COMPILATION OF THE FOREST BIOMASS/PRODUCTION DATASET FOR ASSESSING CARBON STORAGE IN FORESTS OF THAILAND

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For the reliable assessment of carbon accumulation in the forests of Thailand, this study aims to compile and analyze a dataset related to forest biomass and net primary productivity (NPP) of forests in Thailand. The following two procedures were applied for data collection: 1) literature reference, and 2) field survey in case study sites. The case study sites were set in western Thailand and biomass/NPP were estimated for various types/stages of forest stands. Analysis of these data proved the single allometric relation between basal area (BA) and aboveground biomass (AGB) for almost all types of broadleaved forests in Thailand, which enable to convert the BA in literature to AGB estimates. Furthermore, we found exponential relationships between the top-canopy height (TCH) and AGB for deciduous forests, which enable us to make a rough estimation of AGB from the simple survey of TCH. Finally, we demonstrated biomass-density-distribution mapping for an area of 3 km x 3 km at a test site in Kanchanaburi, where the deciduous type forests are prevailing, by the TCH classification from aerial photographs and field observation.

Introduction

The global terrestrial carbon models demonstrated that deforestation in the tropics is a significant source of atmospheric carbon dioxide (Houghton *et al.* 1985, Detwiler and Hall 1988). However, Lugo and Brown (1992) recently estimated that the accumulation of carbon in the recovering landscape from disturbance was even equal to the net carbon flux due to tropical deforestation. Uncertainty in the results from these models arises from following two major sources: (1) the biomass density (or carbon content) of tropical forests and (2) the rate of land use changes (Brown *et al.* 1989). The difference of models in essential between Lugo-Brown's and others is whether they consider all tropical forest lands as in carbon steady state or not. Today very few undisturbed forests, which are considered to be in carbon steady state, cover the forest area of Thailand. A terrestrial carbon

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model should consider this actual state of forest lands. Recently, actual forest biomass in the tropical Asian region has been evaluated from the forest inventory data (Iversion *et al.* 1994). To quantify forest degradation, however, national forest inventories of all forest classes done at regular intervals are needed, and such data exist in the tropical Asian region only for Peninsular Malaysia (Brown *et al.* 1994). For the region without such a systematic forest inventory, an alternative but simple tool for estimating forest biomass is needed. For this purpose, we compile a forest biomass and production dataset and analyze the relationships among forest biomass and other forest properties to find a simple tool for estimating forest biomass. We present here a simple method for estimating forest biomass and demonstrate biomass-density-distribution mapping for a case study area (3 km x 3 km) with the scale of 1/20,000, which provide a basic tool to quantify forest degradation.

Methods

Data collection from literature reference

Literature on forest stand biomass (or basal area) and/or net primary productivity of forests around Thailand was collected and compiled into a database. In this paper, we focus on natural or naturally-growth forests only (plantations were not included). Database format was designed following "World Forest Biomass and Primary Production Data" (Cannell 1982). Forest types were classified as follows: Mixed deciduous forest (MDF), Dry dipterocarp forest (DDF), Dry evergreen forest (DEF), Hill evergreen forest (HEF), Tropical rain forest (TRF), Mangrove forest (MF) and Pine forest (PF).

Data collection from field survey

Field survey sites and methods

In March 1995, study sites were set in the Erawan National Park and the Mae-Klong Watershed Research Station in western Thailand (Figure 1). Here, we focus on only the deciduous type forests, such as MDF and DDF. Eleven plots for biomass survey were set in stands with various developmental or degraded stages, such as forest fallow, secondary forest after logging, bamboo dominated stand, and old-growth forest. The size of the survey plots was varied from 20 m x 20 m to 40 m x 40 m according to the canopy height of a stand. All trees (> 5 cm in dbh) and bamboos (> 3 cm in dbh) were measured for dbh. 20 - 30 sample trees with various dbh size were selected randomly for height measurement. Hand-made dendrometers were set on all trees larger than 10 cm in dbh for measuring accurate increment. Seven plots were set in March 1995 and dbh of trees (> 5 cm in dbh) and height of same sample trees were remeasured in December 1995 (after a growing season). Additional four plots were set in December 1995.

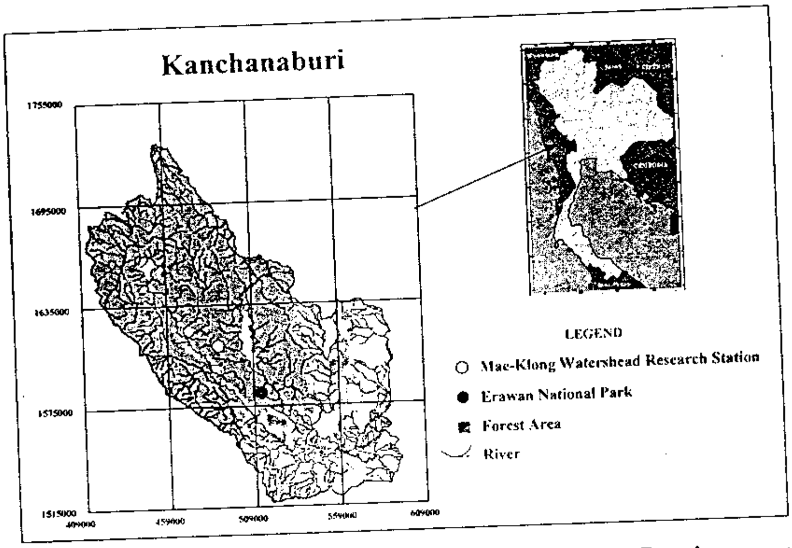


Figure 1. Location of the study sites in Kanchanaburi Province, western Thailand.

Estimation of aboveground biomass(AGB) and net primary production(NPP)

The published allometry equations which estimates single tree dry weight from D^2H or D are used for census data of this field survey. For trees, we employed the allometric equations determined by Ogawa *et al.* (1965) for MDF stand and by Ogino *et al.* (1967) for DDF stand in Thailand. The allometric equations for bamboo species are obtained from Suwannapinunt (1983) for *Thyrsostchys siamensis* and Kutintara *et al.* (1995) for *Bambusa tulda*, *Cephlostachyum pergracile*, *Gigantchloa albociliata and G. hasskariana*. Since the allometry for *B. arundinaceae* is unknown, that for *B. tulda* was adopted here. However, because the allometric equation of leaf weight is known for only *T. siamensis* (Suwannapinunt 1983), leaf biomass (LB) of bamboo in a stand is calculated assuming LB = 0.0236AGB, which is an average ratio for *T. siamensis* in the surveyed plots. For the estimation of the net primary production (NPP), we assumed that the annual leaf litter fall is equivalent to LB of a stand, which is estimated from the allometric equations, and the annual branch litter fall is 0.3825 * LB (Ogino *et al.* 1967). Ogino *et al.* (1967) applied this assumption for trees in a DDF stand but here we adopted this assumption not only for trees in DDF stands but also for trees and bamboos in MDF stands.

Biomass-density-distribution mapping

The case study area (3 km x 3 km) for biomass-density-distribution mapping was set in the Maeklong Watershed Research Station. The 1/15,000 scale topographic map of this area was used for this purpose. First, the vegetation of study area was divided from the aerial photographs taken in 1984 (1/10,000) and 1985 (1/20,000) into the following four types: forest (tree height > c.10 m), bamboo or bush (tree height < c.10 m), fallow (glass, banana) and agriculture area or bare land. Then, forest area was classified into the following three subtypes according to the top canopy height (TCH) which was roughly estimated from the aerial photographs and field observations: closed forest (c.30 m < TCH < c.40 m), secondary forest (c.20 m < TCH < c.30 m) and open forest(c.10 < TCH < c.20 m). In this study, TCH is found to be a practical tool for estimating forest biomass. This mapping for the case study area was done as a state of 1985.

Results

Data collection

Literature references

Data from 27 stands was obtained from Master Thesis' of Kasetsart University and dat from 14 stands were from original papers (Cannell 1982, Ogino *et al.* 1967). More than half of them measured or estimated AGB but only several papers recorded NPP.

Field survey

AGB and NPP estimates, and general information of 11 field survey plots in Kanchanaburi Province are listed in Table 1. Nine plots were the MDF type stand including secondary forests, two plots were the DDF type stand. NPP was estimated for 7 plots (6 in MDF). The range of AGB was 40.0 - 356.6 Mg/ha, while that of NPP rate was estimated as 5.7 - 19.6 Mg/ha/year.

Some allometric relationships among stand properties

Basal area(BA) - AGB

The field survey data (MDF and DDF in Kanchanaburi) shows the closed allometric relationships between BA and AGB for both tree and bamboo (Figure 2). The tree data from whole Thailand including both deciduous and evergreen forest types shows a single allometric line, which is almost the same as that of the Kanchanaburi MDF/DDF data, between BA and AGB (Figure 3). These relationships are expressed as follows:

Kanchanaburi (this study) [MDF, DDF: n=11 (tree), n=9 (bamboo)]
AGB (tree > 5 cm dbh) $= 2.8318BA^{1.286}$ $R^2=0.9745$
AGB (Bamboo > 3 cm dbh) $= 4.4752BA^{0.9164}$ $R^2=0.8609$
Whole Thailand (all broadleaved stands: n=50)
AGB(tree > 5 cm dbh) $= 2.9743BA^{1.2204}$ $R^2=0.8906$

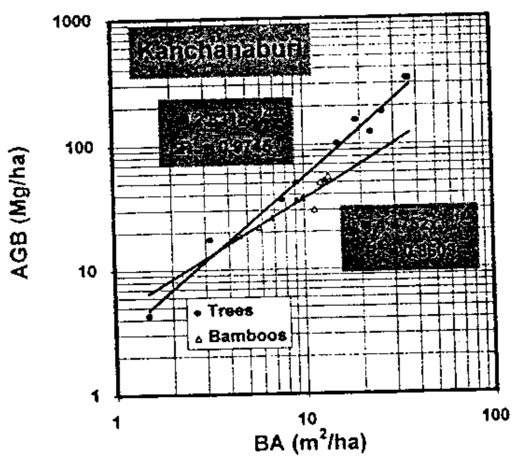


Figure 2. Relationships between basal (BA) aboveground biomass (AGB) for trees and bamboos in survey plots (Kanchanaburi).

Top canopy height (TCH) - AGB

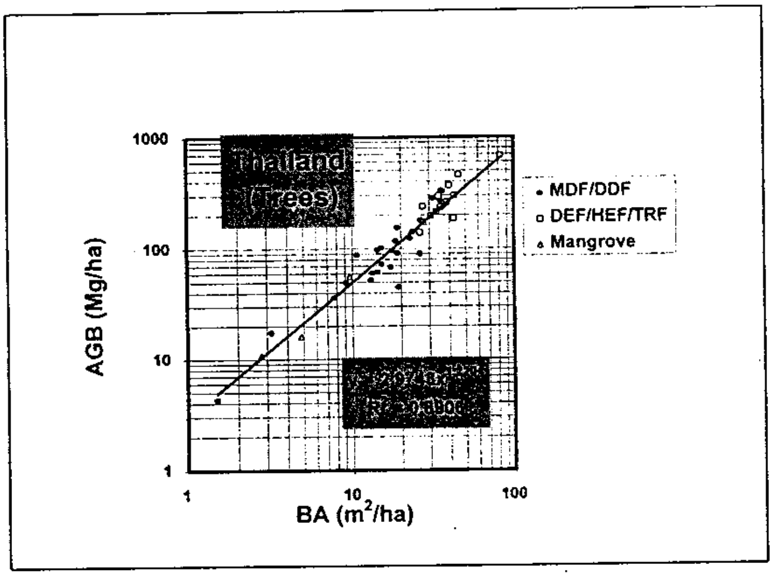
As shown in Figure 4, the field survey data in Kanchanaburi (MDF, DDF) demonstrates the exponential relationship between TCH and AGB (including tree and bamboo). The data from the whole of Thailand for deciduous forest (MDF, DDF) also showed the very similar relationship as seen in the Kanchanaburi data (Figure 5). On the contrary, ever-green forest types did not show such relationship but the ratio AGB/TCH in evergreen forests is much higher than that in the deciduous forests. The TCH - AGB relationship for deciduous type forests is expressed as follows:

Table 1. Summary of above ground biomass (AGB) and net primary production (NPP) estimates of natural forest stands at Erawan(Er) and Mae-Klong (MK) survey sites in Kanchanaburi. (Biomass: December 1995; NPP: March - December 1995)

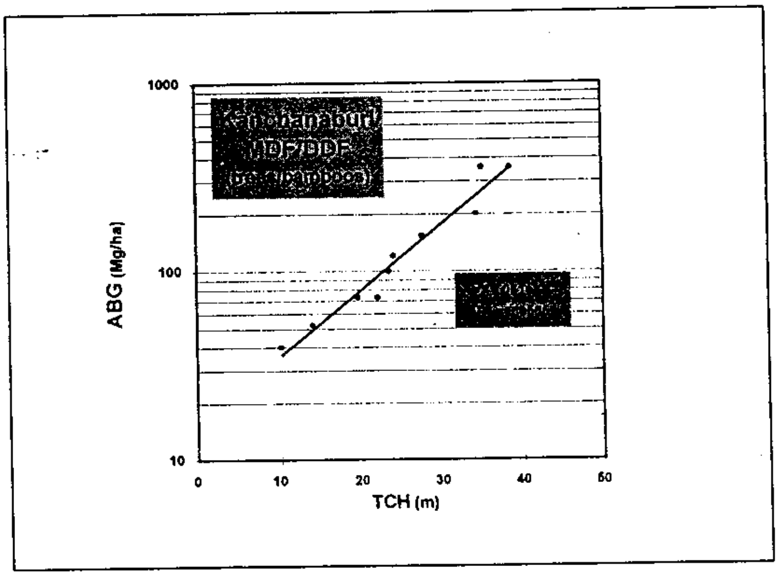
Plot No.	General information									Trees (> 5 cm in dbh)							Bamboos			AGB	NPP*
	Latitude (N)	Longitude (E)	Alt. (m)	Slope (Deg)	Azim. (Deg)	Plot size (m x m) Trees	Plot size (m x m) Bamboos	Forest type	Status	TCH m	DBH Max,cm	BA m²/ha	LB Mg/ha	LA m²/ha	AGB Mg/ha	NPP* Mg/ha	BA m²/ha	AGB Mg/ha	NPP* Mg/ha	Mg/ha	Mg/ha
Er-1	14'19'31	99'08'12	520	0		40x40		DDF	Old growth	23.5	97.3	22.9	2.3	1.8	123.5	5.7	-	-	-	123.5	5.7
Er-2	14'21'29	99'08'10	520	0		40x40		MDF	Old growth	24.0	63.4	15.2	1.8	1.8	101.8	4.0	4.56	18.7	2.9	120.5	6.9
Er-4	14'21'01	99'08'13	520	0		40x40		MDF	Old growth	34.3	121.2	26.5	2.7	3.0	178.8	8.9	5.78	21.9	10.7	200.7	19.6
Er-5	14'22'39	99'07'20	390	4	N13W	20x19.95	19.95x10 bamboo	MDF	Secondary growth (logged)	23.4	34.2	9.2	1.4	1.7	49.7	-	12.27	50.1	-	99.8	-
Er-6	14'21'51	99'07'32	420	8	S80W	20x19.81	19.8x20 bamboo	MDF	Secondary growth (logged)	19.6	22.5	7.7	1.2	1.6	36.1	-	9.84	37.0	-	73.1	-
Er-7	14'22'02	99'07'42	460	6	N10W	30x29.84		DDF	Old growth	27.6	52.5	19.1	2.8	2.0	154.1	-	-	-	-	154.1	-
Er-8	14'22'33	99'08'55	90	26	S27W	20x17.98	10x8.99 bamboo	MDF	Young growth (Logged or cleared)	10.2	12.7	1.5	0.1	0.2	4.3	-	9.25	35.7	-	40.0	-
Mk-1	14'34'24	98'50'44	100	15	S50W	25x28.98	5x28.98 bamboo	MDF	Old-growth	38.5	112.4	35.6	2.5	2.2	330.6	8.2	6.78	25.8	7.6	356.4	15.8
Mk-2	14'35'26	98'51'25	240	25	N10E	20x18.13		MDF	Young growth (11 yrs after cultivation)	14.0	27.5	13.1	1.7	2.3	52.0	11.4	**	**	**	52.5	11.4
Mk-3	14'34'58	98'51'09	180	16	S28W	30x28.84	10x28.84 bamboo	MDF	Secondary growth (logged)	22.0	30.4	3.2	0.5	0.6	17.4	1.0	13.54	55.8	6.4	73.2	7.4
Mk-4	14'34'33	98'51'25	230	23	S85E	30x27.62	10x27.62 bamboo	MDF	Old-growth	35.0	128.1	36.6	2.7	2.4	326.6	5.2	11.39	30.0	5.3	356.6	10.5

* NPP is tentatively calculated assuming that litter production is 1.3825LB. For bamboo, we assumed LB = 0.0236AGB.

** There are a small number of *Musa acuminata* (wild banana) plants in Mk-2 but their biomass is less than 5 % of total AGB.



gure 3. Relationship between basal area (BA) and aboveground biomass (AGB) for trees. Data includes various broadleaved forest types, such as MDF, DDF, DEF, TRF, HEF and mangrove forest from all over Thailand.



'igure 4. Exponential relationship between top canopy height (TCH) and aboveground biomass (AGB) for survey plots in Kanchanaburi (MDF/DDF).

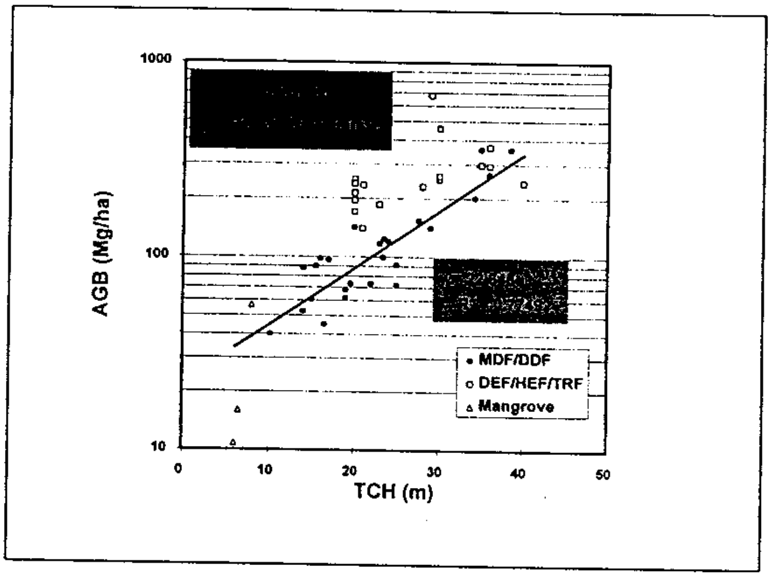


Figure 5. Relationships between top canopy height (TCH) and aboveground biomass (AGB) for various forest types. Data includes various broadleaved forest types, such as MDF, DDF, DEF, TRF, HEF and mangrove forest from all over Thailand. The regression line is drawn for deciduous forests (MDF, DDF).

Kanchanaburi(this study) (MDF, DDF: n=11)

$AGB = 16.061e^{0.0803TCH}$ $R^2=0.9555$

Whole Thailand(MDF, DDF: n=33)

$AGB = 22.645e^{0.067TCH}$ $R^2=0.7749$

AGB - leaf biomass(LB)

Figure 6 presents the allometric relationships between AGB and LB for both deciduous forests(MDF, DDF) and evergreen forests(DEF, HEF, TRF). The slopes of these lines in logarithmic scale are less than 1, which implies that LB tend to saturate with increase of AGB. The ratio LB/AGB is apparently higher in evergreen forests.

Deciduous forests(MDF, DDF)

$LB = 0.4526AGB^{0.3255}$ $R^2=0.4812$

Evergreen forests (DEF, HEF, TRF, MF)

$LB = 0.2348AGB^{0.6037}$ $R^2=0.8701$

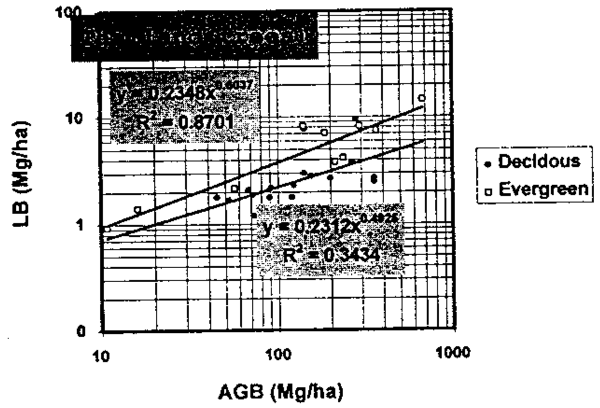


Figure 6. Difference of relations of aboveground biomass (AGB) to leaf biomass (LB) between deciduous type and evergreen type of broadleaved forests in Thailand.

AGB - NPP

Although very few NPP data is available at the present, AGB - NPP relationships for both deciduous type forests(MDF, DDF) and evergreen type forest (TRF, DEF, HEF, MF) are shown in Figure 7 in which data from India (deciduous mixed forests) and Malaysia (tropical rain forests) (Cannell 1982) were also plotted. This figure shows that NPP rates of evergreen forests are higher than those of deciduous forests. In addition, NPP seems to reach a peak at AGB around 200 - 300 Mg/ha for both deciduous and evergreen forests, but much more data is necessary to conclude.

Biomass-density-distribution mapping

From the TCH - AGB relationship for deciduous type forests, the vegetation of the case study area (forest types are mainly MDF but partially DDF) were classified into six levels of biomass-density by classification of TCH from the aerial photographs of 1984 (1/10,000) and 1985(1/20,000) and field observation. The biomass of agricultural crops, such as maize and cassava, is assumed less than 10 Mg/ha. The map (Figure 8) shows the biomass-density-distribution estimated for 1985.

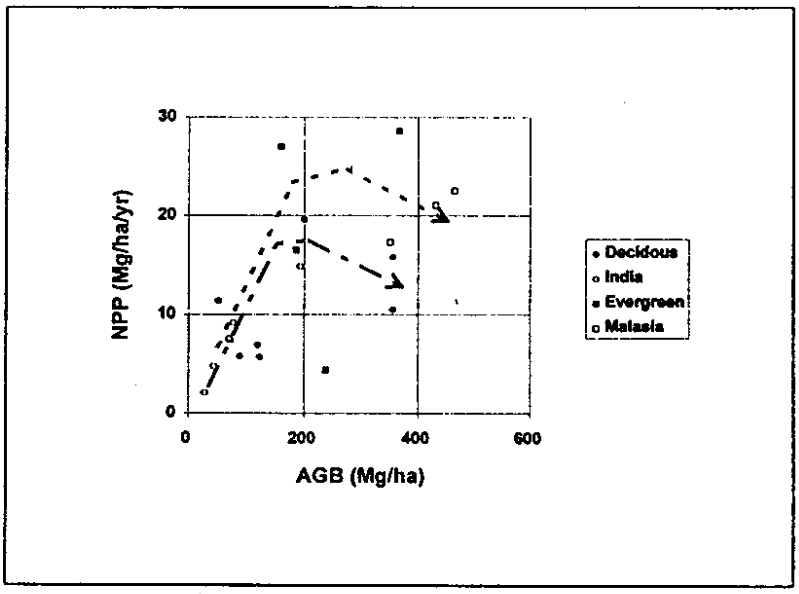


Figure 7. **Net primary production (NPP) rates plotted against the aboveground biomass (AGB). Data includes the Indian mixed deciduous forests and Malaysian tropical rain forests.**

Discussion

Importance of bamboo in relation to total stand AGB

Bamboos dominates in the stands with small AGB (Figure 9). The AGB ratio of bamboo/total is less than 10 % for the stands with large AGB(> 300 Mg/ha) but more than 50 % for the stands with small AGB(< 100 Mg/ha). These results suggests that we cannot neglect bamboo biomass for biomass estimation of MDF stands, especially for small - medium stocked stands (AGB < 300 Mg/ha).

Tools for conversion of forest inventory data to AGB

The allometric relationship between basal area and AGB for most broadleaved forests with various developmental/degraded stages is useful for the simple estimation of AGB from BA in the literature or from forest inventory. The equation for bamboos examined only 9 stands but including 5 species with different sizes. Furthermore, an exponential relationship between TCH and AGB for deciduous type forests enables to make a rough estimation of AGB from a simple survey of TCH.

Vegetation class	Maximum height(m)	Biomass density (Mg/ha)	(median)
Closed forests	30 - 40	180 - 400	(290)
Secondary forest	20 - 30	80 - 180	(130)
Open forests	10 - 20	35 - 80	(57.5)
Bamboos and bush	10 - 20	35 - 80	(57.5)
Fallow (glass,banana)	< 10	< 35	(17.5)
Agricultural crops	< 5	< 15	(7.5)

Figure 8. Biomass density distribution in the study area of Mae-Klong Watershed Research Station. As a state of 1985.

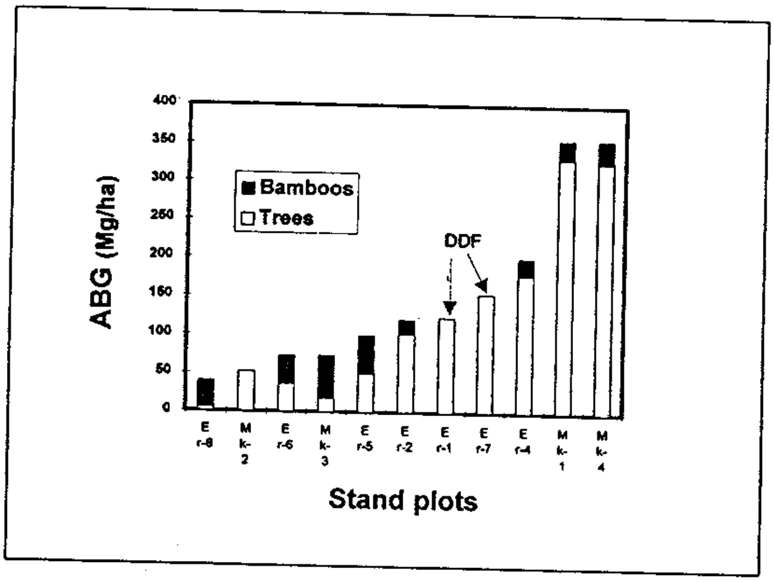


Figure 9. Aboveground biomass (AGB) of stand and the difference in biomass proportion of bamboos. The biomass proportion of bamboo is larger in small AGB stands.

Application of the biomass-density-distribution map

Coupling with the digital terrain map, the biomass-density-distribution map shows not only the vegetation types (land use types) but also the biomass-density levels in the 3-D scale. This produces a basic tool for assessing the carbon storage distribution from the satellite image. Some vegetation indices derived from the remote-sensing data, such as NDVI, can be examined for predicting vegetation biomass based on this biomass-density-distribution map. We consider that the procedures we presented here are easy to apply and effective to assess the distribution of carbon storage in an area where no forest inventory data exists, though it is still necessary to collect more examples from other regions.

Conclusion

1. A single allometric relationship was found between stand basal area(BA) and aboveground biomass (AGB) for most broadleaved forests over Thailand. AGB of stand is able to be estimated from BA of trees and bamboos in a stand.

2. Relative dominance of bamboos is high in degraded MDF stands with small AGB.

3. An exponential relationship was found between top canopy height (TCH) and AGB in deciduous forests (MDF, DDF). TCH is the most simple, practical tool for estimating AGB for deciduous forests in Thailand.

4. Biomass-density-distribution mapping for a relatively small area, such as 3 km x 3 km, was demonstrated by classifying TCH into three levels from aerial photograph and field observation.

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