Forest structure and carbon stock of Suan Phueng Nature Education Park in Ratchaburi Province, Western Thailand

UTAIN CHANLABUT[1,♥], BENCHAWAN NAHOK[2]

[1]Department of General Science, Faculty of Science and Technology, Muban Chombueng Rajabhat University. Chombueng District, Ratchaburi Province, 70150, Thailand. Tel./fax.: +66-890-170654, ♥email: utaincha@mcru.ac.th

[2]Department of General Science, Faculty of Education, Chaiyaphum Rajabhat University. Muang District, Chaiyaphum Province, 36000, Thailand

Abstract. *Chanlabut U, Nahok B. 2022. Forest structure and carbon stock of Suan Phueng Nature Education Park in Ratchaburi Province, Western Thailand. Biodiversitas 23: 4314-4321.* Forests play an important role in the global carbon budget. Yet, carbon stocks in tropical forests are uncertain depending on many factors. This study aims to study forest structures and carbon stocks in Suan Phueng Nature Education Park, Ratchaburi, Western Thailand. In 12 plots of 20×20 m, an inventory of trees ≥ 4.5 cm diameter at breast height (DBH) was carried out. Soil samples were also collected in sampling plots. To describe forest structures, ecological parameters were analyzed (IVI, diversity indices, basal area, and DBH size classes). Forest carbon stocks were calculated based on biomass and soils. Allometric equations were used to calculate aboveground biomass and converse to carbon stock. The soil carbon was analyzed using the wet oxidation method. The result showed that the lower montane forest (493.74 ± 90.20 Mg C ha^{-1}) had the highest forest carbon stock, followed by the dry evergreen + mixed deciduous forest (203.83 ± 82.74 Mg C ha^{-1}), and mixed deciduous forest (145.46 ± 47.90 Mg C ha^{-1}). In the three forests, there were atotal of 637 trees belonging to 70 species in 29 families. Shannon's diversity index was 3.59 with a range of 2.17-3.21, indicating a moderate to high diversity. Tree density was 1,137.50 stems ha^{-1} with a range of 737.50-1,581.25 stems ha^{-1}. The basal area had a range of 5.82-11.11 m^2 ha^{-1}. The DBH classes exhibited J-shaped distribution. The large trees (≥ 71 cm) had a greater aboveground carbon stock, despite their lower density. This indicates their importance as carbon sinks in the forest. This study highlights that the forests in Suan Phueng Nature Education Park not only have the potential to be carbon stocks but also contain a high diversity of tree species.

Keywords: Allometric equation, carbon budget, carbon sequestration, climate change, plant community

INTRODUCTION

Forests play a key role in the global carbon cycle. They are one of the largest carbon sinks as they store 45-50% of terrestrial carbon stocks (Pan et al. 2011). They absorb about 7.6 ± 49 GtCO$_2$eyr^{-1} to stabilize the global carbon flux between the atmosphere and the biosphere (Harris et al. 2021). Forests accumulate carbon via carbon sequestration (Sedjo and Sohngen 2012). Through this process, plants continuously absorb atmospheric CO$_2$ through photosynthesis and then fix carbon to long-term store in their biomass and soil via a series of chemical and biophysical reactions (Keenan and Williams 2018). The amount of carbon sequestered from the atmosphere and stored within the forest ecosystem is forest carbon stock, which is mainly stored in biomass and soil. It is estimated at 1,240 Pg C globally (Lal 2005). The amount of forest carbon stock varies among forest types, ranging from 40-60 Mg C ha^{-1} in boreal forests, 60-130 Mg C ha^{-1} in temperate forests, and 120-190 Mg C ha^{-1} in tropical forests (Lal 2005), which vary depending on many factors, such as forest type, tree species composition (FAO and UNEP 2020). Thus, there are uncertainties in the carbon storage of different vegetation types, especially in the tropics (Grace et al. 2014; Baccini et al. 2017).

Southeast Asia is home to nearly 15% of the world's tropical forests and contains many biodiversity hotpots (Stibig et al. 2014). This region is among the majority of deforestation hotspots including logging and clear-cutting for food production, cash crops, and agriculture (Hansen et al. 2013; Wilcove et al. 2013; Stibig et al. 2014; Imai et al. 2018; Zeng et al. 2018). It contributes to a severe loss of forest area and aboveground forest carbon stocks (Estoque et al. 2019), and emission of CO$_2$ to the atmosphere 16-105 Tg C yr^{-1} between 2000-2005 (Harris et al. 2021). By 2050, the forest would decline by 5.2 million ha and contributes to a decrease in forest carbon stocks by 790 Tg C (Estoque et al. 2019).

Thailand is one of the countries with the most abundant forest resources in Southeast Asia. Forests occupy 31.64% of the country's area (Thammanu et al. 2021). The western part of the country occupies 19.67% of the total forest area, which dominantly occur in Ratchaburi, Phetchaburi, and Kanchanaburi Province. In Ratchaburi, the Suan Phueng Nature Education Park is a protected forest that was established to research and protect unique biodiversity. The forest is important for biodiversity and biogeography. It is a corridor joining two of the largest forest complexes together; the Western Forest Complex and the Kaeng Krachan Forest Complex. The forest is also a bridge connecting four biogeographical regions, including Indo-Chinese, Sino-Malayan, Indo-Burmese, and Eastern Indian, where are biodiversity hotpots of both plants and animals. Like other forest areas in Southeast Asia, forests in the park

have been challenged by anthropogenic disturbances including population growth, land-use changes, and fires (Wilcove et al. 2013; Stibig et al. 2014). This would lead to the emission of CO_2 into the atmosphere. It is difficult to precisely predict the amount of CO_2 emission without adequate data on the carbon stocks that the forests contain.

There are some previous studies in proximity forests within the same region. In Kanchanaburi Province in the Thong Pha Phum National Forest, the aboveground carbon stock has been estimated to be 137.73, 70.29, and 48.14 tons C ha^{-1} for the tropical rain forest, dry evergreen forest, and mixed deciduous forest, respectively (Terakunpisut et al. 2007). In the Kaeng Krachan National Park, the carbon stock was estimated for various forest types, ranging from 33.01-103.10 tons C ha^{-1} for the aboveground carbon stock, and 43.97-107.77 tons C ha^{-1} for the soil carbon stock (National Park Research Center 2019). In the Mae Nam Phachi Wildlife Sanctuary of Ratchaburi Province, the aboveground carbon stock was estimated at 14.55-43.22 ton C ha^{-1} for tropical deciduous forests (Chaiyo et al. 2012). However, the information on carbon stock potential is still lacking in Suan Phueng Nature Education Park. To address and fill in the gap, forest inventory and field measurement in forest ecosystems are required for forest carbon data.

Therefore, this study focuses on the carbon stocks in different forest communities, especially in terms of aboveground biomass and carbon stock. The objectives of this research were (i) to examine the forest structures and (ii) to estimate the aboveground and soil carbon stocks. An accurate of estimate forest carbon stock is important for global warming scenarios and planning to reduce CO_2 emissions (Egusa et al. 2020). Therefore, determining the spatial distribution of the carbon source and carbon sink of the forest ecosystem will be extremely helpful for our research into the carbon cycle of the terrestrial ecosystem and to address global warming.

MATERIALS AND METHODS

Study area

The Suan Phueng Nature Education Park was chosen for this study. It is located in Suan Phueng District, Ratchaburi Province, Thailand. The park has an area of 212.64 km^2. Its area is part of the western boundary of Thailand, which borders Myanmar. Most of the area is mountainous terrain, which is a part of the Tanowsri mountain range. Its elevation has a range of 210 – 1,150 above mean sea level, with a declination of 45%. The mean annual temperature was 29.0°C with a range of 17.9-39.1°C. The mean annual rainfall was 1,226.9 millimeters. The wet season occurs from May to October, but the rainfall is limited from June to July. This area has been considered to be in "the rain shadow zone" because the rain is blocked by the Tanowsri mountain range (Chaiyo et al. 2011). The park is covered by various forest types, such as mixed deciduous forests, dry evergreen forests, lower montane rain forests, and rain forests. As the forest areas are close to the border of Thailand and Myanmar, sampling

areas were chosen based on the ability to access the area safely. Therefore, three different forest communities were chosen to represent the forest (Table 1).

Inventory and analysis for forest structure

A total of 12 20 × 20 m plots (0.04 ha) were set up in three forest communities. Trees with a diameter at breast height (DBH) ≥ 4.5 cm were inventoried by measuring both their height and diameter (Ruslim et al. 2021). Ecological parameters were used for investigating the forest structure including the Importance Value Index (IVI), diversity indices, frequency of DBH, density, and basal area. In addition, both species and families were counted for each plot. The diversity indices were calculated using Shannon-Wiener's diversity index (Magurran 1988). Simpson's diversity index was also used for examining the dominant species (Simpson 1949). The IVI was analyzed using the equation (Curtis and McIntosh 1951):

$$IVI = RD + RF + RD_O$$

Where; RD is the relative density of the tree species, RF is the relative frequency, and RD_O is the relative dominance. They were calculated as RD: number of individuals of the species × 100/total number of plots, RF: number of plots in which species occurred × 100/ total number of plots, and RD_O: total basal area of species × 100/total basal area of all the species.

Estimation of aboveground biomass and carbon stock

The aboveground biomass was calculated using the allometric equations, then summing the stem, branches, and leaf mass of individual trees. As there were many types of forests in the study area, different allometric equations were applied for each one. The allometric equation proposed by Ogawa et al. (1965) was used for the mixed deciduous forests and the one by Tsutsumi et al. (1983) for both dry evergreen forests and lower montane forests. The equations are as follows.

Mixed deciduous forest
$$W_S = 0.0509(D^2H)^{0.919}$$
$$W_B = 0.00893(D^2H)^{0.977}$$
$$W_L = 0.014(D^2H)^{0.669}$$

Dry evergreen forest
$$W_S = 0.0396(D^2H)^{0.933}$$
$$W_B = 0.00349(D^2H)^{1.03}$$
$$W_L = \frac{W_S}{22.5 + 0.025W_S}$$

Where; D: diameter at breast high (DBH), H: height of trees, W_S: weight of stem biomass (kg), W_B: weight of branch biomass (kg), and W_L: weight of leaves biomass (kg). The aboveground biomass carbon was calculated by multiplying with a conversion factor of 0.47. The potential of atmospheric CO_2 absorption through photosynthesis by the forest was calculated by multiplying with a conversion factor of 3.667 (IPCC 2006).

Table 1. Locality of three study sites in Suan Phueng Nature Education Park, Thailand

Study site	Forest type	Coordinates	Elevation (msl.)
Huai Phak	MDF	13°31'15.82"N, 99°14'31.73"E	184 – 218
Huai Khokmu	MDF+DEF	13°27'11.23"N, 99°13'44.32"E	377 –719
Khao Krachom	LMF	13°34'1.56"N, 99°11'43.73"E	854 – 842

Note: MDF: mixed deciduous forest, DEF + MDF: dry evergreen forest + mixed deciduous forest, LMF: lower montane forest

Sampling and analysis of soil carbon

Soil samples were collected at two depth intervals; topsoil (0-30 cm) and subsoil (30-100 cm) to calculate the carbon stock at one meter. Two methods were used for sampling the soil. To calculate the soil bulk density, undisturbed samples were collected using a soil core (6 cm diameter, 5 cm long) at the center of the sampling plot. In addition, the undisturbed sample was wrapped in plastic and labeled. To analyze the soil organic carbon (SOC), disturbed soil samples were collected using a soil auger at three holes laid in a triangular pattern in the plots. Disturbed samples were mixed to make a composite sample for each soil depth. Then, they were packed into plastic bags and conveyed to the laboratory.

The soil samples were prepared and analyzed. The composite samples were air-dried at room temperature. Then, the dried samples were ground in a mortar and passed through a 2-mm and 0.5-mm sieve. The samples were analyzed using the wet oxidation method for soil organic carbon (Walkley and Black 1934). The undisturbed samples were dried in a hot oven at 105°C for 48 hours to reach a constant weight. The dried samples were weighed and calculated using the core method for soil bulk density (Blake and Hartage 1986).

The soil carbon stocks were calculated and expressed in the unit of Mg C ha^{-1}, which was calculated by multiplying the SOC concentration by the total soil density and soil thickness. The equations were as follows:

$$C_{stocks} = C_{conc.}\left(kg\ Mg^{-1}\right) \times B.D.\left(Mgm^{-3}\right) \times D\ (m.)$$

Where; C_{stocks}: soil organic carbon stocks (Mg C ha^{-1}) for any soil depth, $C_{conc.}$: the concentration of soil organic carbon in any soil layer, B.D.: soil bulk density (Mg m^{-3}), and D: the soil depth interval (m).

Statistical analysis

Data analyses were performed using statistical software (SPSS). Both the aboveground biomass and carbon stocks in the forest were expressed as average with standard deviation. Analysis of variance (ANOVA) was used to determine the differences in means within both the aboveground biomass and forest carbon stock. The independent sample t-test was also used for testing the differences between aboveground carbon stock and soil carbon stock at the 95% level of confidence (P<0.05).

RESULTS AND DISCUSSION

Structure and composition of forest community

A total of 637 stems with a diameter ≥ 4.5 cm at breath height (DBH) were found in the total area of the three forest communities. They covered 80 species, but there were only 70 known species in 29 families. The families that had higher numbers of species were Fabaceae (11 species), Sapindaceae (six species), Malvaceae (five species), Anacardiaceae (four species), and Moraceae (four species). This result concurs with other finding that Fabaceae is the most speciose tree family in tropical forest (Kacholi et al. 2015). The ecological parameters of the forest structures are shown in Table 2. Based on the Importance Value Index (IVI), the Khao Krachom (KJ) was dominated by the species present in the lower montane forest (LMF). In Huai Phak, the dominant species were common species present in the mixed deciduous forest (MDF), so it was assigned as this forest type (Popradit et al. 2015). In Huai Khokmu, the community was dominated by both dry evergreen forest and mixed deciduous forest that was established with both types of forest communities. So, we assigned it as dry evergreen forest + mixed deciduous forest (DEF + MDF). In addition, these species, shown in Table 2, also had higher carbon biomass than other species because species with a higher IVI value indicated higher carbon storage (Harefa et al. 2022).

The Shannon's diversity index (H´) was 3.59 in the entire research area. H´ was the highest in the MDF (3.21), followed by the DEF + MDF (2.68), and then the LMF (2.17). The forest communities in the Suan Phueng Nature Education Park had a moderate to high diversity based on the H´ value (Marod et al. 2018). The Simpson's index (D) was 0.06 for the overall area, ranging from 0.06 to 0.20 for the three sites (Table 2). The lower Simpson's index value indicated that there were no highly dominant species in the forest communities.

Among three forests, tree density ranged from 737.50-1,581.25 tree ha^{-1} with an average of 1,137.50 tree ha^{-1}. The MDF showed the highest density, followed by the DEF + MDF, and the LMF (Table 2). Compared to other forest ecosystems in Thailand, the tree density of MDF in Huai Phak (1,581.25 tree ha^{-1}) was higher than that reported in Doi Suthep-Pui National Park in northern Thailand (1,102 tree ha^{-1}) and Phu Khao-Phu PanKham. The DEF+MDF in Huai Khokmu (1,108.33 tree ha^{-1}) was lower than that reported in the Doi Suthep-Pui National Park (2,451 tree ha^{-1}) (Khamyong et al. 2018). The MDF in the present study was also higher than that reported from Mae Nam Phachi Wildlife Sanctuary, which is near and borders the study site

of the present study (Chaiyo et al. 2012). The basal area was higher in the LMF (11.11 m^2 ha^{-1}), while the MDF was the lowest (5.82 m^2 ha^{-1}). The basal area increases with decreasing density, which inferred negative relation between the basal area and tree density (Table 2). The MDF consisted of more trees with DBH smaller than 10 cm, while the LMF contained larger DBH trees (Figure 1). The highest stem volume and largest diameter need more area to settle, resulting in a lower tree density (Terakunpisut et al. 2007).

The distribution of the DBH trees were shown in Figure 1. The entire forests showed L-shaped distributions (Figure 1; All), and there were quite similar among forest types. The lower montane forest (LMF) had a DBH range of 4.70-101.82 cm with a mean of 26.88 ± 20.24 cm. Specifically, tree with DBH 21-30 cm (30.51%) was the most abundant, followed by ≤10 cm (25.42%), 11-20 cm (18.64%), 31-40 cm (7.63%), 41-50 cm (5.08%), 51-60 cm (5.08%), 61-70 cm (3.39%), and ≥71 cm (4.24%). The dry evergreen forest + mixed deciduous forest (DEF+MDF) had a DBH range of 4.50-91.95 cm with a mean of 14.51±10.38 cm. Specifically, tree with DBH 11-20 cm (47.74%) was the most abundant, followed by tree with DBH ≤10 cm (37.59%), 21-30 cm (7.89%), 31-40 cm (4.14%), 41-50 cm (1.13%), 51-60 cm (0.75%), 61-70 cm (0.38%), and ≥71 cm (0.38%). In the mixed deciduous forest (MDF), DBH varied between 4.50-40.80 with a mean of 10.76 ± 5.90 cm. In this forest site, trees with DBH ≤ 10 cm (65.22%) were the most abundant, followed by 11-20 cm (28.46%), 21-30 cm (4.74%), and 31-40 cm (1.58%). Among three forest sites, there were reductions in some DHB sizes. As a result, it showed discontinue of DBH size and abnormal J-shape distribution. This reflects the result of deforestation in the past (Imai et al. 2018), especially the MDF in Huai Phak. In addition, this area was subject to tin mining 40-50 years ago. Logging in the past can explain the lack of large trees in this area.

Forest carbon stocks

Among three forest sites, forest carbon stocks are shown in Table 3. The mean aboveground carbon stock was the highest for the LMF (312.38 ± 59.30 Mg C ha^{-1}), followed by the DEF+MDF (91.71 ± 34.32 Mg C ha^{-1}), and MDF (42.07 ± 20.62 Mg C ha^{-1}). The differences in aboveground carbon stock were likely due to several factors including basal area, tree density, and DBH (Joshi and Dhyani 2019; García-Vega and Newbold 2020; Sahoo et al. 2021), which all differed among the forest sites (Table 2). The mean soil carbon stock was also the highest for the LMF (181.36 ± 69.07 Mg C ha^{-1}), followed by the DEF+MDF (112.12 ± 58.39 Mg C ha^{-1}), and the MDF (103.40 ± 54.19 Mg C ha^{-1}). Yet, there was no significant difference between the three forests (Table 3). In general, soil carbon content is influenced by the accumulation of organic matter that is controlled by litter input and decomposition (Sahoo et al. 2021). Evidence of burning

can be observed in field surveying of two latter forests (LMF, DEF+MDF), while it did not exist in the LMF. The effect of fires could decrease the accumulation of organic matters (de Andrade et al. 2017). However, the rate of leaves falling, and decomposition was not investigated in this study. This could differ among three forests depending on forest types and species composition, which is interesting for study beyond. The mean total carbon stock (aboveground + soils) was in the order of LMF (493.74 ± 90.20 Mg C ha^{-1}) > DEF+MDF (203.83 ± 82.7 Mg C ha^{-1}) > MDF (145.46 ± 47.90 Mg C ha^{-1}). The result was similar to a previous study in the Kaeng Krachan National Park that indicated the montane forest stored the highest carbon stocks in both biomass and soils, followed by the dry evergreen mixed with deciduous forest, and mixed deciduous forest (National Park Research Center 2019). Moreover, the total carbon stock estimate for the lower montane forest is higher than those in other areas, such as Kaeng Krachan National Park and Thong Pha Phum National Park (Terakunpisut et al. 2007; National Park Research Center 2019). This would indicate that the lower montane forest in Khao Krachom is one of the most important carbon sinks for the western part of Thailand.

For the total carbon stock, the forest carbon was calculated from the aboveground biomass and soil. Carbon storage between aboveground and soil differed among the forest communities (Figure 2). In both Huai Khokmu and Huai Phak, the carbon stock was mainly stored in the soil. In Khao Krachom, however, the total carbon stock was mostly in the aboveground biomass. The soil carbon stocks did not significantly differ among the three sites, indicating that the soil carbon may be stable and could not be higher than this. Thus, the proportion of the aboveground biomass carbon could increase beyond the current level, and they will be important carbon sinks for these areas.

DBH size class and aboveground biomass carbon

The distribution of DBH size classes and aboveground biomass carbon (AGBC) are shown in Table 4. In total area, tree with DBH ≥ 71 cm (23.55%) had the highest ABGC, followed by 21-30 cm (16.84%), 11-20 cm (13.28%), 11-20 cm (13.28%), 31-40 cm (12.21%), 51-60 cm (11.66%), 61-70 cm (10.37%), 41-50 (8.54%), and ≤10 (3.56%). In the LMF, tree with DBH ≥71 cm (32.71%) had the highest AGBC, followed by 21-30 cm (15.6%), 51-60 cm (15.56%), 61-70 cm (13.86%), 41-50 cm (10.12%), 31-40 cm (8.02%), 11-20 cm (3.41%), and ≤10 cm (0.71%). In the DEF + MDF, tree with DBH 11-20 cm (27.07%) had the highest ABGC, followed by 31-40 cm (20.3%), 21-30 cm (18.31%), ≥71 cm (9.95%), 41-50 cm (7.58%), 51-60 cm (6.35%), 61-70 cm (5.63%), and ≤10 cm (4.82%). In the MDF, tree with DBH 11-20 cm (41.43%) had the highest AGBC, followed by 21-30 cm (21.21%), ≤10 cm (20.53%), and 31-40 cm (16.83%).

Table 2. Quantitative characteristics of three forest sites in Suan Phueng Natural Education Park, Thailand

Study site (Forest types)	No. of species	Density (stem ha⁻¹)	BA (m² ha⁻¹)	Species with highest IVI	Diversity indices	
					H´	D
KJ (LMF)	22	737.50	11.11	1. *Anisoptera costata* Korth. (78.78) 2. *Castanopsis* spp. (72.98) 3. *Castanopsis rhamnifolia* (Miq.) A. DC. (22.35) 4. *Carallia brachiata* (Lour.) Merr (16.95) 5. *Garuga pinnata* Roxb. (16.65) 6. Other 17 taxa (92.28)	2.17	0.20
KM (DEF + MDF)	49	1,108.33	9.25	1. *Areca catechu* L. (62.35) 2. *Artocarpus heterophyllus* Lam. (20.94) 3. *Croton persimilis* Müll.Arg. (14.40) 4. *Vitex limonifolia* Wall. ex Walp. (10.63) 5. *Durio* sp. (9.89) 6. Other 44 taxa (181.79)	2.68	0.20
LD (MDF)	42	1,581.25	5.82	1. *Croton persimilis* Müll.Arg. (25.99) 2. *Lagerstroemia floribunda* Jack var. *cuspidate* C.B.Clarke (24.46) 3. *Vitex limonifolia* Wall. ex Walp. (22.00) 4. *Cleistanthus gracillis* Hook.f. (16.05) 5. *Arfeuillea arborescens* Pierre ex Radlk. (13.06) 6. Other 37 taxa (198.43)	3.21	0.06
Total area	80	1,137.50	20.10	1. *Anisoptera costata* Korth. (31.87) 2. *Areca catechu* L. (26.60) 3. *Castanopsis* spp. (22.13) 4. *Croton persimilis* Müll.Arg. (13.03) 5. *Lagerstroemia floribunda* Jack var. cuspidata C.B.Clarke (11.07) 6. Other 75 taxa (195.29)	3.59	0.06

Note: BA: basal area, KJ: Khao Krachom, KM: Huai Khokmu, LD: Huai Phak
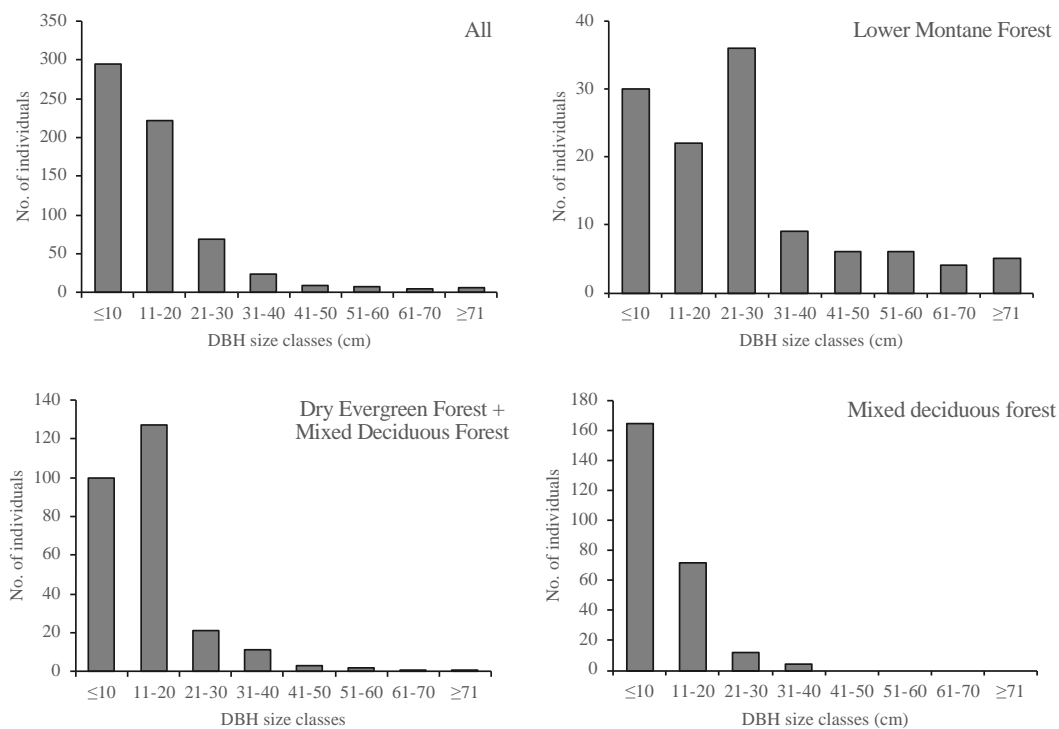
Figure 1. Distribution of different DBH size classes in three forest communities; All: all forest communities combined, lower montane forest at Khao Krachom, dry evergreen mixed with deciduous forest at Huai Khokmu, and mixed deciduous forest at Huai Phak, Thailand

Table 3. Carbon stocks of three forest sites in Suanpueng Natural Education Park, Thailand

Forest type	Site	Carbon stock (Mg C ha⁻¹)		
		Aboveground	Soil	Total
LMF	Khao Krachom	312.38 ± 59.30[a]	181.36 ± 69.07[a]	493.74 ± 90.20[a]
DEF + MDF	Huai Khokmu	91.71 ± 34.32[b]	112.12 ± 58.39[a]	203.83 ± 82.74[b]
MDF	Huai Phak	42.07 ± 20.62[b]	103.40 ± 54.19[a]	145.46 ± 47.90[b]
Total areas	-	140.57 ± 120.28	129.41 ± 65.32	269.98 ± 165.03

Note: different letters in the same column show differences in mean value at 95% level confidence (p<0.05)

Table 4. Comparison of percentage of both aboveground carbon stock and tree density in each size class in three study sites

DBH Size class (cm)	LMF (Khao Krachom)		DEF+MDF (Huai Khokmu)		MDF (Huai Phak)		Total area	
	Carbon stock (%)	Tree density (%)	Carbon stock (%)	Tree density (%)	Carbon stock (%)	Tree density (%)	Carbon stock (%)	Tree density (%)
≤10	0.71	25.42	4.82	37.59	20.53	65.22	3.56	46.31
11-20	3.41	18.64	27.07	47.74	41.43	28.46	13.28	34.69
21-30	15.60	30.51	18.31	7.89	21.21	4.74	16.84	10.83
31-40	8.02	7.63	20.30	4.14	16.83	1.58	12.21	3.77
41-50	10.12	5.08	7.58	1.13	n/a	n/a	8.54	1.41
51-60	15.56	5.08	6.35	0.75	n/a	n/a	11.66	1.26
61-70	13.86	3.39	5.63	0.38	n/a	n/a	10.37	0.78
≥71	32.71	4.24	9.95	0.38	n/a	n/a	23.55	0.94
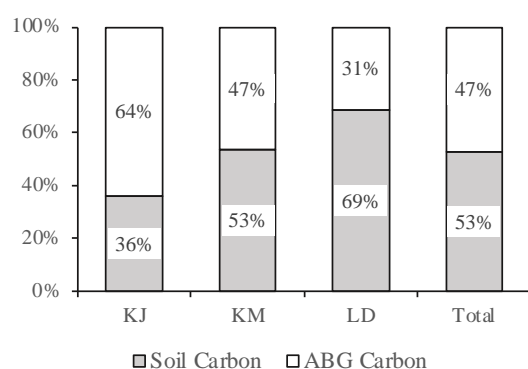
Figure 2 Proportion of two carbon pools for three forest sites in this study; KJ: Khao Krachom, KM: Huai Khokmu, LD: Huai Phak, Thailand. Total: Total areas

The distribution of AGBC was similar to the distribution of DBH class, indicating the positive relationship between tree size and the amount of carbon in biomass. Carbon stock can be influenced by the basal area, tree size, and growth pattern (Borah et al. 2015). It showed that tree size plays an important role in forest carbon stocks. As a result, there were differences in forest carbon stock among forest sites due to the different distribution of DBH classes. To highlight a large tree, despite lower tree densities the tree with DBH ≥ 71 cm showed higher AGBC in both all forests combined and LMF. It indicated the importance of large trees on forest carbon storage, that large-diameter trees store disproportionately large amounts of biomass carbon and are a key driver of the carbon cycle in the forest site (Mildrexler et al. 2020). In the context of conservation, large-diameter trees should be first prioritized in preservation for stabilizing the regional carbon balance. Therefore, the area with a high density of large trees should be highly protected. Otherwise, once it has been deforested, it can emit an enormous amount of CO_2 into the atmosphere. However, the high density of small trees in both MDF and DEF+MDF also had the potential to store carbon in the future.

In conclusion the diversity of forest communities in the Suan Phueng Nature Education Park ranged from mid to high based on the Shannon–Wiener's diversity index. Fabaceae was the most species among other families. Based on IVI, the dominant tree species differed among forest sites and were assigned to three different forest communities. All forests had J–shape distribution of DBH classes, but there were quite differences in tree size among forests. The reductions of some DBH classes were observed, especially the MDF in the Huai Phak. It was due to deforestation and mining, which is extensive in the past for this area. Other forest parameters differed among forest sites including basal area, density, and the number of species. The LMF had the highest forest carbon stock followed by the DEF+MDF, and MDF, and there was the same trend for both aboveground biomass and soil carbon stock. The distribution of large DBH trees likely contributed to the difference in aboveground biomass carbon among the three forests. The bigger DBH trees (≥71 cm) showed disproportionally large aboveground carbon stocks, which highlights the importance of large DBH trees in forest carbon stock. This study revealed the forest structure and carbon stock, which fill in the gap of information about forest carbon stock in the forest ecosystem of western Thailand. In addition, it highlights the role of different forest types in the Suan Phueng Nature Education Park as carbon sinks and absorbing CO_2 from the atmosphere.

ACKNOWLEDGEMENTS

REFERENCES

Baccini A, Walker W, Carvalho L, Farina M, Sulla-Menashe D, Houghton RA. 2017. Tropical forests are a net carbon source based on aboveground measurements of gain and loss. Science 358: 230-234. DOI: 10.1126/science.aam5962.

Blake GR, Hartage KH. 1986. Bulk Density. In: Klute A (eds). Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods. American Society of Agronomy-Soil Science Society of America, Madison. DOI: 10.2136/sssabookser5.1.2ed.c13.

Borah M, Das D, Kalita J, Deka Boruah, HP, Phukan B, Neog B. 2015. Tree species composition, biomass and carbon stocks in two tropical forest of Assam. Biomass Bioenergy 78: 25-35. DOI: 10.1016/j.biombioe.2015.04.007.

Chaiyo U, Garivait S, Wanthongchai K. 2011. Carbon storage in above-ground biomass of tropical deciduous forest in Ratchaburi Province, Thailand. World Acad Sci Eng Technol 58: 636-641. DOI: 10.13140/2.1.3011.0723.

Chaiyo U, Garivait S, Wanthongchai K. 2012. Structure and carbon storage in aboveground biomass of mixed deciduous forest in Western Region, Thailand. GMSARN Intl J 6: 143-150.

Curtis JT, McIntosh RP. 1951. An upland forest continuum in the Prairie-Forest Border Region of Wisconsin. Ecology 32: 476-496. DOI: 10.2307/1931725.

de Andrade RB, Balch JK, Parsons AL, Armenteras D, Roman-Cuesta RM, Bulkan J. 2017. Scenarios in tropical forest degradation: carbon stock trajectories for REDD+. Carbon Balance Manag 12: 6. DOI: 10.1186/s13021-017-0074-0.

Egusa T, Kumagai T, Shiraishi N. 2020. Carbon stock in Japanese forests has been greatly underestimated. Sci Rep 10: 7895. DOI: 10.1038/s41598-020-64851-2.

Estoque RC, Ooba M, Avitabile V, Hijioka Y, DasGupta R, Togawa T, Murayama Y. 2019. The future of Southeast Asia's forests. Nat Commun 10: 1829. DOI: 10.1038/s41467-019-09646-4.

FAO, UNEP, 2020. The State of the World's Forests 2020. Forests, Biodiversity and People. Rome. DOI: 10.4060/ca8642en.

García-Vega D, Newbold T, 2020. Assessing the effects of land use on biodiversity in the world's drylands and Mediterranean environments. Biodivers Conserv 29: 393-408. DOI: 10.1007/s10531-019-01888-4.

Grace J, Mitchard E, Gloor E. 2014. Perturbations in the carbon budget of the tropics. Glob Change Biol 20: 3238-3255. DOI: 10.1111/gcb.12600.

Hansen MC, Potapov PV, Moore R, Hancher M, Turubanova SA, Tyukavina A, Thau D, Stehman SV, Goetz SJ, Loveland TR, Kommareddy A, Egorov A, Chini L, Justice CO, Townshend JRG. 2013. High-resolution global maps of 21st-century forest cover change. Science 342: 850-853. DOI: 10.1126/science.1244693.

Harefa, MS, Nasution Z, Mulya MB, Maksum A. 2022. Mangrove species diversity and carbon stock in silvofishery ponds in Deli Serdang District, North Sumatra, Indonesia. Biodiversitas 23: 655-662. DOI: 10.13057/biodiv/d230206.

Harris NL, Gibbs DA, Baccini A, Birdsey RA, de Bruin S, Farina M, Fatoyinbo L, Hansen MC, Herold M, Houghton RA, Potapov PV, Suarez DR, Roman-Cuesta RM, Saatchi SS, Slay CM, Turubanova SA, Tyukavina A. 2021. Global maps of twenty-first century forest carbon fluxes. Nat Clim Change 11: 234-240. DOI: 10.1038/s41558-020-00976-6.

Imai N, Furukawa T, Tsujino R, Kitamura S, Yumoto T. 2018. Factors affecting forest area change in Southeast Asia during 1980-2010. PLOS ONE 13: 1-14. DOI: 10.1371/journal.pone.0197391.

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

Joshi RK, Dhyani S. 2019. Biomass, carbon density and diversity of tree species in tropical dry deciduous forests in Central India. Acta Ecol Sin 39: 289-299. DOI: 10.1016/j.chnaes.2018.09.009.

Kacholi DS, Whitbread AM, Worbes M. 2015. Diversity, abundance, and structure of tree communities in the Uluguru forests in the Morogoro region, Tanzania. J For Res 26: 557-569. DOI: 10.1007/s11676-015-0078-0.

Keenan TF, Williams CA. 2018. The terrestrial carbon sink. Ann Rev Environ Resour 43: 219-243. DOI: 10.1146/annurev-environ-102017-030204.

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. Chiang Mai Univ J Nat Sci 17: 289-306. DOI: 10.12982/CMUJNS.2018.0021.

Lal R. 2005. Forest soils and carbon sequestration. For Ecol Manag 220: 242-258. DOI: 10.1016/j.foreco.2005.08.015.

Magurran AE. 1988. Ecological Diversity and its Measurement. Princeton University Press, New Jersey, US. DOI: 10.1007/978-94-015-7358-0.

Marod D, Thinkampheang S, Thongsawi J, Phumphuang W, Kohkerd T, Hermhuk S, Nakthanom A. 2018. Forest structure and species composition in the dry evergreen forest at Wang Nam Khiao Forestry Student Training and Research Station, Nakhon Ratchasima Province. Thai For Ecol Res J 2: 45-54.

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. DOI: 10.3389/ffgc.2020.594274.

National Park Research Center. 2019. Report of Study on Carbon Stocks in ASEAN Heritage Areas, Kaeng Krachan National Park, National Park Research Report 16. National Parks Research and Innovation Development Center, National Parks of Thailand, Petchaburi.

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 South East Asia 4: 49-80.

Pan Y, Birdsey RA, Fang J, Houghton R, Kauppi PE, Kurz WA, Phillips OL, Shvidenko A, Lewis SL, Canadell JG, Ciais P, Jackson RB, Pacala SW, McGuire AD, Piao S, Rautiainen A, Sitch S, Hayes D. 2011. A large and persistent carbon sink in the world's Forests. Science 333: 988-993. DOI: 10.1126/science.1201609.

Popradit A, Srisatit T, Kiratiprayoon S, Yoshimura J, Ishida A, Shiyomi M, Murayama T, Chantaranothai P, Outtaranakorn S, Phromma I, 2015. Anthropogenic effects on a tropical forest according to the distance from human settlements. Sci Rep 5: 14689. DOI: 10.1038/srep14689.

Ruslim Y, Sandalayuk D, Kristinningrum R, Alam AS, 2021. Estimation of above ground biomass and carbon stocks of *Tectona grandis* and *Gmelina arborea* stand in Gorontalo Province, Indonesia. Biodiversitas 22: 1497-1508. DOI: 10.13057/biodiv/d220354.

Sahoo UK, Tripathi OP, Nath AJ, Deb S, Das DJ, Gupta A, Devi NB, Charturvedi SS, Singh SL, Kumar A, Tiwari BK. 2021. Quantifying tree diversity, carbon stocks, and sequestration potential for diverse land uses in Northeast India. Front Environ Sci 9: 1-14. DOI: 10.3389/fenvs.2021.724950.

Sedjo R, Sohngen B. 2012. Carbon sequestration in forests and soils. Ann Rev Resour Econ 4: 127-144. DOI: 10.1146/annurev-resource-083110-115941.

Simpson EH. 1949. Measurement of diversity. Nature 163: 688. DOI: 10.1038/163688a0.

Stibig HJ, Achard F, Carboni S, Raši R, Miettinen J. 2014. Change in tropical forest cover of Southeast Asia from 1990 to 2010. Biogeosciences 11: 247-258. DOI: 10.5194/bg-11-247-2014.

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: 93-102.

Thammanu S, Han H, Marod D, Srichaichana J, Chung J. 2021. Above-ground carbon stock and REDD+ opportunities of community-managed forests in Northern Thailand. PLoS One 16: 1-21. DOI: 10.1371/journal.pone.0256005.

Tsutsumi T, Yoda K, Sahunalu P, Dhanmanonda P, Prachaiyo B. 1983. Forest: Felling, burning and regeneration. In: Kyuma, K, Pairitra C (Eds). Shifting Cultivation. Natural Science, Vol.5 No.1A, Tokyo.

Walkley A, Black IA. 1934. An examination of the Degtjareff 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.

Wilcove DS, Giam X, Edwards DP, Fisher B, Koh LP. 2013. Navjot's nightmare revisited: Logging, agriculture, and biodiversity in Southeast Asia. Trends Ecol Evol 28: 531-540. DOI: 10.1016/j.tree.2013.04.005.

Zeng Z, Estes L, Ziegler AD, Chen A, Searchinger T, Hua F, Guan K, Jintrawet AF, Wood E. 2018. Highland cropland expansion and forest loss in Southeast Asia in the twenty-first century. Nat Geosci 11: 556-562. DOI: 10.1038/s41561-018-0166-9.