Sm.	33	33	1	0.35	0.35	0.40	0.01
Phyllanthus emblica L.	28	32	2	0.34	0.30	0.53	0.02
Irvingia malayana Oliv. ex A.W.Benn.	31	31	1	0.33	0.33	0.39	0.01
Vietnamosasa ciliata (A.Camus) T.Q.Nguyen	29	29	1	0.31	0.31	0.37	0.01
Imperata cylindrica (L.) Raeusch.	25	28	2	0.30	0.27	0.51	0.02
Senna garrettiana (Craib) H.S.Irwin & Barneby	26	26	1	0.28	0.28	0.35	0.01
Mangifera caloneura Kurz	26	26	1	0.28	0.28	0.35	0.01
Terminalia chebula Retz.	26	26	1	0.28	0.28	0.35	0.01
Antidesma ghaesembilla Gaertn.	26	26	1	0.28	0.28	0.35	0.01
Adenanthera pavonina L.	26	26	1	0.28	0.28	0.35	0.01
Melientha suavis Pierre	25	25	1	0.27	0.27	0.35	0.01
Curcuma alismatifolia Gagnep.	24	24	3	0.26	0.26	0.67	0.02
Artocarpus lacucha Buch.-Ham. ex D.Don	24	24	1	0.26	0.26	0.34	0.01
Calamus diepenhorstii Miq.	24	24	1	0.26	0.26	0.34	0.01
Curcuma sessilis Gage	21	21	1	0.22	0.22	0.32	0.01
Careya arborea Roxb.	19	21	2	0.22	0.20	0.47	0.01
Bothriochloa bladhii (Retz.) S.T.Blake	20	20	1	0.21	0.21	0.31	0.01
Dipterocarpus tuberculatus Roxb.	20	20	1	0.21	0.21	0.31	0.01
Eurycoma longifolia Jack	20	20	1	0.21	0.21	0.31	0.01
Olax psittacorum (Lam.) Vahl	20	20	1	0.21	0.21	0.31	0.01
Microcos tomentosa Sm.	19	19	1	0.20	0.20	0.30	0.00
Dioscorea bulbifera L.	18	18	1	0.19	0.19	0.30	0.00
Ziziphus oenoplia (L.) Mill., 1768	18	18	1	0.19	0.19	0.30	0.00
Morinda coreia Buch.-Ham.	17	17	2	0.18	0.18	0.45	0.01
Amphineurion marginatum (Roxb.) D.J.Middleton	17	17	1	0.18	0.18	0.29	0.00
Syzygium cumini (L.) Skeels	17	17	1	0.18	0.18	0.29	0.00
Dioscorea hispida Dennst.	15	15	1	0.16	0.16	0.27	0.00
Carallia brachiata (Lour.) Merr.	15	15	1	0.16	0.16	0.27	0.00
Vietnamosasa pusilla (A.Chev. & A.Camus) T.Q.Nguyen	14	14	3	0.15	0.15	0.60	0.01
Ampelocissus martinii Planch.	13	13	1	0.14	0.14	0.26	0.00
Diospyros variegata Kurz	13	13	1	0.14	0.14	0.26	0.00
Tacca leontopetaloides (L.) Kuntze	9	13	3	0.14	0.10	0.56	0.00
Flacourtia indica (Burm.fil.) Merr.	12	12	1	0.13	0.13	0.25	0.00
Colona auriculata (Desf.) Craib	12	12	1	0.13	0.13	0.25	0.00
Bridelia affinis Craib	11	11	3	0.12	0.12	0.58	0.00
Peltophorum dasyrrhachis (Miq.) Kurz	11	11	1	0.12	0.12	0.25	0.00
Garcinia cowa Roxb.	8	11	2	0.12	0.09	0.39	0.00
Suregada multiflora (A.Juss.) Baill.	10	10	3	0.11	0.11	0.57	0.00
Cratoxylum cochinchinense (Lour.) Blume	10	10	1	0.11	0.11	0.24	0.00
Canarium subulatum Guillaumin	10	10	1	0.11	0.11	0.24	0.00
Mukia sp.	9	9	1	0.10	0.10	0.23	0.00
Sindora siamensis Teijsm. ex Miq.	9	9	1	0.10	0.10	0.23	0.00
Parinari anamensis Hance	9	9	2	0.10	0.10	0.40	0.00
Kaempferia rotunda L.	8	8	2	0.09	0.09	0.39	0.00
Chromolaena odorata (L.) R.M.King & H.Rob.	8	8	1	0.09	0.09	0.22	0.00
Combretum sp.	7	7	1	0.07	0.07	0.22	0.00
Bombax anceps Pierre	7	7	2	0.07	0.07	0.38	0.00
Memecylon scutellatum (Lour.) Hook. & Arn.	3	7	3	0.07	0.03	0.52	0.00
Dipterocarpus intricatus Dyer	6	6	2	0.06	0.06	0.38	0.00
Waltheria indica L.	6	6	3	0.06	0.06	0.54	0.00
Garuga pinnata Roxb.	6	6	2	0.06	0.06	0.38	0.00

Tiliacora triandra (Colebr.) Diels	5	6	2	0.06	0.05	0.37	0.00
Asparagus racemosus Willd.	6	6	1	0.06	0.06	0.21	0.00
Dillenia obovata (Blume) Hoogland	6	6	1	0.06	0.06	0.21	0.00
Strychnos nux-blanda A.W.Hill	5	5	2	0.05	0.05	0.37	0.00
Unknown	5	5	1	0.05	0.05	0.20	0.00
Litsea glutinosa (Lour.) C.B.Rob.	5	5	1	0.05	0.05	0.20	0.00
Ageratum conyzoides L.	5	5	2	0.05	0.05	0.37	0.00
Anthoshorea roxburghii (G.Don) P.S.Ashton & J.Heck.	4	4	1	0.04	0.04	0.20	0.00
Holarrhena curtisii King & Gamble	2	4	2	0.04	0.02	0.35	0.00
Centotheca lappacea (L.) Desv.	4	4	1	0.04	0.04	0.20	0.00
Cheilocostus speciosus (J.Koenig) C.D.Specht	4	4	3	0.04	0.04	0.53	0.00
Diospyros sp.	3	3	1	0.03	0.03	0.19	0.00
Trema angustifolia (Planch.) Blume	3	3	2	0.03	0.03	0.35	0.00
Tetracera loureiroi (Finet & Gagnep.) Pierre ex Craib	3	3	1	0.03	0.03	0.19	0.00
Elephantopus scaber L.	3	3	1	0.03	0.03	0.19	0.00
Mitrephora wangii Hu	3	3	1	0.03	0.03	0.19	0.00
Catunaregam tomentosa (Blume ex DC.) Tirveng.	3	3	1	0.03	0.03	0.19	0.00
Dendrophthoe sp.	2	2	1	0.02	0.02	0.18	0.00
Eriosema chinense Vogel	2	2	1	0.02	0.02	0.18	0.00
Leea indica (Burm.f.) Merr.	2	2	1	0.02	0.02	0.18	0.00
Buchanania siamensis Miq.	2	2	1	0.02	0.02	0.18	0.00
Harrisonia perforata (Blanco) Merr.	2	2	1	0.02	0.02	0.18	0.00
Aporosa villosa (Lindl.) Baill.	2	2	1	0.02	0.02	0.18	0.00

Note: FC: Frequency of citation, UR: Use-reports, NU: Number of uses, CI: Cultural importance index, RFC: Relative frequency of citation, RI: Relative importance index, CV: Cultural value index. The values <0.005 are shown as 0.00

Table 8. Ethnobotanical values of mushrooms and animals in Ban Nong Ma-U Community Forest

	Species	FC	UR	CI	RFC	RI	CV	Use-categories
Mushrooms	*Russula emetica* (Schaeff.) Pers.	34	34	0.36	0.36	0.70	0.13	HF
	Termitomyces spp.	50	50	0.53	0.53	0.80	0.28	HF
	Astraeus hygrometricus (Pers.) Morgan	79	79	0.84	0.84	0.97	0.71	HF
	Amanita spp.	84	84	0.89	0.89	1.00	0.80	HF
	Mycoamaranthus cambodgensis (Pat.) Trappe, Lumyong, P.Lumyong, Sanmee & Zhu L.Yang	2	2	0.02	0.02	0.51	0.00	HF
Animals	*Oecophylla smaragdina* (Fabricius, 1775)	41	41	0.44	0.44	0.75	0.10	HF
	Apis dorsata Fabricius, 1793	13	13	0.14	0.14	0.41	0.01	HF
	Apis florea Fabricius, 1787	22	23	0.24	0.23	0.77	0.06	HF, MD
	Leiolepis spp.	17	17	0.18	0.18	0.46	0.02	HF
	Melolontha melolontha (Linnaeus, 1758)	12	12	0.13	0.13	0.40	0.01	HF
	Cyriopagopus minax (Thorell, 1897)	18	18	0.19	0.19	0.47	0.02	HF

Note: FC: Frequency of citation, UR: Use-reports, CI: Cultural importance index, HF: Human Food, MD: Medicine. The values <0.005 are shown as 0.00

Quantitative ethnobotanical data of plants are represented in Table 7. *Curcuma parviflora* had the highest use by the local people at Ban Nong Ma-U based on the maximum value cited by the users (FC = 74), followed by *Amorphophallus macrophyllum* (FC = 70), *Cratoxylum formosum* (FC = 66), *Azadirachta indica* (FC = 54), and the other species had the FC between 2 and 47. The use-report (UR) indicates the sum of uses of the species in the given use-categories; namely, *Phoenix loureiroi* was employed in two, as used in the category of human food and materials mentioned by 14 and 34 informants, respectively, out of nine different use-categories. Hence, the sum of uses of this species (UR) was 48. The diversity of plant uses varied across 1 to 3 use-categories. Most of them were only 1 use (66.28%), followed by 2 uses (24.42%), and 3 uses (9.30%).

The CI values ranged from 0.02 to 0.79. The five most significant species based on the CI index were *C. parviflora*, *A. macrophyllum*, *C. formosum*, *A. indica*, and *Amorphophallus paeoniifolius*. The values were 0.79, 0.74, 0.73, 0.57, and 0.52, respectively. This CI index takes into account not only the spread of the use (number of informants) for each species but also its versatility; for example, *P. loureiroi* and *Albizia lebbeck* had the same CI index value (0.51). Although they were cited with the same use-report (UR) value of 48, they were mentioned by different numbers of informants (FC): *P. loureiroi* with 42 and *A. lebbeck* with 48. In the case of species with only one use, CI would be equal to RFC values, such as *Adenia viridiflora,* with one use in the category of human food, so CI is equal to RFC (0.48). Among the RI and CV indices, the five most significant species in CI values were also among the top five in RI and CV. But *C. formosum* showed the greatest RI and CV among other species, with the values of 0.80 and 0.11, respectively. The RI and CV indices take into account the frequency of citation (FC) and the number of uses (NU). *C. formosum* contributed to a lower FC value than *C. parviflora* and *A. macrophyllum*, but showed a higher value of NU than these two species. Theoretically, the RI index varies from 0 if nobody mentions any use of the plant, to 1 in the case where the plant was the most frequently mentioned as useful and in the maximum number of use-categories (Tardío and Santayana 2008). Interestingly, the highest RI and CV values were observed in *C. formosum*, at 0.80 and 0.11, respectively. *Curcuma alismatifolia* also exhibited a high RI value of 0.67, while showing lower FC and UR values than those of the most significant species. RI and CV indices are influenced by both the number of informants who mention its usefulness (FC) and the diversity of uses (NU). Furthermore, our findings confirm the impact of FC and NU on RI and CV values, indicating that the more versatile a plant, the more widespread its usefulness. That means those versatile plants with several uses are generally more familiar to people than those with only one use (Tardío and Santayana 2008).

Overall, we conclude that *C. parviflora*, *A. macrophyllum*, *C. formosum*, *A. indica*, *A. paeoniifolius*, *C. alismatifolia*, and *P. loureiroi* are the most culturally significant species, as indicated by the highest CI, RFC, RI, and CV values among all species. Notably, most of these species, including *C. parviflora*, *A. macrophyllum*, *C. formosum*, *A. indica*, and *A. paeoniifolius*, were primarily used as staple foods for local households. In addition, *C. alismatifolia* holds a special place for its blossoms, cherished in worship rituals. Furthermore, the leaves of *P. loureiroi* are essential for crafting traditional brooms, a practice integral to the region's cultural heritage. For *D. tuberculatus*, it was ecologically significant for its abundant populations and substantial contribution to carbon accumulation. It was also culturally significant, as local villagers used it for packaging and food wrapping in this study. Establishing a comprehensive framework for the effective development, promotion, and sustainability of such NTFPs may support the region. This includes harvesting protocols, reproductive strategies, and value-added product development. Such efforts may facilitate sustainable livelihoods, enhance community participation, and support conservation of forest resources in the region.

Five species of edible mushrooms and six species of animals were utilized from the Ban Nong Ma-U Community Forest, as shown in Table 8. All of them were reported to be used for human consumption, except *Apis florea*, which is used for medicinal purposes. The CI ranged from 0.02 to 0.89 in mushrooms and 0.13 to 0.44 in animals. Mushrooms in the *Amanita* genus were assigned to be the most significant species of wild mushrooms based on the highest CI value of 0.89, while *Oecophylla smaragdina* was the most significant species in the animal NTFP group with the highest CI value of 0.44.

Investigation of the ecological and social characteristics of the Ban Nong Ma-U Community Forest revealed that numerous Fabaceae species dominated the forest stand and were widely utilized by the residents for NTFP consumption. Among these, *S. obtusa*, *X. xylocarpa*, and *S. siamensis* were ecologically significant, as indicated by high IVI, biomass, and carbon accumulation. Most NTFPs were used for food, materials, and medicines, with several tree species contributing to NTFP production. *C. parviflora* emerged as the most culturally significant NTFP species, as indicated by the highest CI value. In conclusion, our results indicate that Ban Nong Ma-U Community Forest exhibits moderate biodiversity, modest carbon stocks, and high NTFP richness.

These findings underscore the forest's significance in maintaining species diversity and populations, conserving economically valuable timber species, facilitating carbon sequestration and storage, and supporting the productivity of NTFPs that contribute to food security and local livelihoods. Furthermore, the forest is vital to supporting local collectors who rely on forest products, including food, medicines, materials, and resources for social practices. Additionally, it contributes significantly to ecosystem integrity and the preservation of cultural traditions.

Nowadays, rising collaboration and incentives of local communities residing around forests through community-based forest management are a key strategy to enhance sustainable forest management, increase biomass and carbon stock, and support climate change mitigation and adaptation through local community participation (Fischer et al. 2023; Aprilia 2025). Additionally, valuing carbon sequestration over time or through carbon credit trading projects has been focused on community forests in Thailand (Chaiya 2025). This challenges all stakeholders to balance economic and ecological incentives to enhance carbon sequestration without decreasing diverse species, ensuring that livelihood options for local communities are sustainably provided by the community forests. Such evidence was found in Nepal's community forest, where Pandey et al. (2014) reported a reduction in species richness with increasing carbon stock. Moreover, they suggested that an incentive mechanism to maintain species richness, together with a mechanism to secure carbon stocks and conservation and carbon benefits in community forestry, should be investigated.

We recommend increasing efforts in education, training, and research support for implementing socially acceptable practices at all levels of decision-making. Emphasis should be placed on enhancing species abundance, diversity, and carbon storage in this forest. These objectives can be achieved through targeted enrichment planting of valuable native timber species, adoption of site-specific restoration approaches, and implementation of wildfire mitigation strategies such as controlled fuel management and the establishment of firebreaks. Furthermore, effective protection and utilization schemes that integrate local knowledge for species with rare populations and high economic value should be collaboratively developed through community networks to support community-based governance. These actions will facilitate the further development of community forest planning focused on sustainable management of species composition and diversity, carbon storage, and NTFP productivity.

This study employed a single-site, cross-sectional design and assessed only the biomass of living woody plants. To deepen understanding, future research should therefore include long-term monitoring of ecological and social values, economic evaluation of NTFPs, and comprehensive assessment of carbon storage in both woody biomass and soils. Together, these unified efforts would provide more robust insights into sustainable community forest management practices.

In conclusion, the Ban Nong Ma-U Community Forest in Sa Kaeo Province, Thailand, delivers clear ecological and livelihood benefits under a community-based management model, supporting both biodiversity conservation and rural well-being. Vegetation surveys across 54 plots recorded 68 woody species (54 genera; 30 families), with Fabaceae as the most species-rich family and *D. tuberculatus* as the most ecologically dominant tree (highest IVI), while *S. multiflora* and *S. siamensis* were most important at the sapling and seedling stages, respectively, indicating ongoing recruitment despite a disturbance history. Diversity was moderate (H´ = 2.48-2.96) and size-class structure was dominated by intermediate stems, consistent with past harvesting and fire impacts, which also contributed to modest biomass and carbon storage (tree biomass 59.49 ton ha^{-1}; tree carbon stock 27.96 ton C ha^{-1}). Social assessments documented high dependence on non-timber forest products (97 NTFPs), dominated by wild plants used primarily for food, with several culturally salient species (e.g., *C. parviflora*, *A. macrophyllum*, *C. formosum*, *A. indica*, *A. paeoniifolius*, *C. alismatifolia*, and *P. loureiroi*) identified through ethnobotanical indices, underscoring the forest's role in food security, household materials, traditional practices, and health care. Collectively, the results highlight that sustaining these benefits will require an integrated framework that simultaneously strengthens regeneration of key timber species, reduces wildfire and overharvesting risks, and formalizes locally acceptable harvesting protocols and value-added development for priority NTFPs, ensuring that conservation incentives (including carbon-focused initiatives) do not erode species diversity or livelihood access.

ACKNOWLEDGEMENTS

This research is funded by the Fundamental Fund Project No. 133/2567, Srinakharinwirot University, Thailand. The authors sincerely thank the key informants and the villagers of Nong Ma-U Village, Sa Kaeo Province, Thailand, for their hospitality and assistance during the study. We are especially grateful to Sukid Rueanruea and Petcharat Chankeaw from the Royal Forest Department (RFD) for their help with species identification. The authors declare that they have no conflict of interest.

REFERENCES

Agarwal S, Sairorkham B, Sakitram P, Lambin EF. 2022. Effectiveness of community forests for forest conservation in Nan province, Thailand. J Land Use Sci 17 (1): 307-323. https://doi.org/10.1080/1747423X.2022.2078438.

Aprilia R. 2025. The potential of carbon sequestration in community forests for climate change mitigation and disaster risk reduction. Asean Nat Disaster Mitigation Edu J 2 (2): 129-143. https://doi.org/10.61511/andmej.v2i2.2025.1520.

Aye YY, Pampasit S, Umponstira C, Thanacharoenchanaphas K, Sasaki N. 2014. Floristic composition, diversity and stand structure of tropical forests in Popa Mountain Park. J Environ Prot 5 (17): 1588-1602. https://doi.org/10.4236/jep.2014.517150.

Budiharta S, Holl KD. 2025. Harnessing opportunities to upscale forest landscape restoration in Indonesia. Trees For People 21: 100917. https://doi.org/10.1016/j.tfp.2025.100917.

Chaiya C. 2025. Empowering climate resilience: A people-centered exploration of Thailand's greenhouse gas emissions trading and sustainable environmental development through climate risk management in community forests. Heliyon 11 (2): e41844. https://doi.org/10.1016/j.heliyon.2025.e41844.

Chashike A, Shibru S, Gebre T, Uncha A. 2025. Ethnobotanical study of traditional medicinal plants and associated indigenous knowledge in Melokoza District, South Ethiopia. Tree For People 20: 100849. https://doi.org/10.1016/j.tfp.2025.100849.

Cook FEM. 1995. Economic Botany Data Collection Standard. Royal Botanic Gardens, Kew, Richmond.

Eiadthong W. 2008. Endemic and rare plants in dry deciduous dipterocarp forest in Thailand. In: Proceedings of the FORTROP II: Tropical forestry change in a changing world. Faculty of Forestry, Kasetsart University, 17-20 November 2008. [Thai]

Ekasari I, Widjaya AH, Latifah D, Sahromi. 2024. Floristic composition and structure of Dipterocarps habitat in Dramaga Research Forest, Bogor, Indonesia. IOP Conf Ser: Earth Environ Sci 1425: 012008. https://doi.org/10.1088/1755-1315/1425/1/012008.

Fambayun RA, Istomo, Ramadhan DE. 2021. The growth performance of dipterocarps species and understorey diversity in the Gunung Dahu Research Forest, Leuwiliang, Bogor. IOP Conf Ser: Earth Environ Sci 914: 012042. https://doi.org/10.1088/1755-1315/914/1/012042.

Fischer HW, Chhatre A, Duddu A, Pradhan N, Agrawal A. 2023. Community forest governance and synergies among carbon, biodiversity and livelihoods. Nat Clim Chang 13: 1340-1347. https://doi.org/10.1038/s41558-023-01863-6.

Georgiadis P. 2021. Ethnobotanical knowledge against the combined biodiversity, poverty and climate crisis: A case study from a Karen community in Northern Thailand. Plants People Planet 4 (4): 382-391. https://doi.org/10.1002/ppp3.10259.

Hansmann R. 2024. Social, ecological and economic synergies of forests for sustainability contradict projects involving large-scale deforestation for energy production. Ecol Civiliz 1 (4): 10013. https://doi.org/10.70322/ecolciviliz.2024.10013.

He F, Hu XS. 2005. Hubbell's fundamental biodiversity parameter and the Simpson diversity index. Ecol Lett 8 (4): 386-390. https://doi.org/10.1111/j.1461-0248.2005.00729.x.

IPCC [Intergovernmental Panel on Climate Change]. 2006.: Forestland. In: IPCC guidelines for national greenhouse gas inventories. National Greenhouse Gas Inventories Programme, Japan.

Issaree M. 1982. Primary Production of Plant Communities in Old Clearing Areas at Sakaerat Environmental Research Station, Pakthongchai, Nakhon Ratchasima. [Thesis]. Kasetsart University, Bangkok. [Thai]

IUCN [International Union for Conservation of Nature]. 2025. The IUCN Red List of Threatened Species. Version 2025-2. https://www.iucnredlist.org.

Jenkins M, Schaap B. 2018. Forest Ecosystem Services. Background study prepared for the thirteenth session of the United Nations Forum on Forests. https://www.un.org/esa/forests/wp-content/uploads/2018/05/UNFF13_BkgdStudy_ForestsEcoServices.pdf.

Kabir ME, Webb EL. 2006. Saving a forest: The composition and structure of a deciduous forest under community management in Northeast Thailand. Nat Hist Bull Siam Soc 54 (2): 239-260.

Kanhom B, Moungsrimuangdee B, Waiboonya P, Yodsa-nga P, Larpkern P. 2019. Plant diversity and biomass carbon stocks of Nong Mek Community Forest, Khok Sung District, Sa Kaeo Province. Thai J For 38 (2): 41-55.

Kent M, Coker R. 1992. Vegetation Description and Analysis: A practical Approach. CRC Press, Inc.

Khamyong N, Wangpakapattanawong P, Chairuangsri S, Inta A, Tiansawat P. 2018. Tree species composition and height-diameter allometry of three forest types in Northern Thailand. Nat Life Sci Commun 17 (4): 289-306. https://doi.org/10.12982/CMUJNS.2018.0021.

Magurran AE. 2007. Species abundance distributions over time. Ecol Lett 10 (5): 347-354. https://doi.org/10.1111/j.1461-0248.2007.01024.x

Marod D, Hermhuk S, Sungkaew S, Thinkampheang S, Kamyo T, Nuipakdee W. 2019. Species composition and spatial distribution of dominant trees in the forest ecotone of a mountain ecosystem, Northern Thailand. Environ Nat Resour J 17 (3): 40-49. https://doi.org/10.32526/ennrj.17.3.2019.21.

Martin G. 1995. Ethnobotany: A Methods Manual. WWF International, UNESCO and Royal Botanic Gardens, Kew/Chapman and Hall, London.

Mechaala S, Bouatrous Y, Adouane S. 2022. Traditional knowledge and diversity of wild medicinal plants in El Kantara's area (Algerian Sahara gate): An ethnobotany survey. Acta Ecol Sin 42 (1): 33-45. https://doi.org/10.1016/j.chnaes.2021.01.007.

Mills MB, Malhi Y, Ewers RM, Kho LK, Teh YA, Both S, Burslem DFRP, Majalap N, Nilus R, Huasco WH, Cruz R, Pillco MM, Turner EC, Reynold G, Riutta T. 2023. Tropical forests post-logging are a persistent net carbon source to the atmosphere. Proc Natl Acad Sci USA 120 (3): e2214462120. https://doi.org/10.1073/pnas.2214462120.

Noinarai T, Sunthornhao P, Pothitan R. 2020. Utilization of non-timber forest products by the local communities around Phu Laen Kha National Park, Chaiyaphum Province. Thai J For 39 (2): 137-150.

Ogawa H, Yoda K, Kira T. 1965. A preliminary survey on the vegetation of Thailand. Nature and life in Southeast Asia 1: 21-157.

Pandey SS, Cockfield G, Maraseni TN. 2014. Dynamics of carbon and biodiversity under $REDD^+$ regime: A case from Nepal. Environ Sci Policy 38: 272-281. https://doi.org/10.1016/j.envsci.2014.01.005.

Pibumrung P, Gajaseni N, Popan A. 2008. Profiles of carbon stocks in forest, reforestation and agricultural land, Northern Thailand. J For Res 19: 11-18. https://doi.org/10.1007/s11676-008-0002-y.

Plybour C, Laosuwan T, Uttaruk Y, Awichin P, Rotjanakusol T, Itsarawisut J, Singharath M. 2025. An investigation of plant species diversity, above-ground biomass, and carbon stock: Insights from a dry dipterocarp forest case study. Diversity 17 (6): 428. https://doi.org/10.3390/d17060428.

Podong C, Krivutthinun P. 2018. Tree species richness and diversity of community forestry in Uttaradit Province, Thailand. Nat Environ Pollut Technol 17 (1): 87-92.

Pokhrel RK, Gautam AP. 2024. Community forest, environment conservation and rural livelihood. Geog J Nepal 17 (1): 151-162. https://doi.org/10.3126/gjn.v17i01.63945.

Pooma R, Suddee S. 2014. Tem Smitinand's Thai plant names, revised edition 2014. Office of the Forest Herbarium, Department of National Parks, Wildlife and Plant Conservation, Bangkok.

RECOFTC. 2025. Community forest governance in Thailand: The Community Forest Act and the Citizens' Forest Network. [Updated 2025 Feb 28; cited 2025 Sep 1]. https://www.recoftc.org/stories/thailand-community-forest-act-governance

Ruziman HH, Ismail A, Pardi F, Mohd Hatta SKM. 2022. Edaphic influences on tree species composition and community structure in a secondary-lowland dipterocarp forest of Kota Damansara Forest Reserve, Selangor. Malays Appl Biol 51 (4): 11-21. https://doi.org/10.55230/mabjournal.v51i4.06.

Saisor N, Prathepha P, Saensouk S. 2021. Ethnobotanical study and utilization of plants in Khok Nhong Phok Forest, Kosum Phisai District, Northeastern Thailand. Biodiversitas 22 (10): 4336-4348. https://doi.org/10.13057/biodiv/d221026.

Shannon CE, Weaver W. 1949. The Mathematical Theory Communication. University of Illinois, IL.

Shiva MP, Jantan I. 1998. Non-Timber Forest Products from Dipterocarps. In: Appanah S, Turnbull JM (eds). A Review of Dipterocarps: Taxonomy, Ecology and Silviculture. Centre for International Forest Research, Bogor, Indonesia.

Tardío J, Pardo-de Santayana M. 2008. Cultural importance indices: A comparative analysis based on the useful wild plants of Southern Cantabria (Northern Spain). Econ Bot 62: 24-39. https://doi.org/10.1007/s12231-007-9004-5

Terakunpisut J, Gajaseni N, Ruankawe N. 2007. Carbon sequestration potential in aboveground biomass of Thong Pha Phum National Forest, Thailand. Appl Ecol Environ Res 5 (2): 93-102.

Thammanu S, Han H, Ekanayake EMBP, Jung Y, Chung J. 2021b. The impact on ecosystem services and the satisfaction therewith of community forest management in Northern Thailand. Sustainability 13 (23): 13474. https://doi.org/10.3390/su132313474.

Thammanu S, Han H, Marod D, Srichaichana J, Chung J. 2021c. Above-ground carbon stock and $REDD^+$ opportunities of community-managed forests in northern Thailand. PLoS One 16 (8): e0256005. https://doi.org/10.1371/journal.pone.0256005.

Thammanu S, Han H, Marod D, Zang L, Jung Y, Soe KT, Onprom S, Chung J. 2021a. Non-timber forest product utilization under community forest management in northern Thailand. For Sci Technol 17 (1): 1-15. https://doi.org/10.1080/21580103.2020.1862712.

Thanh Tuan N, Quang Bao T, Rodríguez-Hernández DI, Gliottone I. 2021. Tree diversity and species composition of tropical dry forests in Vietnam's Central Highlands Region. Forestry Studies 75 (1): 80-103. https://doi.org/10.2478/fsmu-2021-0013.

Wang N, Bi H, Peng R, Zhao D, Liu Z. 2023. Disparities in soil and water conservation functions among different forest types and implications for afforestation on the Loess Plateau. Ecol Indic 155: 110935. https://doi.org/10.1016/j.ecolind.2023.110935.

Whitmore TC. 1984. Tropical Rain Forest of the Far East. 2nd Ed. Clarendon, New York.

Wimolsakcharoen W, Dumrongrojwatthana P, Trébuil G. 2020. Production of non-timber forest products (NTFPs) and diversity of harvesters' practices and decision-making processes in northern Thailand community forests. Bois For Trop 343: 39-52. https://doi.org/10.19182/bft2020.343.a31845.

Wiriyabancha C. 2020. Guide to Permanent Sample Plot Establishment and Field Data Collection. Forest Research and Conservation Office, Department of National Parks, Wildlife and Plant Conservation, BKK. https://pubhtml5.com/irdz/pmso/คู่มือการวางแปลงตัวอย่างถาวรและการเก็บข้อมูลภาคสนาม/86. [Thai]