BIODIVERSITAS
Volume 24, Number 2, February 2023
Pages: 799-809

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d240216

Forest structures and carbon stocks of community forests with different forest management in Maha Sarakham Province, Thailand

WANNACHAI WANNASINGHA, BHUVADOL GOMONTEAN♥, YANNAWUT UTTARUK
Department of Biology, Faculty of Science, Mahasarakham University, Kantharawichai District, Maha Sarakham 44150, Thailand.
Tel/fax.: +66-43-754245, ♥email: bhuvadol.g@msu.ac.th

Manuscript received: 24 December 2022. Revision accepted: 3 February 2023.

Abstract. *Wannasingha W, Gomontean B, Uttaruk Y. 2023. Forest structures and carbon stocks of community forests with different forest management in Maha Sarakham Province, Thailand. Biodiversitas 24: 799-809.* Forest management comprises strategies and practices to regulate human activities and the utilization of forest products. Management and regulations have various effects on forest structure, tree diversity and carbon accumulation. This study was conducted in three community forests with different levels of rule regulations and managed duration in the northeast of Thailand. Thirty of 20×20 m plots were placed for recording all trees with diameter at breast height (dbh) ≥4.5 cm and >1.3 m height. One hundred and fifty plots of soil samples at 0-25 cm and 25-50 cm depths were also collected for organic carbon analysis. Forest carbon stocks were calculated from the sum of carbon in aboveground biomass (AGB) and soil organic carbon (SOC). The results showed that tree density, basal area, Shannon diversity index and evenness index of the best practices (BP) plots were higher than the plots in which moderate (MP) and slight practices (SP) were applied. Tree heights of the BP and MP forests were higher than the SP forest. The L-shape of dbh class distribution in all community forests means they were secondary forests; tree density was highest in the small dbh class and declined in the bigger size class. The bigger dbh class tree showed higher aboveground carbon (AGC) despite the lower tree density in all community forests. Most of the BP forest plots had the highest carbon stock (93.89, 80.52 and 54.96 Mg C ha^{-1}) and CO_2 absorption (344.25, 295.23 and 201.53 Mg $CO_{2equiv.}$) compared with the others. Our results demonstrate the importance of forest management in affecting forest structures, carbon sequestration and carbon dioxide absorption from the atmosphere to reduce and mitigate climate change.

Keywords: Aboveground biomass, dry dipterocarp forest, forest structure, non-timber forest products, soil organic carbon

INTRODUCTION

Forests cover approximately 4.06 billion hectares (31%) of the total area worldwide (FAO and UNEP 2020). They play a very important role in regional and global carbon cycles (Mitchard 2018) and global mitigation of climate variability (Zhao et al. 2022). Carbon from the atmosphere is retained in above-belowground biomass such as stems, branches, leaves and roots (Meeussen et al. 2021; Ramachandra and Bharath 2019) and dead organic matter including woody debris and surface litter (Zhu et al. 2017) through the photosynthesis process (Pandey et al. 2019). It is also accumulated in soil organic matter (Ramachandra and Bharath 2020) through the decomposition of plant litter and fine-root biomass (Świątek and Pietrzykowski 2022).

Currently, in response to global climate issues, many countries around the world have plans and policies related to natural resources management that focus on forest resources (Meragiaw et al. 2021). Globally, the forest area defined as the community-managed forest has been increasing to approximately 15.5% of the global forest area (Rights and Resources Initiative 2014). Recently decade, Thailand’ s government giving priority to communities to co-manage their forest and announced the Community Forestry Act (CFA) B.E. 2562 (2019) to register good practices in community forests that could be maintained for their diversity and ecological services (Royal Forest Department 2019). According to Brendler and Carey (1998) that the efforts of local people in their community forest are a demonstration of forest management that consists of conservation considered alongside economic development and cultural values.

However, the utilization, intensity and frequency level of various human activities can disturb forest structures i.e., different frequencies and intensities of slash and selective logging impact compositional-structural diversity (de Quesada and Kuuluvainen 2020). Tree cutting affected tree density, basal area, and the number of species (Htun et al. 2011). Woody extraction affected species richness, species diversity and forest structure (Ortiz et al. 2019). Disturbances from the removal of timber, firewood, litter collections and poles for household construction affected the biomass and carbon stock of forests (Gautam and Mandal 2016). Thus, to preserve forest areas and mantain biodiversity, forests must be maintained and protected in multiple dimensions. The concept of sustainable forest management has been a main model of forest management and practices in the government and private sectors in Thailand. Forest areas that utilize and are located close to human settlement areas have been referred to as "community forests". Different communities have different management practices depending on cultures, rules/regulations, intensive incomes, and time duration history. There are many community forests in Thailand have been registered and unregistered under the Community Forestry Act (CFA) B.E. 2562 (2019).

Currently, there is 0.23 million ha which includes a total of 5,216 sites and 5,314 utilizer villages registered under the CFA as community forests in the Northeast of Thailand (Royal Forest Department 2022). Forest areas in the Northeast of Thailand were 2.51 million ha, whereas Maha Sarakham Province was 0.02 million ha (3.81% of the total province area) (Royal Forest Department 2020). In this study, we focus on the community forests in Maha Sarakham Province of northeast Thailand, located outside the protected area.

Normally, logging or timber harvesting is prohibited in all areas of community forests. Local people mainly take advantage of non-timber forest products (NTFPs). The forest in the northeast has been conserved for living and daily life purposes such as medicinal plants, edible plants, rattan, firewood, natural dyes, resin, insects, mushroom, honey, lac, and wild fruits. (Larpkern et al. 2017; Royal Forest Department 2009). Therefore, community forest management is a mechanism for the goal of sustainable forest management. It is also an option to slow down the loss of forest area and achieve global carbon neutrality through good forest management practices. However, in Thailand, there has been only limited study of the outcome of different time duration and rule regulations of community forest management on forest structure and carbon stock areas in Thailand. Therefore, our study aims to assess forest structures and carbon stocks in various rule regulations and management practices of three community forests.

MATERIALS AND METHODS

Study area

This study was conducted in three dry dipterocarp, community forests in Maha Sarakham Province, Northeastern Thailand. The three research sites (Figure 1) were Nong Meg-Nong Hi community forest (Best practices, BP: 16°27'50.00"N, 103°1'28.00"E), Khok Nong Kong community forest (Moderately practices, MP: 16°25'45.00"N, 103°0'25.00"E) and Na Si Nuan community forest (Slightly practices, SP: 16°20'34.00"N, 103°12'53.00"E). All three sites were located in the same topographic (same province) and climatic zone. They were located in a tropical area classified according to the Köppen-Geiger climate classification system (Beck et al. 2018). The topographical characteristics were relatively nearly level to undulating, about 130-230 m above sea level with an average temperature of 27.1 °C and average annual rainfall of 1,201.9 mm (Thai Meteorological Department 2020). As the presurvey, all study sites had been disturbed from previous utilization. At least a half-decade ago, they served as the community forest. All past the activities such as selective logging, non-timber forest products, etc. harvesting were common in the areas. They are in between the stage of secondary succession. Most of the community forests in the northeastern part of Thailand were inevitably related to local culture (ancestor’s spirit) which they respect. The sign of natural disaster and severe human disturbance i.e., forest fire, logging operations, and land invasion. However, the difference among the forest was the first initiation that occurred at the BP to start the rules/regulations for protecting their forests in practice.

Each site was classified by differences in management duration, level of utilization and degree of rule enforcement. This classification includes management awarded and registered Community Forestry Act (CFA) B.E. 2562. In order to stratify sampling, Na Si Nuan was assigned as the SP. It is a public forest without a community forest committee and unofficially registered as a community forest, therefore, it has weak collective management practices and implementation of regulations/rules. The other two sites Khok Nong Kong (MP) and Nong Meg-Nong Hi (BP) were already registered as community forest. The MP community forest is managed by the community forest committee. It is assigned as moderate management practices (MP). The BP community forest has been classified as a forest managed using best practices (BP). Forest areas are surrounded with rice fields, village households, vegetation planting areas, schools, and bureaucratic offices.

The BP was located beyond the community settlements, while the MP and SP forests were located beside the main road. The previous study reported an indicator set suits for guiding regulation and management since 2008 for BP forest (Gomontean et al. 2008). The forest committee operated with a high degree of rule regulations such as fine punishment and demarcated forest border to conserve forest resources under the supervision of the local communities who live close to a forest area. In 1999, they received the "Flag of forest conservation for life-saving" from Her Majesty Queen Sirikit, and were awarded "People who love the forest, the forest community project" as it was a provincial-level project in 2016. The physical location of SP and MP gives an opportunity to access forest resources easier than BP. In addition to the regulation of rules and management practices, the SP forest also allows harvesting, but not in the other forests. Currently, all forest resources that have been harvested were non-timber forest products (NTFPs) for domestic demand and to generate household-intensive income, such as fuelwood, plant litter, seasonal mushrooms, seasonal edible insects, medicinal plants, wild fruits, seasonal small lizards, and livestock foraging. Logging was prohibited on all sites. Each harvesting activity of NTFPs has different impacts on forest characteristics and structure, wandering footpaths for searching fuelwood and mushrooms, collecting fruits and insects, and digging for insects and small lizards have an impact in the abundance of tree species (Dao and Hölscher 2018). Lopping trees impacted forest structure (Zhu et al. 2007). Harvesting fruits from the forest has a significant effect on seedling and adult densities (Gaoue et al. 2017). Over-exploitation of NTFPs (edible plants, wild fruits, medicinal plants, leaves, flowers, seeds, barks, fuelwood and fibers) can negatively impact biodiversity and cause decreased species richness (Masoodi and Sundriyal 2020; Thammanu et al. 2021).

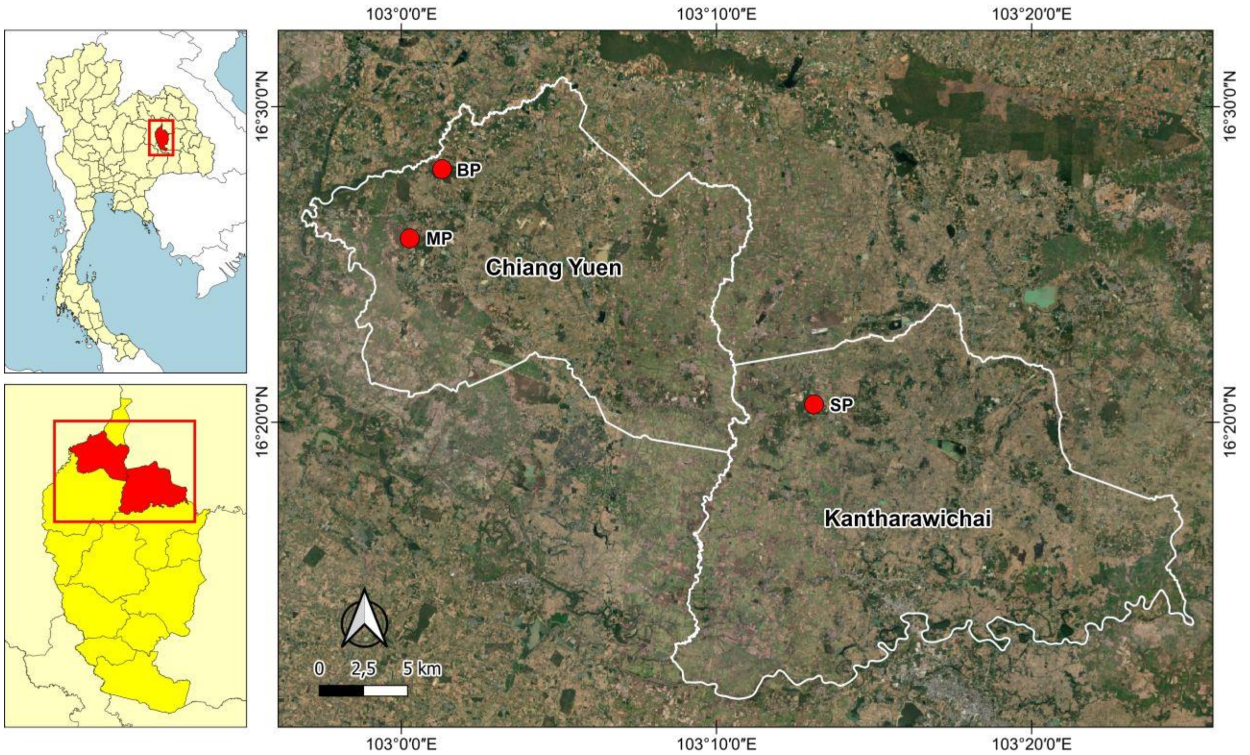

Figure 1. Map showing the locations of the study sites in Maha Sarakham Province, Northeastern Thailand. Note: SP as the slight practice site, MP as the moderate practice site, and BP as the best practice site

Procedures data collection and analysis

Quantitative ecological parameters and forest structure

Sampling plots were set up in all three community forests. A total of thirty plots of 20×20 m were set up. Specimens were collected and identified to species. Total height and diameter at breast height (dbh) of all trees with ≥4.5 cm dbh and height >1.3 m were recorded for quantitative analysis of ecological parameters and forest structure analysis. Density, basal area, size class distribution, diversity indices (Shannon Wiener's diversity index (H')), Evenness index (J), Important value index (IVI) were analyzed (Balslev et al. 1987; Krebs 1999).

Aboveground biomass and carbon

Aboveground biomass of trees (AGB) stocks was calculated by using the allometric equation proposed by Ogawa et al. (1965). All biomass of trees was multiplied by a carbon fraction of 0.47 to convert to carbon contents (IPCC 2006).

$$W_S = 0.0396D^2H^{0.9326}$$
$$W_B = 0.003487D^2H^{1.0270}$$
$$W_L = (28.0/W_{TC} + 0.025)^{-1}$$
$$W_T = W_S + W_B + W_L$$
$$AGC_{stocks} = W_T \times 0.47$$

Where: W_S represents the biomass of stems (kg), W_B represents the biomass of branches (kg), W_L represents the biomass of leaves (kg), W_{TC} represents the biomass of stems and branches (kg), W_T represents the total aboveground biomass of tree (Mg ha^{-1}), D represents the diameter at breast height (cm), H represents the height of the tree (m), AGC_{stocks} represents aboveground carbon of tree (Mg C ha^{-1}).

Soil organic carbon stocks

Soil core samples were collected at 0-25 cm and 25-50 cm depth using a soil auger and used for soil bulk density analysis. Soil samples were analyzed for soil organic carbon (SOC) by the wet oxidation method (Walkley and Black 1934). The amount of organic carbon stock was expressed in Mg C ha^{-1}, which was obtained by multiplying the soil organic carbon concentration, soil bulk density and thickness of a soil layer (Batjes 1996).

$$SOC_{stocks} = (C \times BD \times D) / 100$$

Where SOC_{stocks} represents carbon stocks (Mg C ha^{-1}), C represents carbon concentration in each soil layer (g C g^{-1}), BD represents soil bulk density (g m^{-3}), and D represents the thickness of this soil layer (m), and 100 represents the conversion factor of g C m^{-2} to Mg C ha^{-1}.

Estimation of forest carbon and CO_2 absorption storage

Forest carbon stocks were estimated by the sum of aboveground carbon of trees (AGC_{stocks}) in aboveground biomass (allometric equations) and soil organic carbon stock (SOC_{stocks}) (Mg C ha^{-1}).

$$\text{Forest carbon} = AGC_{stocks} + SOC_{stocks}$$

Forest $CO_{2absorption}$ was estimated by the following equation.

$$\text{Forest } CO_{2absorption} = \text{Forest carbon} \times (44/12)$$

Where forest carbon represents a sum of aboveground carbon of tree (AGC_{stocks}) and soil organic carbon (SOC_{stocks}) (Mg C ha^{-1}), and Forest $CO_{2absorption}$ represents carbon dioxide absorption (Mg $CO_{2equiv.}$), 44/12 represents the ratio of CO_2 to C, CO_2 is composed of one molecule of carbon (atomic weight = 12.00) and two molecules of oxygen (atomic weight = 16.00).

Statistical analysis

All data were analyzed using ANOVA with Duncan's multiple range tests method to assess differences in aboveground carbon of trees, basal area, tree height, tree density, and soil organic carbon in different management regimes of community forests at a 95% confidence level ($p<0.05$). Independent sample t-tests were used to assess the difference in soil organic carbon at both 0-25 cm and 25-50 cm soil depths in each forest area at a 95% confidence level ($p<0.05$). Data were collected and statistically analyzed using the software suite of MS Excel and IBM SPSS Statistics 22.

RESULTS AND DISCUSSION

Quantitative ecological parameters and forest structure

Tree species in all three forest sites were classified into 29 families, 57 genera, and 66 species (Table 1). Previous studies reported the number of tree species between 31 and 78 in various community forests of Maha Sarakham Province (Bukaew et al. 2009; Choopan 2007; Sakorn et al. 2020). The number of tree species was not significantly different among the 3 sites 45 (SP), 47 (BP), and 48 (MP) species. However, among the 3 sites, there were 7 (SP), 6 (MP), 9 (BP) unique species and 30 common species found. The results were similar to Htun et al. (2011) which found that moderately disturbed areas have the maximum number of species, followed by undisturbed and highly disturbed areas. Tree density was not significantly different in all forest sites. However, the BP forest had the highest tree density while the SP forest had the lowest. Our results showed that, for the community forest, the application of restriction rules could prevent the loss of trees from unintentional or intentional human activities. The number of trees in the highly disturbed forest was lower than that of undisturbed forests in all tree ages (Htun et al. 2011). In addition, the restriction of access to forest areas for exploitation affects the density of early trees (Bhuyan et al. 2003). Pandey et al. (2019) reported that the highest tree density was found in undisturbed forest areas and decreased with increasing levels of disturbance. Forest areas with rule regulations could prevent the loss of plant species and promote seedling regeneration (Li et al. 2022) from human activities such as cutting (Htun et al. 2011), and fire ignition (Pairuang et al. 2020). Moreover, many previous reports found that the utilization of wood, fodder, pouching, and timber harvesting may affect the plant habitat and decrease the density and number of species in the forest areas (Adekunle et al. 2013; Martínez-Meléndez et al. 2021).

The BP and MP forests had a significantly higher average basal area (space occupation of plants) and average tree height than the SP forest (Table 1). History of protection and the biology of species themselves could inhibit former recruitment and growth of tree species existing in the area. Trees with large canopy cover could affect the growth of small understory plant species by limiting the amount of light reaching the ground which could prohibit the photosynthesis and growth process of understory trees (Damptey et al. 2021). Distance of forest area from human settlements could induce more illegal cutting of tree lopping, fuelwood collection, and NTFPs from an easy approach (Dao et al. 2016; Zhu et al. 2007). Highly disturbed areas, such as those subjected to timber harvesting and selective logging could decrease tree density and canopy cover leading to human access to extract forest resources and finally decrease the total basal area of trees (Banda et al. 2006). In addition, the collection of fuel woods, extraction of mature trees and livestock foraging influenced shrub density and canopy cover of highly disturbed areas compared with undisturbed areas (Mishra et al. 2004). Sumida et al. (2013) also found that undisturbed areas had the highest tree height compared with disturbed areas. For species with economic value, the BP and MP forests also conserved a higher number of species, tree density, tree height, and basal area than the SP forest but differences were not significant.

The exploitation from high to low utilization levels of forest resources generally induces the loss of species. Our study found that the BP forest could conserve more diversity of tree species than the other 2 sites as it showed the highest value of the Shannon diversity index (H') (Table 1). The results agreed with Kumar and Ram (2005) that the highest number of species is found in forests with low anthropogenic disturbance. However, SP forest had a higher value of H' than the MP forest due to the characteristics of forests and the response to disturbance or human activities may not be the same for forests in each area where an intermediated disturbance occurred (Htun et al. 2011).

From the Important Value Index (IVI) of all sites (Table 2) it was found that IVI percentage of each species of the top five species in the BP forest was more evenly than other sites. The most important species were also different i.e. *Pterocarpus macrocarpus* in the BP forest, *Shorea obtusa* in the MP forest, and *Dipterocarpus obtusifolius* in the SP forest. *P. macrocarpus* is an economically valuable plant with high monetary value. In addition, the top five ranked species consisting of 4 (SP), 4 (MP), and 5 (BP) species (Table 2) were classified as valuable economic trees (Forest plantation act 2015). *Xylia xylocarpa* was the only common species in all 3 forest sites, while 4 of 5 top rank species i.e. *P. macrocarpus*, *S. siamensis*, *S. obtusa*, and *X. xylocarpa*. were common in both BP and MP forests. This could be the result of different regulations and management activities from the past decade in each forest. Moreover, for the dbh size (RDo), all the five top-ranked species in both BP and MP forests had even of dbh size, while in the SP forest, only the first top-ranked species was dominant in size.

Table 1. Show the quantitative ecology values of trees in different management regimes of community forests

Parameter	Forest management SP	MP	BP
Forest trees			
Family	21	25	25
Genus	40	45	44
Species	45	48	47
No. of trees (stem)	452.00	492.00	628.00
Tree density (stem ha^{-1})	1,130.00±78.69^{A}	1,230.00±197.30^{A}	1,570.00±155.22^{A}
Basal area (m^2 ha^{-1})	11.69±1.12^{A}	18.33±1.25^{B}	19.53±3.05^{B}
Tree height (m)	6.40±0.22^{A}	8.87±0.39^{B}	8.23±0.44^{B}
Shannon diversity index	3.06	2.83	3.25
Evenness index	0.80	0.73	0.84
Economic trees			
Family	6	8	6
Genus	10	12	12
Species	12	13	13
No. of trees (stem)	234.00	285.00	305.00
Tree density (stem ha^{-1})	585.00±65.32^{A}	712.50±206.80^{A}	762.50±100.50^{A}
Basal area (m^2 ha^{-1})	7.87±1.13^{A}	11.76±1.87^{A}	12.84±2.50^{A}
Tree height (m)	7.24±0.38^{A}	9.75±0.45^{B}	9.46±0.61^{B}
Shannon diversity index	1.71	1.63	2.01
Evenness index	0.69	0.63	0.78

Note: SP: the slight practice site, MP: the moderate practice site, BP: the best practice site. Different uppercase letters in the columns indicate significant differences between the three forest sites according to Duncan's Multiple Range Test at 95% level confidence ($p < 0.05$). Data are means±s.e

Table 2. Importance Value Index (IVI) of tree species in different management practices of community forests

Forest management	Scientific name	D (stem ha^{-1})	F (%)	BA (m^2 ha^{-1})	RD (%)	RF (%)	RDO (%)	IVI (%)	AGB (Mg ha^{-1})	AGC (Mg C ha^{-1})
SP	*Dipterocarpus obtusifolius* Teijsm. ex Miq.*	285.00	80	4.54	25.22	5.41	38.85	69.48	20.05	9.42
	Xylia xylocarpa (Roxb.) Taub.*	92.50	10	0.41	8.19	6.76	3.50	18.45	1.42	0.67
	Mangifera caloneura Kurz.*	42.50	20	0.97	3.76	1.35	8.27	13.39	4.70	2.21
	Cratoxylum formosum (Jacq) Benth. & Hook. f. ex Dyer	62.50	60	0.42	5.53	4.05	3.62	13.21	1.43	0.67
	Shorea siamensis Miq.*	52.50	40	0.68	4.65	2.70	5.80	13.15	3.24	1.52
MP	*Shorea obtusa* Wall. ex Blume*	360.00	60	3.47	29.27	4.26	18.95	52.47	17.56	8.26
	Shorea siamensis Miq.*	85.00	70	2.77	6.91	4.96	15.10	26.97	19.31	9.08
	Pterocarpus macrocarpus Kurz*	65.00	70	2.95	5.28	4.96	16.11	26.36	19.39	9.11
	Rothmannia wittii (Craib) Bremek.	130.00	70	0.73	10.57	4.96	3.98	19.52	3.00	1.41
	Xylia xylocarpa (Roxb.) Taub.*	102.50	10	0.64	8.33	7.09	3.52	18.94	2.90	1.36
BP	*Pterocarpus macrocarpus* Kurz*	112.50	60	3.16	7.17	4.20	16.20	27.56	22.35	10.50
	Shorea siamensis Miq.*	112.50	60	2.82	7.17	4.20	14.45	25.81	20.53	9.65
	Shorea obtusa Wall. ex Blume*	117.50	60	2.09	7.48	4.20	10.72	22.40	13.54	6.36
	Xylia xylocarpa (Roxb.) Taub.*	180.00	80	1.04	11.46	5.59	5.31	22.37	4.33	2.04
	Sindora siamensis Miq.*	115.00	50	1.08	7.32	3.50	5.54	16.36	4.93	2.32

Note: *Economic tree. SP: the slight practice site, MP: the moderate practice site, BP: the best practice site. D: density, F: frequency, BA: basal area, RD: relative density, RF: relative frequency, RDO: relative dominance

Size class distribution

The analysis of the relationship of each size class distribution (dbh class) with tree density, Shannon diversity index, basal area, and aboveground carbon stock of the 3 forest sites are shown in Figure 2. The results demonstrated L-shape distribution (higher of small stems) (Figure 2A). The small size (≤9.5 cm class) showed the highest tree density but then declined as the bigger size class increased. The results are consistent with previous reports that tree density decreased from smaller to bigger size classes (Ao et al. 2020; Rawal and Subedi 2022). The number of species and Shannon diversity index (Figure 2B-C) drastically decreased from small to bigger dbh class in all forests. We also found that Shannon diversity index was more drastically decreased in the SP forest than the MP and BP forests and such traits are common patterns found in forest areas affected by human activity. The results are consistent with previous reports, such as Endris et al. (2017); Kacholi (2014) that increasing tree size classes results in a drastically decreased number of species and Shannon diversity index. Basal area and AGC were increased from smaller to bigger size classes in the BP and MP forests (Goode et al. 2020). The SP forest also had the lowest AGC compared to the other 2 sites, especially in the biggest dbh class (Figure 2D-E). Generally, the AGC increased according to the number of big trees and dbh class increases (Gogoi and Sahoo 2018; Mildrexler et al. 2020; Shirima et al. 2015). In the SP forest, basal area and AGC increased in the first to middle range of the dbh class but became lowest in the biggest dbh class (≥24 cm). This showed the characteristics of forests are influenced by previous regulation and management, resulting in the loss of large tree species from human disturbances and exploitations (Tavankar and Bonyad 2015).

Aboveground biomass and carbon

Aboveground biomass (AGB) and aboveground carbon (AGC) stocks in the BP and MP forests were significantly higher than in the SP forest. AGB and AGC stocks in economic trees stocks in the BP and MP forests were higher than in SP forest but were not significantly different (Table 3). In general, biomass was attributed to a high number of stems, dbh size, and tree height in the BP and MP forests. Easy access to the forest, such as in the SP forest in the past, could lead to the loss of tree populations as it had the lowest tree density in the bigger dbh class (Figure 2A). From basal area of the top five rank IVI species, only *D. optusifolius* had significantly occupied the most space in the SP forest (4.54 m^2 ha^{-1}) compared with the other species. Different from the SP, in the MP and BP, all top five's species were evenly in space occupation (Table 2). Human utilization by harvesting tree biomass and natural disturbance would have affected AGB and AGC stocks (Hoover and Smith 2021). Harvesting activities such as resource extraction, grazing, stem cutting, agriculture practices, fire ignition, and invasive species, together with easy access to sites, had a high impact on tree biomass and carbon storage (Khadanga and Jayakumar 2020). Cutting trees and collecting firewood in the highly disturbed area resulted in significantly lower AGB and AGC stocks than in the undisturbed and moderately disturbed area (Borah et al. 2019). The absence or presence of rule regulation and management could influence forest products, such as biomass and carbon (Luyssaert et al. 2008).

From Table 4, the top five biomass rank in the SP forest, *D. optusifolius* is the most space-occupied species and the most significant AGB stock (20.05 Mg ha^{-1}) and AGC stock (9.42 Mg C ha^{-1}) while the others forest the top five's species were more value evenness. Human disturbance in different human-modified forests resulted in negative effects on biomass or forest structure characteristics (Pelletier et al. 2017). An increasing level of disturbance causes changes in the characteristics of the plant community, and eventually the population structure of trees (Mishra et al. 2004).

According to the IVI of the top five trees, species found in all three sites were *S. siamensis* and *X. xylocarpa*. The common tree species found in all 3 forests based on relative dominance and AGC of the top five trees were *Canarium subulatum*, *S. siamensis*, and *P. macrocarpus*. These trees are commonly considered indicator species of dry dipterocarp forests (Santisuk 2012). Thus, they might express a high value of the number of stems, basal area distribution, and eventually the AGB and AGC stocks.

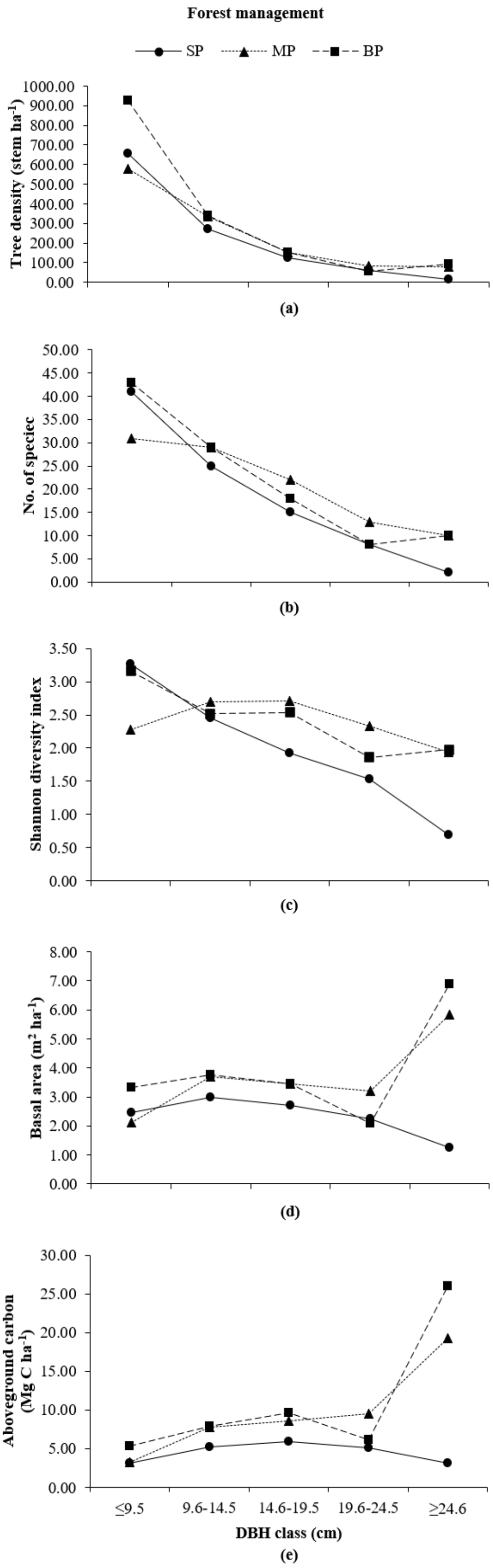

Figure 2. Distribution of trees in DBH classes affects tree density (A), number of species (B), Shannon diversity index (C), basal area (D), and aboveground carbon stocks (E). in different management regimes of community forests. Note: SP as the slight practice site, MP as the moderate practice site, and BP as the best practice site

From the top five ranked of AGC, there were 4 species classified as economic value trees. The percentage of total AGC of these species in each forest were 14.37 (63.89%), 28.27 (58.37%), and 33.65 (61.23%) Mg C ha^{-1} in the SP, MP, and BP forest, respectively (Table 4). The percentage ratio showed that economic value trees performed a very important role in promoting carbon accumulation in those differently managed forests. Moreover, *P. macrocarpus* represented the AGC, one of the high economic values in Thailand, in the BP and MP forests (Table 4). Currently, it is classified as an endangered species on the IUCN Red List of Threatened Species (Barstow 2019). This plant has been highly utilized for reforestation, ornamental plants, medicinal plant, building materials, furniture, home appliances, firewood, agricultural tools, charcoal, musical instruments and sculpture art (Chen et al. 2018; Pakkad et al. 2002; Sritram 2016).

Soil organic carbon

The analysis of soil organic carbon stocks of all 3 forests is shown in Table 3. SOC stock at 0-50 cm depth and top soil layer (0-25 cm depth) in the BP forest were significantly higher than in SP and MP forests. However, SOC stock at 25-50 cm depth in the BP forest was not significantly higher than in the SP and MP forests. Also noted that SOC stock in the topsoil (0-25 cm) was significantly higher than that of the lower soil (25-50 cm) in all forest sites (Table 3). The BP and MP forests represented a high tree density with close canopy compared with the SP forest (Table 1) which supported the process of increasing soil organic matter through the decomposition of various plant litters in the area from various soil fauna and decomposer activity (Huang et al. 2020).

A long duration of rule regulation and management of those 2 sites also limited the number of villagers who accessed the forest area and reduced human disturbances. The frequency of extractions of biomass removal, and firewood collections are a cause of a decline in pH, carbon and loss of soil nutrients (Ruwanza and Shackleton 2017). In addition, logging and harvesting biomass from forests reduces soil organic carbon accumulation (Mayer et al. 2020; Tolessa and Senbeta 2018). Like the report by Mayer et al. (2020), controlling or limiting the exploitation of forests may help reduce the removal of biomass from forests and increase soil carbon accumulation through biomass degradation from forest yields, demonstrating trends that support our study.

Forest carbon stocks

The results showed that the forest carbon stock (AGC_{stocks} + SOC_{stocks}) of the BP forest was higher than in the MP and SP forests (93.89, 80.52, and 54.96 Mg C ha^{-1}, respectively). A trend of forest carbon dioxide absorption was similar to forest carbon stock in the BP forest, being higher than in the MP and SP forests (344.25, 295.23, and 201.53 Mg $CO_{2\ equiv}$, respectively) (Table 3). Considering the status of those areas in regard to the intensity level of forest management, the BP forest was the best-managed forest area, followed by the MP and SP forests (moderate and slight management). The intensity level of forest management or human activity (disturbance) clearly affects the amount of carbon sequestration and carbon dioxide absorption in forest areas (Birdsey et al. 2006). Managing forests helps to increase the amount of carbon sequestration (Janowiak et al. 2017) and affects carbon changes in forests (Karki et al. 2016). In addition, BP and MP forests comprised AGC stock (58.54-60.16%) higher than SOC stock (41.46-39.84%). In contrast, the SP forest had SOC stock (59.07%) more than AGC stock (40.93%) (Table 3).

Table 3. Comparison of aboveground biomass and carbon stocks of trees and soil organic carbon in different management regimes of community forests

	Forest management						Average	%
	SP	**%**	**MP**	**%**	**BP**	**%**		
Trees (included economic trees)								
AGB (Mg ha^{-1})	47.86±5.94^{A}		103.06±6.71^{B}		116.94±25.16^{B}		89.29±10.22	
AGC (Mg C ha^{-1})	22.50±2.79^{A}	40.93%	48.44±3.15^{B}	60.16%	54.96±11.82^{B}	58.54%	41.97±4.80	54.86%
Economic trees								
AGB (Mg ha^{-1})	35.11±6.01^{A}		69.82±10.75^{A}		85.20±22.50^{A}		63.37±9.12	
AGC (Mg C ha^{-1})	16.50±2.82^{A}	30.02%	32.81±5.05^{A}	40.75%	40.04±10.58^{A}	42.65%	29.79±4.29	38.95%
Soil organic carbon								
0-25 cm	21.73±1.00$^{A\ a}$	39.54%	21.70±1.00$^{A\ a}$	26.95%	26.74±2.03$^{B\ a}$	28.50%	23.39±0.84	30.60%
25-50 cm	10.73±0.54$^{A\ b}$	19.53%	10.38±0.43$^{A\ b}$	12.89%	12.18±0.91$^{A\ b}$	12.97%	11.10±0.38	14.51%
0-50 cm	32.47±1.37^{A}	59.07%	32.08±1.34^{A}	39.84%	38.92±2.73^{B}	41.46%	34.49±1.13	45.11%
Total carbon and CO_2 absorbtion								
Forest carbon (Mg C ha^{-1})	54.96		80.52		93.89		76.46	
Forest CO_2 absorption (Mg $CO_{2\ equiv.}$)	201.53		295.23		344.25		280.34	

Note: SP: the slight practice site, MP: the moderate practice site, BP: the best practice site. % as the ratio of carbon AGC/SOC stocks to forest carbon. Different Uppercase letters in the columns indicate significant differences between the three forest sites according to Duncan's Multiple Range Test at 95% level confidence ($p < 0.05$). Different lowercase letters in the row indicate significant differences between the 0-25 and 25-50 cm in each site according to Independent Samples T-Test at 95% level confidence ($p < 0.05$). Data are means±s.e

Table 4. Aboveground biomass (AGB) and aboveground carbon (AGC) stocks of tree species's rank in different management practices

Forest management	Scientific name	AGB (Mg ha^{-1})	AGC (Mg C ha^{-1})	%
SP	*Dipterocarpus obtusifolius* Teijsm. ex Miq.*	20.05	9.42	41.88
	Mangifera caloneura Kurz *	4.70	2.21	9.82
	Shorea siamensis Miq.*	3.24	1.52	6.78
	Canarium subulatum Guillaumin	2.76	1.30	5.76
	Pterocarpus macrocarpus Kurz *	2.59	1.22	5.41
MP	*Pterocarpus macrocarpus* Kurz*	19.39	9.11	18.82
	Shorea siamensis Miq.*	19.31	9.08	18.74
	Shorea obtusa Wall. ex Blume*	17.56	8.26	17.04
	Canarium subulatum Guillaumin	9.53	4.48	9.24
	Sindora siamensis Miq.*	3.89	1.83	3.77
BP	*Pterocarpus macrocarpus* Kurz*	22.35	10.50	19.11
	Shorea siamensis Miq.*	20.53	9.65	17.56
	Dipterocarpus tuberculatus Roxb.*	15.18	7.13	12.98
	Shorea obtusa Wall. ex Blume*	13.54	6.36	11.58
	Canarium subulatum Guillaumin	9.68	4.55	8.28

Note: *Economic tree. SP: the slight practice site, MP: the moderate practice site, BP: the best practice site. %: the ratio of tree carbon species i to total tree carbon

Table 5. Comparison of aboveground carbon stocks (AGC) and soil organic carbon (SOC) stocks in dry dipterocarp forest with another community forest (CF) and Natural forest (NF)

Type	Study site	Carbon stock (Mg C ha^{-1})				References
		AGC	SOC		Total C stock	
CF	Maha Sarakham Province, Thailand	41.97	34.49[1]	0-50	76.46	This study
CF	Khon Kaen Province, Thailand	19.27	36.19[2]	0-60	55.46	Jundang et al. (2010)
CF	Chiang Mai Province, Thailand	37.38	10.88[3]	0-120	48.26	Duangthip et al. (2022)
NF	Phrae Province, Thailand	320.60	48.67[4]	0-15	369.27	Asanok et. al. (2021)
NF	Phayao Province, Thailand	71.99	117.50[5]	0-40	189.49	Intanil et al. (2016)
NF	Savannakhet Province, Lao PDR	22.33	18.71[6]	0-30	41.04	Vicharnakorn et al. (2014)

Note: Number means to soil (sample) depth in each site. 1 at 0-50 cm, 2 at 0-60 cm, 3 at 0-120 cm, 4 at 0-15 cm, 5 at 0-40 cm, and 6 at 0-30 cm

Comparison of aboveground carbon and soil organic carbon stock with other forest areas

From Table 5, AGC and SOC stocks compared to another study, both community and natural forests, in Thailand and neighboring countries. There was a high variation in total carbon stock among different types of forests. Among the community forests, this study site showed higher carbon stored in the biomass, soil carbon and total carbon stock than the others. However, total carbon stock in this study is drastically low when compared with natural forests except in Lao PDR. The two-time lower tree density was directly relevant to AGC. The allometric equation used for the estimation of tree biomass is tightly related to tree dbh, tree height, and the number of stems found in the area (Ogawa et al. 1965). The amount of SOC not only depends on direct and indirect factors such as biological activities, the decomposition rate of plant litter, altitude, slope, the difference of soil bulk density and soil depth is a significant effect on SOC (Batjes 1996; Hu et al. 2018; Sariyildiz 2008). However, the relationship between these factors needs more investigation.

In conclusion, forest management concerns strategies and methods for controlling and limiting quantities utilized as forest yields. This affects the structure and environmental factors of forests, as well as biomass production sources for carbon sequestration in forest areas. Our study showed the result of different community forest management practices on tree species, tree density, basal areas, biomass, and carbon stocks. The economic value species were also protected and remained in all types of community forests, but the dominant species was different. We could mention that structure and ecological parameters were prone to be better with the degrees of rule regulation and practices. However, community forest areas at any level of management (best, moderate, and slightly management) not only serve ecosystem goods and services but also act as the balance of carbon reservoirs. Moreover, good forest practices models will promote forest condition and restoration, increase biodiversity and contribute to mitigating climate change.

ACKNOWLEDGEMENTS

This research was financially supported by Mahasarakham University, Thailand. The thesis grant for the Doctoral degree was supported by the Science Achievement Scholarship of Thailand (SAST). We would like to thank the Department of Biology, Faculty of Science, Mahasarakham University for the laboratory support. We also give special thanks to Adrian R. Plant, a native English speaker, who help to approve the language in the manuscript.

REFERENCES

Adekunle VAJ, Olagoke AO, Ogundare LF. 2013. Logging impacts in tropical lowland humid forest on tree species diversity and environmental conservation. Appl Ecol Environ Res 11 (3): 491-511. DOI: 10.15666/aeer/1103_491511.

Ao A, Changkija S, Tripathi SK. 2020. Species diversity, population structure, and regeneration status of trees in Fakim Wildlife Sanctuary, Nagaland, northeast India. Biodiversitas 21 (6): 2777-2785. DOI: 10.13057/biodiv/d210654.

Asanok L, Taweesuk R, Kamyo T. 2021. Plant functional diversity is linked to carbon storage in deciduous dipterocarp forest edges in northern Thailand. Sustainability 13: 11416. DOI: 10.3390/su132011416.

Balslev H, Luteyn JL, Øllgaard B, Holm-Nielsen LB. 1987. Composition and structure of adjacent unflooded and floodplain forest in Amazonian Ecuador. Opera Bot 92: 37-57.

Banda T, Schwartz MW, Caro T. 2006. Woody vegetation structure and composition along a protection gradient in a miombo ecosystem of western Tanzania. For Ecol Manag 230: 179-185. DOI: 10.1016/j.foreco.2006.04.032.

Barstow M. 2019. *Pterocarpus macrocarpus*. The IUCN Red List of Threatened Species 2019: e.T32308A2813424. https://www.iucnredlist.org/species/32308/2813424.

Batjes NH. 1996. Total carbon and nitrogen in the soils of the world. Eur J Soil Sci 47 (2): 151-163. DOI: 10.1111/j.1365-2389.1996.tb01386.x.

Beck HE, Zimmermann NE, McVicar TR, Vergopolan N, Berg A, Wood EF. 2018. Present and future Köppen-Geiger climate classification maps at 1-km resolution. Sci Data 5: 180214. DOI: 10.1038/sdata.2018.214.

Bhuyan P, Khan ML, Tripathi RS. 2003. Tree diversity and population structure in undisturbed and human-impacted stands of tropical wet evergreen forest in Arunachal Pradesh, Eastern Himalayas, India. Biodiv Conserv 12 (8): 1753-1773. DOI: 10.1023/A:1023619017786.

Birdsey R, Pregitzer K, Lucier A. 2006. Forest carbon management in the United States. J Environ Qual 35: 1461-1469. DOI: 10.2134/jeq2005.0162.

Borah N, Athokpam FD, Das AK, Garkoti SC. 2019. Aboveground tree carbon stocks along a disturbance gradient in wet tropical forests of South Assam, India. In: Garkoti SC, Van Bloem SJ, Fulé PZ, Semwal RS (eds). Tropical Ecosystems: Structure, Functions and Challenges in the Face of Global Change. Springer, Singapore. DOI: 10.1007/978-981-13-8249-9_6.

Brendler T, Carey H. 1998. Community forestry, defined. J For 96 (3): 21-23. DOI: 10.1093/jof/96.3.21.

Bukaew S, Thamsenanupap P, Tanee T. 2009. Plant Diversity and Utilization of Forest Products in Khok Yai Community Forest, Wapi Pathum District, Maha Sarakham Province. Environ Nat Resour J 7: 36-50.

Chen J, Ge S, Liu Z, Zhang D, Peng W. 2018. GC–MS explores health care components in the extract of *Pterocarpus macarocarpus* Kurz. Saudi J Biol Sci 25 (6): 1196-1201. DOI: 10.1016/j.sjbs.2017.12.013.

Choopan T. 2007. Plant Diversity and Ethnobotany in Khok-Rai Forest, Chiang Yuen District, Maha Sarakham Province. J Sci Technol MSU 26 (2): 150-157.

Damptey FG, Adofo E, Duah-Gyamfi A, Adusu D, Opuni-Frimpong E. 2021. Logging effects on seedling regeneration and diversity in a tropical moist semi-deciduous forest in Ghana. Geol Ecol Landsc. DOI: 10.1080/24749508.2021.1952769.

Dao THH, Hölscher D. 2018. Impact of non-timber forest product use on the tree community in north-western Vietnam. Forests 9 (7): 431. DOI: 10.3390/f9070431.

Dao THH, Saborowski J, Hölscher D. 2016. Patterns of tree community differences in the core and buffer zones of a nature reserve in north-western Vietnam. Glob Ecol Conserv 8: 220-229. DOI: 10.1016/j.gecco.2016.09.011.

de Quesada G, Kuuluvainen T. 2020. Tree diametric-species diversity is affected by human impact in old Scots pine dominated forest in boreal Fennoscandia. For Ecosyst 7: 8. DOI: 10.1186/s40663-020-0219-6.

Duangthip N, Anongrak N, Kachina P, Khamyong S. 2022. Plant community structure and carbon storage in a dry Dipterocarp community forest with using *Dipterocarpus tuberculatus* Roxb. leaves as forest product, Northern Thailand. TFERJ 6: 13-30.

Endris A, Seid A, Asefa A. 2017. Structure and regeneration status of woody plants in the Hallideghie wildlife reserve, North East Ethiopia. Intl J Biodivers Conserv 9 (6): 200-211. DOI: 10.5897/ijbc2017.1085.

FAO and UNEP. 2020. The State of the World’s Forests 2020. Forests, biodiversity and people. Rome. DOI: 10.4060/ca8642en.

Forest Plantation Act. 2015. Forest Plantation Act (No. 2), B.E. 2558 (2015, 26th May), vol 132 Part 44a. Bangkok, Thailand: Royal Thai Government Gazette. https://forestinfo.forest.go.th/Content/file/forest_low/forestpark-law2558.pdf.

Gaoue OG, Kouagou M, Natta AK, Gado C. 2017. Response of a tropical tree to non-timber forest products harvest and reduction in habitat size. PLoS ONE 12 (8): e0183964. DOI: 10.1371/journal.pone.0183964.

Gautam TP, Mandal TN. 2016. Effect of disturbance on biomass, production and carbon dynamics in moist tropical forest of eastern Nepal. For Ecosyst 3: 11. DOI: 10.1186/s40663-016-0070-y.

Gogoi A, Sahoo UK. 2018. Impact of anthropogenic disturbance on species diversity and vegetation structure of a lowland tropical rainforest of eastern Himalaya, India. J MT Sci 15 (11): 2453-2465. DOI: 10.1007/s11629-017-4713-4.

Gomontean B, Gajaseni J, Edwards-Jones G, Gajaseni N. 2008. The development of appropriate ecological criteria and indicators for community forest conservation using participatory methods: A case study in northeastern Thailand. Ecol Indic 8 (5): 614-624. DOI: 10.1016/j.ecolind.2007.08.006.

Goode JD, Barefoot CR, Hart JL, Dey DC. 2020. Disturbance history, species diversity, and structural complexity of a temperate deciduous forest. J For Res 31: 397-414. DOI: 10.1007/s11676-018-0746-y.

Hoover CM, Smith JE. 2021. Current aboveground live tree carbon stocks and annual net change in forests of conterminous United States. Carbon Balance Manag 16: 17. DOI: 10.1186/s13021-021-00179-2.

Htun NZ, Mizoue N, Yoshida S. 2011. Tree species composition and diversity at different levels of disturbance in Popa Mountain Park, Myanmar. Biotropica 43 (5): 597-603. DOI: 10.1111/j.1744-7429.2011.00753.x.

Hu PL, Liu SJ, Ye YY, Zhang W, Wang KL, Su YR. 2018. Effects of environmental factors on soil organic carbon under natural or managed vegetation restoration. Land Degrad Dev 29 (3): 387-397. DOI: 10.1002/ldr.2876.

Huang Y, Yang X, Zhang D, Zhang J. 2020. The effects of gap size and litter species on colonization of soil fauna during litter decomposition in *Pinus massoniana* plantations. Appl Soil Ecol 155: 103611. DOI: 10.1016/j.apsoil.2020.103611.

Intanil P, Sanwangsri M, Suwannapat P, Panya M, Limsakul A, Boonpoke A. 2016. Assessment of carbon stock and partitioning in dry dipterocarp forest, Northern Thailand. Proceeding of SEE 2016 in conjunction with ICGSI 2016 and CTI 2016 on “Energy & Climate Change: Innovating for a Sustainable Future”. Bangkok, 28-30 November 2016. [Thailand]

IPCC. 2006. IPCC Guidelines for National Greenhouse Gas Inventories. IGES, Hayama, Japan.

Janowiak M, Swanston C, Ontl T. 2017. Management of Forest Carbon Stocks. U.S. Department of Agriculture, Forest Service, Climate Change Resource Center. https://www.fs.usda.gov/ccrc/topics/management-forest-carbon-stocks.

Jundang W, Puangchit L, Diloksumpun S. 2010. Carbon storage of dry Dipterocarp forest and Eucalypt plantation at Mancha Khiri Plantation, Khon Kaen Province. TJF 29: 36-44.

Kacholi DS. 2014. Analysis of Structure and Diversity of the Kilengwe Forest in the Morogoro Region, Tanzania. Intl J Biodiv 2014: 1-8. DOI: 10.1155/2014/516840.

Karki S, Joshi NR, Udas E, Adhikari MD, Sherpa S, Kotru R, Karky BS, Chettri N, Ning W. 2016. Assessment of Forest Carbon Stock and Carbon Sequestration Rates at the ICIMOD Knowledge Park in Godavari, Nepal. ICIMOD, Kathmandu. DOI: 10.53055/ICIMOD.622,

Khadanga SS, Jayakumar S. 2020. Tree biomass and carbon stock: understanding the role of species richness, elevation, and disturbance. Trop Ecol 61: 128-141. DOI: 10.1007/s42965-020-00070-0.

Krebs CJ. 1999. Ecological Methodology. Addison-Wesley Educational Publishers, California.

Kumar A, Ram J. 2005. Anthropogenic disturbances and plant biodiversity in forests of Uttaranchal, central Himalaya. Biodiv Conserv 14: 309-331. DOI: 10.1007/s10531-004-5047-4.
Larpkern P, Eriksen M, Waiboonya P. 2017. Diversity and uses of tree species in the deciduous Dipterocarp forest, Mae Chaem District, Chiang Mai Province, Northern Thailand. NUJST 25 (3): 43-55.
Li R, Yan Q, Xie J, Wang J, Zhang T, Zhu J. 2022. Effects of logging on the trade-off between seed and sprout regeneration of dominant woody species in secondary forests of the Natural Forest Protection Project of China. Ecol Process 11: 1-18. DOI: 10.1186/s13717-022-00363-3.
Luyssaert S, Schulze ED, Börner A, Knohl A, Hessenmöller D, Law BE, Ciais P, Grace J. 2008. Old-growth forests as global carbon sinks. Nature 455: 213-215. DOI: 10.1038/nature07276.
Martínez-Meléndez N, Ramírez-Marcial N, Martínez-Zurimendi P, Cach-Pérez MJ, García-Franco JG. 2021. How timber harvest affects the structure and diversity of a montane forest in Southern Mexico. Forests 12 (7): 895. DOI: 10.3390/f12070895.
Masoodi HUR, Sundriyal RC. 2020. Richness of non-timber forest products in Himalayan communities-diversity, distribution, use pattern and conservation status. J Ethnobiol Ethnomed 16: 56. DOI: 10.1186/s13002-020-00405-0.
Mayer M, Prescott CE, Abaker WEA, Augusto L, Cécillon L, Ferreira GWD, James J, Jandl R, Katzensteiner K, Laclau JP, Laganière J, Nouvellon Y, Paré D, Stanturf JA, Vanguelova EI, Vesterdal L. 2020. Influence of forest management activities on soil organic carbon stocks: A knowledge synthesis. For Ecol Manag 466: 118127. DOI: 10.1016/j.foreco.2020.118127.
Meeussen C, Govaert S, Vanneste T, Haesen S, Van Meerbeek K, Bollmann K, Brunet J, Calders K, Cousins SAO, Diekmann M, Graae, BJ, Iacopetti G, Lenoir J, Orczewska A, Ponette Q, Plue J, Selvi F, Spicher F, Sørensen MV, Verbeeck H, Vermeir P, Verheyen K, Vangansbeke P, De Frenne P. 2021. Drivers of carbon stocks in forest edges across Europe. Sci Tot Environ 759: 143497. DOI: 10.1016/j.scitotenv.2020.143497.
Meragiaw M, Woldu Z, Martinsen V, Singh BR. 2021. Carbon stocks of above- and belowground tree biomass in Kibate Forest around Wonchi Crater Lake, Central Highland of Ethiopia. PLoS ONE 16 (7): e0254231. DOI: 10.1371/journal.pone.0254231.
Mildrexler DJ, Berner LT, Law BE, Birdsey RA, Moomaw WR. 2020. Large trees dominate carbon storage in forests east of the Cascade Crest in the United States Pacific Northwest. Front For Glob Change 3: 594274. DOI: 10.3389/ffgc.2020.594274.
Mishra BP, Tripathi OP, Tripathi RS, Pandey HN. 2004. Effects of anthropogenic disturbance on plant diversity and community structure of a sacred grove in Meghalaya, northeast India. Biodivers Conserv 13: 421-436. DOI: 10.1023/B:BIOC.0000006509.31571.a0.
Mitchard ETA. 2018. The tropical forest carbon cycle and climate change. Nature 559 (7715): 527-534. DOI: 10.1038/s41586-018-0300-2.
Ogawa H, Yoda K, Ogino K, Kira T. 1965. Comparative ecological studies on three main types of forest vegetation in Thailand. II. Plant biomass. Nat Life Southeast Asia 4: 49-80.
Ortiz CJ, Espinosa CI, Quiroz Dahik C, Aguirre Mendoza Z, Cueva Ortiz E, Gusmán E, Weber M, Hildebrandt P. 2019. Influence of anthropogenic factors on the diversity and structure of a dry forest in the central part of the Tumbesian region (Ecuador-Perú). Forests 10: 31. DOI: 10.3390/f10010031.
Pairuang N, Thapyai C, Asanok L. 2020. The influence of fire protection on plant community changes in Sakunothayan Botanical Garden, Wang Thong District, Phitsanulok Province. Thai J For 39: 28-40.
Pakkad G, Elliott S, Anusarnsunthorn V, James C, Blakesley D. 2002. Forest restoration planting in Northern Thailand. In: Koskela J, Appanah S, Pedersen AP, Markopoulos A (eds). Proceedings of the Southeast Asian Moving Workshop on Conservation, management and utilization of forest genetic resources. FORSPA, Bangkok, Thailand.
Pandey A, Arunachalam K, Thadani R, Singh V. 2019. Forest degradation impacts on carbon stocks, tree density and regeneration status in banj oak forests of Central Himalaya. Ecol Res 35: 208-218. DOI: 10.1111/1440-1703.12078.
Pelletier J, Siampale A, Legendre P, Jantz P, Laporte NT, Goetz SJ. 2017. Human and natural controls of the variation in aboveground tree biomass in African dry tropical forests. Ecol Appl 27 (5): 1578-1593. DOI: 10.1002/eap.1550.
Ramachandra TV, Bharath S. 2019. Global warming mitigation through carbon sequestrations in the Central Western Ghats. Remote Sens Earth Syst Sci 2: 39-63. DOI: 10.1007/s41976-019-0010-z.
Ramachandra TV, Bharath S. 2020. Carbon Sequestration Potential of the Forest Ecosystems in the Western Ghats, a Global Biodiversity Hotspot. Nat Resour Res 29(4): 2753-2771. DOI: 10.1007/s11053-019-09588-0.
Rawal K, Subedi PB. 2022. Vegetation structure and carbon stock potential in the community- managed forest of the mid-western hilly region, Nepal. Asian J For 6: 15-21. DOI: 10.13057/asianjfor/r060103.
Rights and Resources Initiative. 2014. What Future for Reform? Progress and Slowdown in Forest Tenure Reform since 2002. Rights and Resources Initiative, Washington, DC.
Royal Forest Department. 2009. Forestry in Thailand. Royal Forest Department, Bangkok, Thailand.
Royal Forest Department. 2019. Community Forest Act B.E. 2562 (2019). Royal Forest Department. https://www.forest.go.th/communityexpert/2020/03/26/law/.
Royal Forest Department. 2020. Forestry statistics data 2020. Information and Communication Technology Center, Royal Forest Department, Bangkok, Thailand.
Royal Forest Department. 2022. Summary of the establishment of the community forest project by province (สรุปการจัดตั้งโครงการป่าชุมชน รายจังหวัด). Information, Royal Forest Department. http://forestinfo.forest.go.th/fCom_area.aspx.
Ruwanza S, Shackleton CM. 2017. Ecosystem scale impacts of non-timber forest product harvesting: effects on soil nutrients. J Appl Ecol 54: 1515-1525. DOI: 10.1111/1365-2664.12891.
Sakorn P, Chatan W, Promprom W. 2020. Plant diversity in Khoknongklong community forest in Kuthong Sub-district, Chiang Yuen District, Maha Sarakham Province. RMU J 14 (3): 187-199.
Santisuk, T. 2012. Forest of Thailand. National Office of Buddhism, Bangkok, Thailand.
Sariyildiz T. 2008. Effects of gap-size classes on long-term litter decomposition rates of beech, oak and chestnut species at high elevations in northeast Turkey. Ecosystems 11: 841-853. DOI: 10.1007/s10021-008-9164-x.
Shirima DD, Totland Ø, Munishi PKT, Moe SR. 2015. Relationships between tree species richness, evenness and aboveground carbon storage in montane forests and miombo woodlands of Tanzania. Basic Appl Ecol 16 (3): 239-249. DOI: 10.1016/j.baae.2014.11.008.
Sritram S. 2016. Tree diversity and local utilization in Rahan Forest, Mueang Surin District, Surin Province. King Mongkut's Agric J 34 (3): 96-105.
Sumida A, Miyaura T, Torii H. 2013. Relationships of tree height and diameter at breast height revisited: Analyses of stem growth using 20-year data of an even-aged Chamaecyparis obtusa stand. Tree Physiol 33: 108-118. DOI: 10.1093/treephys/tps127.
Świątek B, Pietrzykowski M. 2022. Impact of leaf litter and fine roots in the pool of carbon, nitrogen and phosphorus accumulated in soil in various scenarios of regeneration and reconstruction of forest ecosystems. Forests 13 (8): 1207. DOI: 10.3390/f13081207.
Tavankar F, Bonyad AE. 2015. Effects of timber harvest on structural diversity and species composition in hardwood forests. Biodiversitas 16: 1-9. DOI: 10.13057/biodiv/d160101.
Thai Meteorological Department. 2020. Climate of Maha Sarakham Province. Climatological Center, Meteorological Development Division, Thai Meteorological Department. http://climate.tmd.go.th.
Thammanu S, Han H, Marod, D, Zang L, Jung Y, Soe, KT, Onprom S, Chung J. 2021. Non-timber forest product utilization under community forest management in northern Thailand. For Sci Technol 17: 1-15. DOI: 10.1080/21580103.2020.1862712.
Tolessa T, Senbeta F. 2018. The extent of soil organic carbon and total nitrogen in forest fragments of the central highlands of Ethiopia. J Ecol Environ 42: 20. DOI: 10.1186/s41610-018-0081-4.
Vicharnakorn P, Shrestha R, Nagai M, Salam A, Kiratiprayoon S. 2014. Carbon stock assessment using remote sensing and forest inventory data in Savannakhet, Lao PDR. Remote Sens 6 (6): 5452-5479. DOI: 10.3390/rs6065452.
Walkley A, Black IA. 1934. An examination of the Degiareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci 37: 29-38. DOI: 10.1097/00010694-193401000-00003.
Zhao J, Liu D, Zhu Y, Peng H, Xie H. 2022. A review of forest carbon cycle models on spatiotemporal scales. J Clean Prod 339: 130692. DOI: 10.1016/j.jclepro.2022.130692.

Zhu J, Hu H, Tao S, Chi X, Li P, Jiang L, Ji C, Zhu J, Tang Z, Pan Y, Birdsey RA, He X, Fang, J. 2017. Carbon stocks and changes of dead organic matter in China's forests. Nat Commun 8: 151. DOI: 10.1038/s41467-017-00207-1.

Zhu J, Mao Z, Hu L, Zhang J. 2007. Plant diversity of secondary forests in response to anthropogenic disturbance levels in montane regions of northeastern China. J For Res 12: 403-416. DOI: 10.1007/s10310-007-0033-9.