Structure and Carbon Storage in Aboveground Biomass of Mixed Deciduous Forest in Western Region, Thailand

Ubonwan Chaiyo, Savitri Garivait, and Kobsak Wanthongchai

Abstract— *Thisstudy focuses on the structure and carbon storage in aboveground biomass of mixed deciduous forest (MDF), located in Mae Nam Phachi Wildlife Sanctuary,Ratchaburi Province, Thailand. Experimental plots were set to obtain the structure and aboveground biomass of tree, sapling and bamboo. Allometric equations were used to estimate aboveground biomass of these vegetation types, while seedling, leaf litter, twig and understory were investigated using direct harvesting method. Carbon storage in aboveground biomass was calculated following the IPCC 2006guidelinesfor national greenhouse gas inventory methodology. The obtained resultsindicated that the dominant species of tree stand in MDF are composed of Vitexcanescens, Brideliatomentosa, Xyliaxylocarpa, Largerstroemiacalyxcolata, and Dalbergia cultrate,which have the Important Value Index (IVI)of26.0, 18.85, 11.83, 11.56, and 11.04, respectively. Bamboo has the highestrelative IVIof 43.45, and it was found that the Thyrostachyssimensis is the dominant bamboo species in the area. The number of tree individuals and sapling are 450 ± 218 and 383 ± 225 individuals/ha, respectively, a nd bamboo is 15,342 ± 1,903 culms/ha. The abovegrou nd biomass and associated carbon stock obtained from this study are 77.539± 55.161 tons/ha and 36.44± 25.93 tons C/ha, respectively.*

Keywords— **Mixed deciduous forest, above-ground biomass, carbon stock, Ratchaburi, Thailand.**

1. INTRODUCTION

The western region in Thailand is composed of Tak, Kanchanburi, Ratchaburi, Petchaburi and PrachuapKhiri Khan Provinces, which coversa total area of 53679.018 km^2. The area of mixed deciduous forest (MDF) in this regionrepresents20.01% or 17,501.6 km^2 of natural forest area in Thailand [1]. MDF in Thailand isclassified into three sub-types including upper moist, upper dry and lower dry mixed deciduous forests [2]. In Kanchanaburi province, MDF is composed of these three main sub-typeswith bamboo and bamboo forests. It was stated that the forest type separation of each site depend on the vegetation structure and composition, topography, altitude, and disturbance. These parameters influence the variation of carbon stock in aboveground biomass of each area.Knowledge on the vegetation structure in different types of forest is useful to better understand the carbon storage, carbon sink and source mechanisms or processes.

Also, it was found that MDF has high capacity of carbon sink [3, 4]. In this type of forest, capture of carbon dioxide through photosynthesis ranged about 1-2 kg/m^2 [5]. In 2006, FAO reported that the estimation of carbon stock in tropical forest is about 638Gt in the year 2005. The diameter at breast height (DBH) of tree stands around 20-40 cm is considered asrepresenting the stage of the highest capacity to sink carbon via photosynthesis process [3].However, a forest is variable in structure, which constitutes one of the main parameters in determining the amount of aboveground biomass. The rural human activities,such as the gathering of non-timber forest product (i.e. mushrooms, edible plants, fuel wood), to facilitate hunting and agricultural debris elimination are the principal causesof land use change, and so vegetation structure modification. In addition, MDF is the main type of tropical deciduous forest, and frequently subject to wildfires during dry season with sufficiently large amount of biomass fuel loads on the ground cover. In 2000, wildfires in MDF represented about 70% of the total area of forest fire occurrence in Thailand [6]. The high frequency of wildfires can drastically modify the structure and composition of aboveground biomass,and so play an important role in carbon cycle in ecosystem [7, 8]. Generally, this type of forest is located at an altitude from 50-1,000 m above sea level, with precipitation not exceeding 1,200 mm per year, and the period of drought should not be more than 4 months. During dry season (from December to April), the tree stand shed their leaves leading to accumulation of biomass on the ground cover, which served as fuel for forest burning. Wildfiresinfluence the structure and ecosystem because it can burn the seedling with diameter at root collar less than one centimeter completely [9]. Moreover, they affect the soil properties and respiration processes, as well as its nutrient dynamics [10].

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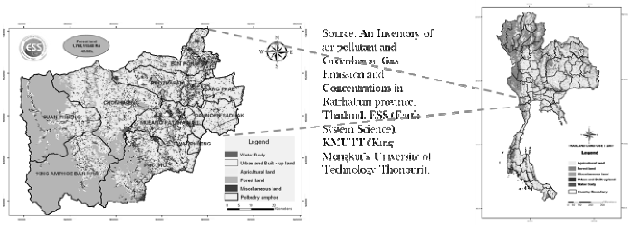
However, data on vegetation structure and carbon storage in aboveground biomass of the MDF are still limited, and the existing information does not cover all regions of Thailand. In this study, the MDF in Ratchaburi province was investigated, and the obtained results from field experiments were then presented and discussed.

2. MATERIALS AND METHODS

Studysite

The study site was set up in a natural mixed deciduous forest in Mae Nam Phachi Wildlife Sanctuary Ratchaburi province(13°32′ N – 13°54′N latitude and 99°49′ E – 99°82′E longitude) (Fig. 1.), located in Baan Beung, Suan Pheung District, Ratchaburi province, about 210 km west of Bangkok, the capital of Thailand. It covers atotal area of 489 km^2,and includesdry dipterocarp forest, mixed deciduous forest, tropical rain forest and pure stand bamboo forest. The altitude of the highest mountain peak areas located in the western part of the province, i.e. Suan Pueng district, Khing Amphoe Ban Kha, and Park Tho district, close to the border of the country with Myanmar. The altitude ofthe study area ranges from 200 to 1,400 m asl. It has been considered as “the rain shadow zone” since most of the rain is blocked by the Tanowsri Mountain Chain. The average total rainfall of 959 – 1,285 mm and mean temperature of 28°Care observed during the year, based on data ofRatchaburi‘s meteorological station during2005 to 2008. The highest temperature during dry season, especially in April, situates between 30.3 – 31.3°C. December corresponds to the coolest month with temperatures interval of 24.5 – 26.9°C. January represents the driest month with only less than 6.5 mm rainfall, and October the wettestmonth, withrainfall level of 117 to 441 mm.



Source:An Inventory of air pollutant and Greenhouse Gas Emission and Concentrations inRatchaburi province, Thailand, ESS (Earth System Science), KMUTT (King Mongkut’sUniversity of Technology Thonburi).

Fig.1. Field experiment study site inRatchaburi province, Thailand

Plot Set Up

The study site was located in a mixed deciduous forest (MDF) of the Mae Nam Phachi Wildlife Sanctuary,Ratchaburi Province, ThailandThree study plots were setup at a terrain with slope <20%. Each plot has a size of 40 m × 40 m. The number of individuals and associate aboveground biomass of tree at DBH>4.5 cmand bamboo were collected in the sub-plot of 20 m × 20 msize located at the left corner of the main 40 m × 40 m plot, while sapling of DBH< 4.5, and height > 1.3 m were from foursub-plotsof 10 m × 10 m size. The data on seedling with total height lesser than 1.3 m, other understory (grass, herb, shrub, climber) and litter (both leaf and small twig) were collected from four 1 m × 1 m subplots (Fig. 2).

Qualitative and Quantitative Analysis of Vegetation

All species of vegetation in the study plot were recorded. For each species, general information of forest vegetation including plantfamily, scientific name, as well as common name, were logged. Theoretically, the evolutioncharacteristics of trees, shrub, ivy, etc., differ by the growth patterns and vegetative individual composition. The differences rely not only in the growth dynamic pattern but also in the variation of environment parameters suitable to each plant species. Information on species and its evolution pattern is useful to better understandthe plant growth and species density influencing the amount of above-ground biomass and biomass fuels during forest fires.

The structure of the MDF was quantitatively characterized by investigating the Important Value Index (IVI) of the plant species. The parameters quantified in relative IVI are relative density, frequency, and dominance, of plant species.

The important value index (IVI) of vegetation structure was obtained based on equation of Curtis, 1959 as

$$IVI = relative\ density + relative\ frequency + relative\ domina \quad (1)$$

where

$$Relative\ Density = \frac{Number\ of\ individual\ of\ the\ species\ i}{Number\ of\ individual\ of\ all\ the\ species} \times 100$$

$$Relatvie\ Frequency = \frac{Number\ of\ occurrence\ of\ the\ species\ i}{Number\ of\ occurrence\ of\ all\ the\ species} \times 100$$

$$Relative\ Dominace = \frac{Total\ basal\ area\ of\ the\ species\ i}{Total\ basal\ area\ of\ all\ the\ species} \times 100$$

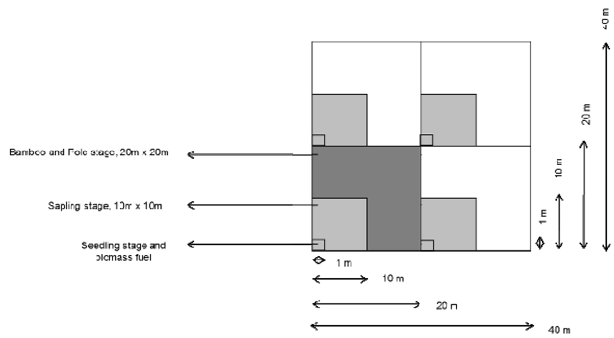


Fig.2. Plot set up for aboveground biomass estimation in MDF at the study site in Ratchaburi province, Thailand

Estimation of Above Ground Biomass and Carbon Stock

DBH and total height were recorded for all tree, sapling and bamboo.Above-ground tree biomass was estimated using the allometric equation from [11], and defined in (2). The estimation of aboveground sapling biomass and above-ground bamboo biomass (*T. siamensis*) were obtained from the allometric equations from [12] and [13], and indicated in (3) and (4), respectively.

$$W_s = 0.0396\, D^2 H^{0.9326}$$
$$W_b = 0.003487\, D^2 H^{1.0270} \qquad (2)$$
$$W_l = \left(\frac{28.0}{W_{tc}} + 0.025\right)^{-1}$$

$$W_s = 0.0893059\, D^2 H^{0.66513}$$
$$W_b = 0.0153063\, D^2 H^{0.58255} \qquad (3)$$
$$W_l = 0.0000140\, D^2 H^{0.44363}$$

where:
D is the diameter at breast height [cm],
H is the height of tree stand [m],
W_s is the mass of stem [kg],
W_b is the mass of branch [kg],
W_l is the mass of leaf [kg],
W_{tc} is the total mass of stem and branch [kg],

$$W_c = 0.0691512\, D^2 H^{0.7930}$$
$$W_t = 0.0883689\, D^2 H^{0.7703} \qquad (4)$$
$$W_{b+l} = W_t - W_c$$

where:
D is the diameter at breast height [cm],
H is the height of culm [m],
W_c is the mass of culm [kg],
W_t is the total mass of culm, branch and leaf [kg],
W_{b+l} is the total mass of branch and leaf [kg],

The understory fuel biomass including seedling, grass, shrub, climber, herb and litter (leaf and twig) was determined directly using gravimetric method, consisting in measuring the fresh weight of the biomass just after its cut. Then, samples were oven-dried at 70 °C for at least 48 h, and weighted again to determine the fuel moisture content and the dry weight. The total dry weight of biomass fuel as live and dead parts were converted from fresh weight and dry weight ratios from the sampling area based on (5).

$$Total\ \ DW\ \ (kg\ \ m^2) = \frac{Total\ \ FW\ \ (kg) \times Subsample\ \ DW\ \ (g)}{Subsample\ \ FW\ \ (g) \times Sample\ \ area\ \ (m^2)} \qquad (5)$$

The carbon stock in the aboveground biomass was calculated based on the IPCC 2006 guidelines for national greenhouse gas inventory by multiplying the 0.47 conversion factor to the biomass [14].

Table 1. The Structure (Abundance, Basal Area (BA), Relative Frequency (RF), Relative Density (RDen), Relative Dominance (RDo), and Ecologiacl Important Value Index (IVI) of Vegetation Plant in MDF Plots Located in the Phachi River Wildlife SanctuayRatchaburi Province, Thailand.

Species	Abundance (indiv./ha)	BA (m^2/ha)	RF	Rden	Rdo	IVI
Thyrsostachys siamensis	15,342	6.8966	8.550	97.202	24.592	130.343
Vitex canescens	75	6.4477	2.850	0.158	22.991	25.999
Bridelia tomentosa	25	8.9419	2.850	0.053	15.942	18.845
Xylia xylocarpa	50	4.9757	2.850	0.106	8.871	11.827
Lagerstroemia calyxcolata	50	1.5844	5.700	0.211	5.650	11.561
Dalbergia cultrata	33	0.4251	8.550	0.211	2.274	11.035
Millettia brandisiang	63	0.9729	5.700	0.264	3.469	9.433
Bauhinia saccoclyx	50	0.8505	5.700	0.211	3.033	8.944
Lannea coromandelica	38	0.6889	5.700	0.158	2.456	8.315
Vitex peduncularis	50	0.4077	5.700	0.211	1.454	7.365
Stereospermum neuranthum	25	0.0784	5.700	0.106	0.279	6.085
Terminalia pierrei	50	0.7923	2.850	0.106	1.413	4.368
Bombax anceps	13	0.6832	2.850	0.053	1.218	4.121
Gratoxylum formosum	25	0.6707	2.850	0.053	1.196	4.098
Heterophragma adenophyllum	25	0.5014	2.850	0.053	0.894	3.797
Xanthophyllum lanceatum	75	0.4233	2.850	0.158	0.755	3.763
Atalantia monopylla	25	0.4210	2.850	0.053	0.751	3.653
Bauhinia variegata	25	0.3887	2.850	0.053	0.693	3.596
Pterocarpus macrocarpus	75	0.2349	2.850	0.158	0.419	3.427
Diospyros castanea	25	0.2437	2.850	0.053	0.435	3.337
Bauhinia glauca	50	0.1823	2.850	0.106	0.325	3.281
Croton oblongifolius	25	0.1408	2.850	0.053	0.251	3.154
Terminaria triptera	25	0.1165	2.850	0.053	0.208	3.110
Lagerstroemia loudonii	25	0.1052	2.850	0.053	0.188	3.090
Shorea obtusa	25	0.0733	2.850	0.053	0.131	3.034
Arfeuilea arborescens	25	0.0645	0.251	0.053	0.115	0.419
Total	**16,354**	**37.7747**	**100**	**100**	**100**	**300**

Table 2. The vegetation density,diameter at breast height (DBH)andheight (Ht) in the study site

Vegetation Category	Density	DBH (cm)			Ht (m)		
		mean	range	SD	mean	range	SD
Tree	450 ±218 individuals/ha	11.13	4.77-38.20	5.65	10.53	9.25-24.30	4.23
Sapling	383 ± 225 individuals/ha	3.02	0.57-4.20	0.85	4.23	1.30-7.80	1.37
Bamboo	15,342 ± 1,903 culms/ha	2.44	1.29-5.87	0.48	7.43	2.00-21.70	2.36

3. RESUTLS AND DISCUSSION

Structure of the studied Mixed Deciduous Forest

The vegetation of the studied MDF was composed of 14 families, 21 genus, and 26 species. The family of Fabaceae was the dominant family, and included 7 species which constituted the highest species distribution in the area (Fig.3.). Another dominant family was the family of Gramineae. This result is in good agreement with the other studies related to MDF, which found that the dominant family in MDF in the western region of Thailand consists in Fabaceae and Gramineaespecies [15].

Species with more than 50 individuals per hectare were *Milletiabrandisiang, Pterocarpusmacrocarpus, T. siamensis, Xanthophyllumlanceatum* and *Vitexcanescens* (Table 1.). In addition, *Brideliatomentosa* covered 23.672% of the total basal area, followed by *T. siamensis, V. carnescens, Xyliaxylocarpa,* and *Largerstroemiacalyxcomata*.

Fig.3. Mixed Deciduous Forest at this Study Area

The bamboo (*T. siamensis*) scored the highest IVI (130.343), followed by *V. canescens, Brideliatomentosa, X. xylocarpa, L. calyxcolata, and Dalbergiacultrata*, respectively (Table 1). Based on the IVI results, it was found that these species constitute the dominant species of the MDF in this area. Other species than these six had always an IVI lower than 10 (Table1).

It should be noted from [15, 16] that for the MDF in Kanchanaburi province, the *P.macrocarpus*was observed as the dominant species with an IVI of 34.40, followed by*X. xylocarpa* with 26.82, *Schleicheraoleosa* with 25.18, *Holarrhenapubescens* with 24.30, and *Berryacordifolia* with 19.62, respectively. Moreover, there were two dominant families of bamboo in Kanchanaburiprovince, including species such as *Bambusatulda, Gigantochloaalbaciliata, G. hasskaliana* and *Cephalostachyumpergracile*. Actually, the dominance of tree and bamboo species in MDF in the western region varies with the topography, weather conditions (e.g. amount of precipitation related to the rain shadow area of our study),altitude, and disturbances including forest fires in particular.

Diameter at Breast Height (DBH), Height (Ht), and Basal Area(BA) Distributionof the Studied MDF Vegetation

Table 2 displays the data of DBH and Ht obtained for the studied MDF.

The number of individual trees, sapling and *bamboo*were 450 ± 218individuals/ha, 383 ± 225 and 15,342 ± 1,903 culms/ha, respectively (Table 2). This result showed that this area had a high variation of vegetation composition. The mean DBH of tree, sapling and bamboo stem were 11.3, 3.02 and 2.44 cm, respectively. The mean height (Ht) of tree, sapling and bamboo stemwere10.53, 4.23 and 7.43 m, respectively (Table 2). The DBH distributions showed higher number of individuals of small size classes (4.5-20 cm), resulting in a small basal area as indicated in Table 1.Tree stands with DBH in the range of 20-40 cm are considered as having the highest capacity to sink carbon via photosynthesis process [4].

The DBHand Ht of each vegetation category from Table 2were used to estimate the above-ground biomass using the allometric equation (2) and (3).

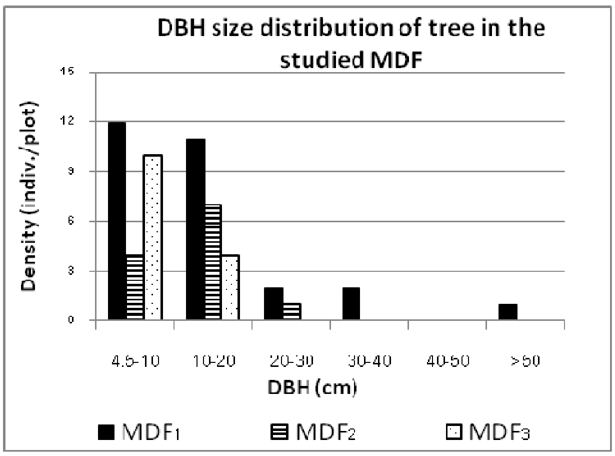


Fig.4. Tree DBH Distribution in MDF Plots

Above-Ground Biomass of Trees

The above-ground biomass of tree and sapling were estimated from 3 parts, i.e. stem, branch and leaf masses, of which the weights were 22.850 ± 18.095, 2.520 ± 2.006, and 0.477 ± 0.550 tons/ha, respectively (Table 3). The total above-ground biomass of tree was therefore25.847 ± 20.651 tons/ha.

In addition, it could be expected that the vegetation in this area should have an important potential of carbon sequestration, since trees were still young, and so should grow up to reach the adult size. In order to evaluate the future capacity of vegetation in carbon capture, the gross and net primary production should be estimated.

Above-Ground Biomass of Bamboo

The results showed that the *T. siamensis*was the major bamboo speciesin this study area. The density of *T. siamensis*was 15,342 ± 1,903 culms/ha, of which theDBH and Ht ranged from 1.29-5.87 cm and 2.00-21.70 m, respectively. The number of clumps were59 ± 32 clumps per plot, and each clump wascomposed of 12 ± 4 culms. The total aboveground biomass of *T. siamensis*was42.606±30.345 tons/ha, including 34.981 ± 25.148 tons/ha of culm, and 7.625 ± 5.197 tons/ha of branch plus leaf (Table 3).

Above-Ground Biomass of Understory and Litter

The understory vegetation was composed of seedling, herb, climber, and grass. The height of seedling was the highest, followed by that of herb, climber and grass, respectively. Their height varies with the structure and composition of living and dead vegetation types. The litter was consisted in leaf and small twigs, with about 4-6 and 1-4 cm depths, respectively. The ground was almost covered by bamboo leaves.

Carbon Stock of Above-Ground Biomass

The obtained above-ground biomass in this study resulted in a carbon stock of 36.44 ± 25.93 tons C/ha, which is of the same order of magnitude as those found in previous studies [3, 17, 20-22]. The comparison of the obtained above-ground biomass and carbon stock with those from literature is summarized in Table 4. For all, the conversion factor of 0.47, which represents an average value of carbon content in biomass, was used following the IPCC 2006 guidelines [13]. From Table 4, it should be noted that the carbon stock resulted from this study is significantly lower than those found in [11] and [19]. This result confirmed the important role of forest structure and vegetation species composition in influencing the amount of above-ground biomass and the associate carbon stock.

Table 3. The Above-Ground Biomass (AGB) of Different Vegetation Categoriesin MDF

Category	Sub-category	AGB (tons/ha)
Tree	Stem	22.850 ± 18.095
	Branch	2.520 ± 2.006
	Leaf	0.477 ± 0.550
Sapling	Stem	0.491 ± 0.021
	Branch	0.075 ± 0.004
	Leaf	<0.0001
Bamboo	Culm	34.981 ± 25.148
	Branch and leaf	7.625 ± 5.197
Biomass fuel	Understory	0.110 ± 0.060
	Litter	6.150 ± 2.640
	Small Twig	2.160 ± 1.440
Total AGB, ton/ha		77.539 ± 55.161

Another important parameter in varying the amount of above-ground biomass is the age of the forest. From Table 4, it could be indicated that the MDF in this study corresponds likely to a secondary MDF, whose carbon stock never exceeds 50 tons C/ha. This finding is plausible, since the studied MDF was frequently disturbed by rural communities, consisting in setting fires to facilitate their activities (e.g. gathering of non-timber forest product, preparation for hunting, etc.).To this parameter, should be added the influence of the topography, altitude, ecological structure of the vegetation, and the vegetative composition.

4. CONCLUSION

Thestructure of the MDF investigated in this study is composed of 14 families, 21 genus, and 26 species. *T. siamensis*is the most important species in Mae Nam Phachi Wildlife Sanctuary, Ratchaburi Province, Thailand. The results of DBH, Ht and density of vegetation showed that the forest area is mainly constituted of young trees, which is very characteristic of

Table 4.Above Ground Biomass (AGB) and deduced Carbon Storage of Mixed Deciduous Forest in Thailand

Study site	AGB (tons/ha)	C-stock (tons C/ha)	Ref.
Ratchaburi Province	77.54± 55.16	36.44± 25.93	This study
Kanchanaburi Province	68.52 ± 48.36 158.68	34.26 ± 24.18 74.58	[17] [19]
Kanchanaburi Province	96.28 ± 33.44	45.28 ± 15.72	[3]
Chaingmai Province	311 49.63 49.60	146.17 23.33 20.49	[11] [20] [21]
Lampang Province	57.50	27.03	[21]
Phetchabun Province	104.59[a] 50.95[b]	49.16 23.95	[22]

[a, b] primary and secondary mixed deciduous forest

a secondary forest. Additionally, the above-ground biomass includes high density of bamboo and about 50% of tree stands. The total carbon stock of the above-ground biomass in this study (i.e. tree, sapling, bamboo and biomass fuel as leaf litter, twig, seedling and understory as climber, grass, herb) amounts 36.44 ± 25.93 tons C/ha.

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