Carbon Sequestration Potential in Aboveground Biomass of Thong Pha Phum National Forest, Thailand

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Abstract: This study assessed the potential of carbon sequestration on aboveground biomass in the different forest ecosystems in Thong Pha Phum National Forest, Thailand. The assessment was based on a total inventory for woody stems at ≥ 4.5 cm diameter at breast height (DBH). Aboveground biomass was estimated using the allometric equation and aboveground carbon stock was calculated by multiplying the biomass with a 0.5 conversion factor. From the results, carbon sequestration among varied different types of forests. Tropical rain forest (Ton Mai Yak station) had higher carbon stock than dry evergreen forest (KP 27 station) and mixed deciduous forest (Pong Phu Ron station) with 137.73 ± 48.07, 70.29 ± 7.38 and 48.14 ± 16.72 tonne C/ha, respectively. In the study area, all forest types had a similar pattern of tree size class, with a dominant size class at ≥ 4.5 - 20 cm. The ≥ 4.5 - 20 cm trees potentially provided a greater carbon sequestration in tropical rain forest and dry evergreen forest while the size of > 20 - 40 cm gave potentially high carbon sequestration in mixed deciduous forest. In conclusion, the greatest carbon sequestration potential is in mixed deciduous forest followed by tropical rain forest and dry evergreen forest in Thong Pha Phum National Forest.

Key words: carbon stock, biomass, allometric equation, diameter at breast height, tropical rain forest, dry evergreen forest, mixed deciduous forest, ecosystem

Introduction

Increasingly convincing evidence shows that the earth is getting warmer and in the future warming could have serious effects on humans (Mann et al., 1998). The atmospheric concentration of carbon dioxide (CO_2), the primary and best studied greenhouse gas, has increased by about 30 % from the start of the industrial revolution till 1992 due to fossil fuel combustion and changes in land use (Mark and Thomas, 2001). The ultimate objective of The United Nations Framework, of which Thailand is a member, is to stabilize atmospheric greenhouse gas concentrations at a level that will not cause dangerous anthropogenic interference with the climate system. The reduction in emission of greenhouse gases by member industrialized countries was called for at the Kyoto Protocol. Thailand has ratified the Kyoto Protocol since August 28, 2002; therefore, the country will voluntarily participate in CO_2 reduction. There are two alternatives to reduce CO_2: decreasing carbon sources and increasing carbon sinks.

The world's forests are prominent sites to study climate change, not only in terms of total net carbon emissions but also in terms of global storage capacity, important for climatic regulation. Processes of nutrient uptake and cycling in forest ecosystems are highly influenced by changes in temperature or precipitation regimes as well as by changes in the atmospheric CO_2 concentration.

Therefore, this study is focusing on carbon sequestration, specifically in terms of aboveground biomass and carbon stock. The estimates of carbon stock are also important for scientific and management issues such as forest productivity, nutrient cycling, and inventories of fuel wood and pulp. In addition, aboveground biomass is a key variable in the annual and long term changes in the global terrestrial carbon cycle and other earth system interactions. It is also important in the modeling of carbon uptake and redistribution within ecosystems. Of most interest is live wood biomass, which is involved in the regulation of atmospheric carbon concentrations. Thus, its dynamics must be understood if annual spatial variations are to be related to spatial weather and climate variables. Other computations, which require an accurate estimate of biomass along with carbon emission and carbon sequestration rates, are defining the carbon status and flux in a given geopolitical

Table 1. Geographical coordinates of the study area and forest types at Thong Pha Phum National Forest.

Name	Location	Forest type	Number sampled plot
Ton mai yai station	1609720 N and 0470402 E	Tropical rain forest	3 (80 x 80 m^2)
KP 27 station	1613596 N and 0470585 E	Dry evergreen forest	4 (80 x 80 m^2)
Phong phu ron station	1619296 N and 0474970 E	Mixed deciduous forest	5 (50 x 50 m^2)

unit for the assessment, for example, of carbon taxes and similar international CO_2 mitigation measures.

Material and Methods

Study area

The study was located at Thong Pha Phum District, Kanchanaburi Province, Thailand which can be classified into three forest types as tropical rain forest, dry evergreen forest and mixed deciduous forest. Three sampling sites were selected, one from each of three forest types. The geographical characteristics of the sampling sites a recorded in Table 1 and Fig. 1

Aboveground biomass assessment was carried out in the three natural forests from November 2002 to April 2003. Average annual rainfall is 1,650 mm, with the rainy season normally running from April to October (Suksawang, 1995). Average annual temperature is 25 ^oC with temperature distributed the range of 9.3 ^oC to 42.2 ^oC in the natural forest. In the study area, the species area curves of all three forests were available at different densities and a square mesh of one plot. Each plot in tropical rain forest, dry evergreen forest and mixed deciduous forest had a square plot of 80 x 80, 80 x 80, and 50 x 50 m^2, respectively. Replications of plots in tropical rain forest at Ton Mai Yak were 3 plots, dry evergreen forest at KP 27 were 4 plots, and mixed deciduous forest at Phong Phu Ron station were 5 plots.

Aboveground biomass and carbon sequestration study

Three different forests were selected on the basis of total inventories for woody stems of DBH ≥ 4.5 cm. The SILVIC Program was used for tree height estimation (H_t) by using a minimum of 40 randomly selected trees of various sizes in the sample plots and following the equation Ogawa, Yoda and Kira (1961):

$$1/H_t = 1/A\,(DBH)^h + 1/H^*$$

Where Ht = height of tree (m)
DBH =diameter at breast height (cm)
A, h, H* =constant

After the trees were harvested, diameter and height were estimated with the SILVIC Program, and allometric regression equations were applied to the data to estimate the total aboveground biomass. Aboveground biomass was calculated by summing the stem, branches and leaf mass of individual trees, using the allometric equations of Tsutsumi et al. (1983) for tropical rain forest and dry evergreen forest, and Ogawa et al. (1965) for mixed deciduous forest, as follows:

Stem (Ws) $= 0.0509*(D^2H)^{0.91}$ Tsutsumi et al. (1983)
Branch (Wb) $= 0.00893*(D^2H)^{0.977}$
Leaf (Wl) $= 0.0140*(D^2H)^{0.669}$
And Stem(Ws) $= 0.0396*(D^2H)^{0.9326}$ Ogawa et al. (1965)
Branch (Wb) $= 0.003487*(D^2H)^{1.027}$
Leaf (Wl) $= ((28.0/WS + WB) + 0.025)^{-1}$

Where Ws = stem mass (kg/individual tree)
Wb = branches mass (kg/individual tree)
Wl = leaf mass (kg/individual tree)

The carbon content was calculated by multiplying the 0.5 conversion factors to aboveground biomass (Atjay et al., 1979; Brown and Lugo, 1982; Iverson et al., 1994; Dixon et al., 1994 and Cannell and Milne, 1995).

Results and Discussion

Aboveground biomass was estimated at the different forest types in order to indicate the proportion of biomass. It was found that DBH and height of trees were distributed among different size classes. The size class characteristics of three different forests a compared in Figure 2, and showing the relationship between DBH and tree density in each size class. This would tend to make the biomass differences even greater. The frequency distribution curves of DBH were all L- shaped, the frequency patterns were more or less exponentially decreasing toward larger diameter classes with a maximum at the left end or smallest DBH size classes.

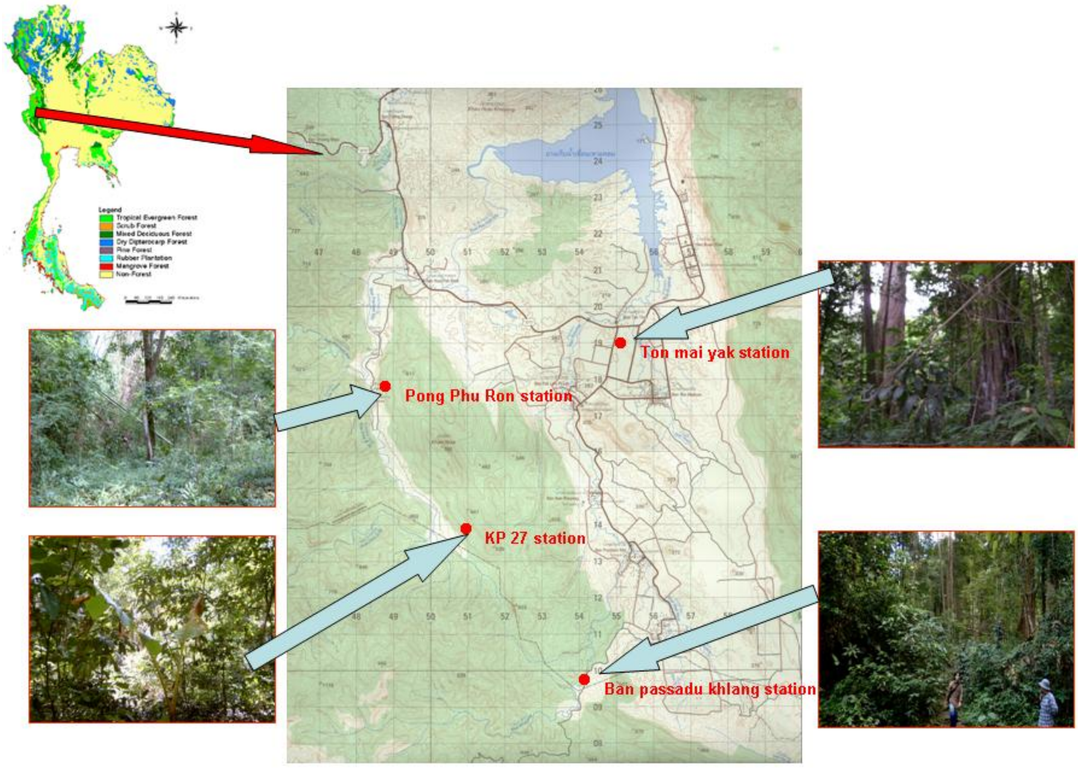

Figure 1. Location map of study area in Thong Pha Phum National Forest, Kanchanaburi Province, Thailand

Aboveground biomass accumulation was highest in tropical rain forest (Fig. 3), while the aboveground biomass in dry evergreen forest was lower than mixed deciduous forest at DBH size class over 100 cm. Although mixed deciduous forest had the highest numbers of trees and species, most trees were smaller than 20 cm in a typical uneven-aged stand resulting in the lowest individual volume and biomass. The main conclusion was that there was an opposite relationship between biomass and tree size class. The most aboveground biomass accumulation was found in big trees of size classes ≥ 80 –100 and ≥ 100 cm. Because these trees had the highest stem volume and large diameter, they also had the lowest numbers of tree densities.

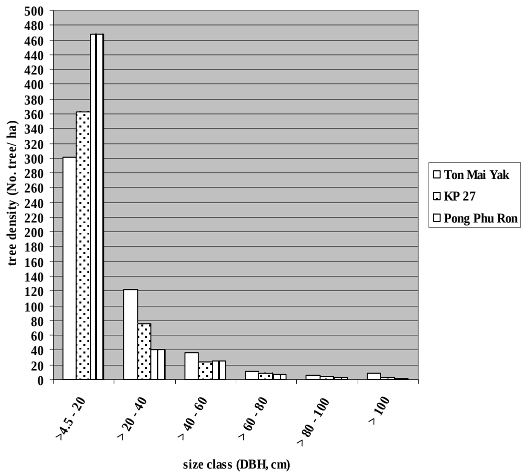

Figure 2. Tree density in different size classes at Ton Mai Yak station, KP 27 station, and Pong Phu Ron station sampling sites

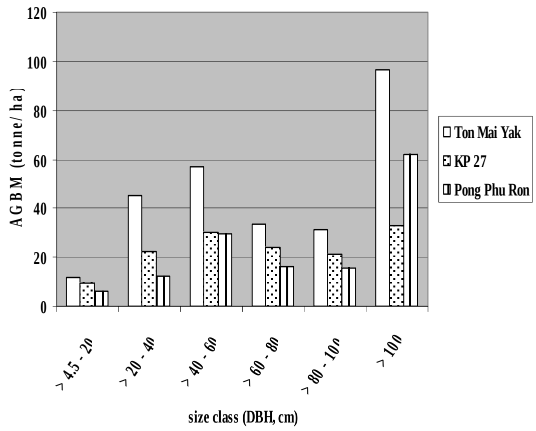

Figure 3. Aboveground biomass in different tree size classes in sampling sites

Table 2. Comparison of tree density and carbon sequestration potential in each size class in the different study sites

Size class (cm)	Tropical rain forest Ton Mai Yak station		Dry evergreen forest (KP 27 station)		Mixed deciduous forest (Pong Phu Ron station)	
	Tree density (%)	C-storage (%)	Tree density (%)	C-storage (%)	Tree density (%)	C-storage (%)
≥4.5 – 20	62.0	4.2	76.22	6.71	85.88	4.49
>20 – 40	25.2	16.5	15.74	16.05	7.50	8.82
>40 – 60	7.4	20.7	5.01	21.42	4.56	20.83
>60 – 80	2.4	12.1	1.64	17.03	1.18	11.31
>80 – 100	1.3	11.4	0.82	15.19	0.59	10.89
>100	1.7	35.2	0.58	23.61	0.30	43.67

The percentage data of tree density and aboveground biomass a presented in Table 2 and show a similar pattern of tree density and aboveground biomass in each size class. In the sample plot, all forests had a dominant size class at ≥ 4.5 – 20 cm, which accounted for 85.88, 76.22 and 61.98 % at Pong Phu Ron station, KP 27, and Ton Mai Yak station, respectively. On the other hand, this size class in all forests had the lowest aboveground biomass accumulation ranging from 4.17 – 6.71% of the total biomass density in this study, due to low stem volume, low basal area and short trees with small diameters.

Comparison of the size class distribution and aboveground biomass showed some evidence of biomass reduction in larger size classes, > 60 – 80 and > 80 – 100 cm, resulting from selective logging in this area. Logging in excess of regrowth is also a significant cause of loss, particularly in Asian forests (Stiling, 1999) and usually destroyed the small sizes of trees during the tree felling and log dragging process (Gajaseni, 2000), which reflected the reduction of classes > 20 – 40 and > 40 – 60 cm size classes in the mixed deciduous forest. In the sample plot, all forests had a similar pattern of tree size class, with a dominant size class at ≥ 4.5 – 20 cm.

Carbon sequestration potential in the different forest types seems to be related to DBH size class (Table 2). In the tropical rain forest and dry evergreen forest, the main tree size classes that had great potential in carbon sequestering were from small up to medium tree size at ≥ 4.5- 20 up to >40 – 60 cm. On the other hand, the main tree size classes that had the highest potential in carbon sequestering in mixed deciduous forest from small up to medium tree size at >20- 40 cm up to > 40 – 60 cm.

For example, in Ton Mai Yak station, the smallest tree in size class ≥4.5 – 20 cm had biomass accumulation or carbon sequestration potential of only 4.2 %. When trees grow up considerably to the next size class at >20 – 40 cm, these trees had the highest carbon sequestration potential. For the size class at >40 – 60 cm, trees had a high carbon sequestration potential but not as much as in size class at >20 – 40 cm. In accordance with dry evergreen forest, trees in size class ≥ 4.5- 20 cm were able to grow fast and store more carbon, while trees in mixed deciduous forest had potential to grow fast and store more carbon at size class of > 20- 40 cm.

The results of aboveground biomass and carbon sequestration in Table 3 show the average aboveground biomass in Ton Mai Yak station (tropical rain forest), KP 27 station (dry evergreen forest) and Pong Phu Ron station (mixed deciduous forest) was 275.46±96.15, 140.58±14.76 and 96.28±33.44 tonne/ha, respectively. Aboveground biomass varied from plot to plot in forest area due to there being different stages of the forest growth cycle, habitat variation, and tree density. The stem weight, especially the tree biomass of bigger trees, is the largest component of a forest's biomass (Ogawa et al., 1965).

In this study, the results included only the tree components of aboveground biomass. In general, root biomass is approximately 25 % of aboveground biomass (Cairns et al., 1997), so the calculated root biomass in Ton Mai Yak station, KP 27 station and Pong Phu Ron station are about 68.87, 35.15, and 24.07 respectively.

Carbon content was calculated from aboveground biomass with the method used by Atjay et al. (1979), Brown and Lugo (1982), Iverson et al. (1994), Dixon et al. (1994) and Cannell and Milne (1995). Carbon content would be about 50% of the amount of total aboveground biomass. Therefore, the aboveground carbon sequestration of the three

Table 3. Aboveground biomass of trees and carbon sequestration at the three study sites

Study sites	Tree density (No./ha)	Stem mass (tonne/ha)	Branch mass (tonne/ha)	Leaf mass (tonne/ha)	Total AGBM (tonne/ ha)	Carbon sequestration (tonne C/ ha)	Calculate root biomass* (tonne C/ ha)
Ton Mai Yak station	745 ± 142.3	217.241± 52.62	54.667± 40.960	3.554± 0.790	275.46± 96.15	137.73± 48.07	34.43
KP 27 station	560 ± 68.9	103.391± 11.16	34.911± 30.487	2.297± 0.493	140.58±14.76	70.29±7.38	17.57
Pong Phu Ron station	544 ± 98.3	110.256± 50.63	30.657± 29.96	0.151± 0.005	96.28±33.44	48.14±16.72	12.03

Note: root biomass* is approximately calculated as 25% of aboveground biomass (Cairns et al., 1997)

forest types were calculated for Ton Mai Yak station as 137.73±48, followed by KP 27 and Pong Phu Ron stations as 70.29±7.38 and 48.14±16.72 tonne C/ha respectively (Table 3).

Data on carbon sequestration in the different forest types showed that the highest amount of carbon was stored in the biomass of tropical rain forest at Ton Mai Yak station. Because tree sizes at Ton Mai Yak station were quite large when compared to other stations then calculated carbon sequestration is the highest at this station. It does not mean that other forest types are not important, because the main groups of small tree sizes at ≥ 4.5 – 20 cm will grow to bigger size in the near future. They will have greater potential for future sequestration if the forests are under appropriate management without human disturbance. Huston and Marland (2003) showed that carbon sequestration depended not only on rates of productivity but also on the size of the tree. Disturbance of landscapes can result in rapid release of large amounts of carbon that will be recaptured slowly as forest regrowth.

In Table 4, comparison of biomass accumulation and carbon sequestration in various forest types showed that the largest biomass was in the tropical rain forest and the lowest biomass in the mixed deciduous forest. The results from this study showed the range of aboveground biomass in tropical rain forest, dry evergreen forest and mixed deciduous forest as 275.46, 140.48, and 96.28 tonne/ ha, with calculated carbon sequestration as 137.73, 70.29, and 48.14 tonne C/ha. Ogawa et al. (1965) reported aboveground biomass data of different forests in Thailand such as tropical rain forest, dry evergreen forest and mixed deciduous forest at 358, 126 and 311 tonne/ ha, with calculated carbon sequestration as 179, 60.30, and 155.50 tonne/ha, based on direct measurement by a destructive method in tropical rain forest in the Forest Reserve of Khao Chong, Trang Province of peninsular Thailand, as well as dry evergreen forest and mixed deciduous at Ping Kong, Chiang Mai Province. As the results of this study show, carbon sequestration was considerably lower

Table 4. A schematic comparison of aboveground biomass and carbon sequestration in different forest types between this study and other studies

	Tropical rain forest		Dry evergreen forest		Mixed deciduous forest		Source
	AGBM (tonne/ha)	C-stock (tonne C/ha)	AGBM (tonne/ha)	C-stock (tonne C/ha)	AGBM (tonne/ha)	C-stock (tonne C/ha)	
Thailand	275.46	137.73	140.58	70.29	96.28	48.14	This study
Thailand	358	179	126	60.30	311	155.50	Ogawa et al. (1965)
Thailand	-	-	252	126	-	-	Drew et al. (1978); cited in Gajaseni (2000)
Thailand	-	-	-	-	31.95-87.75	15.97-175.50	Viriyabuncha et al. (2002)
Malaysia	225-446	112.5-223	-	-	-	-	Brown and Lugo (1982)
Cameroon	238-341	119-170.5	-	-	-	-	
Sri Lanka	153-221	76.5-110.5	-	-	-	-	

than for the Ogawa et al. study, which may suggest that these forests were more disturbed and affected by change in forestland due to different initial study times, site qualities, and carbon sequestering carrying capacities, and reflected that the tropical rain forest in this study was an immature forest. Flint and Richards (1996) reviewed estimates of carbon sequestration in Southeast Asia including India, Thailand, Cambodia, Malaysia and Indonesia ranging from 17.5 tonne C/ha or less in severely degraded tropical dry forest to almost 350 tonne C/ha in relatively undisturbed mature tropical rain forest. The lower biomass values often reflected immature forest.

Brown and Lugo (1982) summarized the total carbon sequestration estimates of tropical forest in three countries including Malaysia, Cameroon and Sri Lanka, ranging from 76.50 tonne C/ha in disturbed tropical rain forest to 223 tonne C/ha in relatively undisturbed mature tropical rain forest with, based on direct measurement, the highest being in Malaysia (112.5 - 223 tonne C/ha), followed by Cameroon (119 – 170.5 tonne C/ha), and Sri Lanka (76.5 – 110.5 tonne C/ha). Biomass lower than those of other forest areas often reflected an immature forest, which may suggest that it was due to human population pressure.

Comparison of the carbon sequestration of tropical rain forest between this study and the study by Brown and Lugo (1982), show that the average total aboveground biomass in Thailand was 137.73 tonne C/ha, which is in the range of carbon sequestration in Malaysia and Cameroon. From annual precipitation data of Thailand, Malaysia and Cameroon as 1400, 2000 and 3000 mm/yr., respectively, this possibly caused the differences in carbon sequestering capacity (Brown and Lugo, 1990).

Another factor that possibly caused the amount of sequestered carbon to be lower than the other forest areas is tree height. Ogawa et al. (1965) reported that the calculated carbon sequestration of tropical rain forest at Khao Chong Forest Reserve, Thailand was 179 tonne C/ha and lower than calculated biomass from Malasia because of the difference in tree height. The tallest tree actually measured there was only 36 m in height, whereas the maximum tree height of tropical rain forest in Malaysia often reaches 60 m (Ogawa et al., 1965). Therefore, plant biomass in Malaysia was greater than here. Thus, the accuracy to estimate biomass by using allometric equations containing both diameter and total height was better than diameter alone.

Chittachumnonk et al. (2002) studied carbon sequestration of Teak plantations in Thailand. There were four study areas located in northern and western regions included Mae Mai Plantation at Muang District, Lampang, Thong Pha Phum Plantation at Thong Pha Phum District, Kanchnaburi, Sri Satchanalai Platation at Sri Satchanalai District, Sukhothai, and Khao Kra Yang Plantation, Wong Thong District, Phitsanulok. The study showed that all aboveground biomass of Teak plantations was equal to 78.15 tonne/ha or equivalent to 646,997.19 tonne of total aboveground biomass of the total study area which was 8,278.50 ha. In the estimate of carbon sequestration of Teak plantation were 39.08 tonne C/ ha. The carbon sequestration in Teak plantation was seemingly near to that of the natural mixed deciduous forest (48.14 tonne C/ha).

Viriyabuncha et al. (2002) studied the evaluation system for carbon storage in forest ecosystems in Thailand. The result showed that carbon sequestration at Doi Suthep – Pui National Park, Chiang Mai, evergreen forest and mixed deciduous forest were in the range 15.97 – 87.75 tonne C/ha. The maximum biomass was found in dry evergreen forest because it was old forest and illegal logging had been strictly controlled. The minimum carbon sequestration was found in dry dipterocarp forest, which was a young forest. The study also showed carbon storage of mixed deciduous forest was in the range 15.97 – 87.75 tonne C/ha. Comparison of the carbon sequestration from this study and Viriyabuncha et al. (2002) indicated a similar range and pattern in that tropical rain forest sequestered carbon at higher rates than dry evergreen forest and mixed deciduous forest as 137.73, 70.29 and 48.14 tonne C/ha, respectively. It indicated that carbon sequestration varies among forest types and ages of forest and that carbon sequestration potential relies on tree size class. Mixed deciduous forest with tree sizes at > 40 – 60 cm had trend of carbon sequestration more than other size classes, while size class at > 20 – 40 and > 40 – 60 cm in dry evergreen forest and tropical rain forest had more carbon sequestration than other size classes.

In conclusion from biomass and carbon sequestration studies, under different levels of disturbance, old – growth forest had more carbon sequestration than logged forest and secondary forest, respectively. Each size class had a different carbon sequestration potential. Most small up to medium sizes of trees had a greater potential for carbon sequestering than big trees due to the forest type because the growth rate is slower in bigger trees. Therefore, conserving and managing small trees at ≥ 4.5 – 20 and > 20 – 40 cm can considerably increase carbon sequestration potential in the near future. If the forest is deforested and changed by human activities, it will potentially cause severe carbon loss to the atmosphere from terrestrial ecosystems in relation to deforestation. In summary, the estimation of aboveground biomass is based on data sets that consider only live trees, and do not consider litter or standing dead trees. Tropical forests tend to carry their biomass in the standing crop relatively more than temperate forests. Therefore, tropical forest inventories, which ignore dead matter, will only have a small loss of proportion to total aboveground biomass than similar inventories in the temperate zone. According to carbon sequestration potential, it is clear that tropical forests are more effective in carbon sequestering than temperate forests due to net productivity differences (Johnson and Sharpe, 1983; cited in Brown et al*.*, 1989). Then tropical forest can play a major role in carbon dioxide reduction as a carbon-sink.

Conclusion

Carbon sequestration varies among forest types and ages of forest and carbon sequestration potential relies on tree size class. Tropical rain forest has the highest potential for carbon sequestration and followed by dry evergreen forest and mixed deciduous forest. Tree sizes in mixed deciduous forest at > 40 – 60 cm has trend of carbon sequestration potential more than other size classes, while size classes at > 20 – 40 and > 40 – 60 cm in dry evergreen forest and tropical rain forest has more carbon sequestration potential than other size classes. This evidence indicates the potential for growth to reach the climax stage of succession in the near future. These smaller trees do not have the highest carbon sequestration potential but they are relevant in terms of their future potential to grow up. With high carbon sequestration potential in Thong Pha Phum National Forest, the Ministry of Natural Resources and Environmental must urgently consider to strictly protect and conserve these forests for sequestering atmospheric CO_2, which can increase the carbon sink in natural forest. So, Thailand can contribute to reducing the problem of greenhouse effects regarding global warming and climate changes.

The problem in this study was that the available data on carbon sequestration in tropical forests were extremely limited and incomplete. In some cases, inappropriate field measurements may have been taken. As a result forest biomass may be significantly under - or overestimated. To resolve these uncertainties will require both improved practices with current field methods and new techniques for measuring processes to understand the carbon dynamics of the world's forests.

Acknowledgements

This work was supported by the TRF/BIOTEC Special Program for Biodiversity Research and Training and PTT Public Company Limited grant BRT T_346002.

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