Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 12 (15): 1537-1546, 2012
ISSN 1812-5654 / DOI: 10.3923/jas.2012.1537.1546

Above Ground Carbon Sequestration in Mangrove Forest Filtration System

[1,2]Sureeporn Nipithwittaya and [3]Surat Bualert
[1]International Postgraduate Programs in Environmental Management,
Graduate School, Chulalongkorn University, Bangkok, Thailand
[2]National Center of Excellence for Environmental and Hazardous Waste Management
Chulalongkorn University, Bangkok, Thailand
[3]College of Environment, Kasetsart University, Bangkok, Thailand

Abstract: The rate of above ground carbon sequestration was examined in mangrove forest filtration system pond within the King's Royally Initiated Laem Phak Bia Environmental Research and Development Project that located in Thailand. It is divided into two sites: the study site and the reference site. The study site is the mangrove filtration system area where is directly affected from the municipal waste water and the reference site is the mangrove forest area where is indirectly affected from the municipal wastewater at Ban Pranaen is located in the north of the cape. The relationships between tree diameter and tree height were used to evaluate above ground biomass by allometric equations and above ground carbon sequestration was calculated by multiplying the percentage of carbon stock. They were carried out two seasons: Wet and dry seasons. The results were revealed that the highest LAI in study site and reference site were 17.67 and 9.66, respectively. The highest above ground biomass was 1.42 and 2.12 t ha^{-1} in study site and reference site, respectively. The percentage of carbon content in the parts of sampled tree was slightly difference in study and reference site. The average of highest above ground carbon sequestration was 11.08 and 2.32 t ha^{-1} in study site and reference site, respectively. Moreover, the results of comparison of LAI, above ground biomass and above ground carbon sequestration confirmed that the mangrove forest filtration system can be high potential of carbon stock source.

Key words: Mangrove forest filtration system, above ground biomass, left area index, above ground carbon sequestration, spatial distribution map

INTRODUCTION

An increased level of atmospheric CO_2 through the combustion of fossil fuel or more precisely its likely effect on the global climate is caused of concerned (Ayukai, 1998). The storage of carbon reduces the greenhouse effect that linked to problems of global climate change (Lim, 2007). Thus, many scientists have recognized the carbon sources or sink. In addition, their studies found that tree can help to reduce the problem of global warming; carbon dioxide is absorbed by tree that used for photosynthesis. Tree can absorb CO_2 from the atmosphere that transformed to biomass. This process is called "carbon sequestration" which is the best effective on CO_2 reduction in atmosphere (Sridang, 2008). Then, forest is an important role of carbon sink and carbon cycle. Therefore, more increasing of forest area can help more carbon sequestration sources and decreasing of CO_2 in the air (Schlesinger, 1990).

Mangrove forest ecosystem plays an important role in the global carbon cycle (Ayukai, 1998). It protects a coast erosion and storms, encourages sediment deposition and provides the most productive ecosystems and their carbon stock per unit area can be enormous (Ong, 1993). To be better understanding the dynamic of carbon cycle in the forest, the amount of Leaf Area Index (LAI) and biomass is concerned in this cycle. The canopy structure of a vegetated area is frequently described in terms of leaf area index. Measurement of LAI is monitored the changing of canopy structure due to pollution and climate change (Gholz *et al*., 1991). It is necessary to measure a LAI with stringent calculation of the amount of CO_2 sequestration by forest (Ishil and Tateda, 2004). The important of LAI stems from the relationship which established between it and a range of ecological processes (rates of photo synthesis, transpiration and evapotranspiration) (McNaughton and Jarvis, 1983; Pierce and Running, 1988); net primary

Corresponding Author: Sureeporn Nipithwittaya, International Postgraduate Programs in Environmental Management, Graduate School, Chulalongkorn University, Bangkok, Thailand Tel: + 66 89 1202011 Fax: +66 2 219 2251

production (Monteith, 1972; Norman, 1980; Gholz, 1982; Meyers and Paw, 1986; Meyers and Paw, 1987); rate of energy exchange between plants and the atmosphere (Gholz *et al*., 1991). The estimate LAI and biomass is a valuable tool for modeling of the ecological processes occurring within a forest and in predicting ecosystem responses. Moreover, this method can be used to estimate LAI and biomass in all season and it can be applied to calculate other area where has the same type of vegetations (Domrongsutsiri, 2001). The final result from the study takes to use for mangrove forest resource management to help an effective improvement of carbon sequestration in the near future.

This study analyzes LAI values, the above ground biomass and the above ground carbon of the two species dominant mangrove trees: *Rhizophora mucronata* and *Avicennia marina* located in the mangrove forest filtration system, Phetchaburi province where as municipal wastewater receiving source before flowing into the sea. The hypothesis is the mangrove filtration system site would more potential of carbon sequestration than natural mangrove site. In this experiment, the main objectives of the study are:

- To estimate the rate of LAI, above ground biomass and above ground carbon in mangrove forest filtration systems
- To determine the distribution pattern of LAI, above ground biomass and above ground carbon
- To evaluate the carbon sink potential of mangrove above ground filtration system area

MATERIALS AND METHODS

Description of study area: The study site is the King's Royally Initiated Laem Phak Bia Environmental Research and Development Project locates in Laem Phak Bia Sub-district, Ban Laem District, Phetchaburi Province**,** Thailand (100.10°E, 13.05°N) (Fig. 1) where rests on an alluvial plain that extends the west to the east along the Gulf of Thailand. The total area is about 10.33 km^2. The study area is the mangrove forests filtration system area where is supported the treated municipal waste water from stabilization treatment pond. The treated municipal wastewater throughout 4,500-10,000 m^3 day^{-1}. The qualities parameters of treated municipal waste water from the lagoon treatment system: DO was 6.5-9.5 mg L^{-1}, conductivity was 1116.10-1462.95 msec, the colors less was 5-7 unit, temperature was 25.7-30.3 degree Celsius and pH was 8.1-8.4 unit which the waste water parameters of study were complied with these standards values of Pollution Control Department (In-on, 2003).

Mangrove forests have strong relationships with the surrounding environment such as tidal inundation, directions and current flow. Directions and current flow speed mainly depends on the tide. The current flow is two directions in this area. There are the high tides which flow through in the north the low tides which flow along the south of costal. Although, the current flow speed rely on the monsoon influencing in each season follow as the North East monsoon during November to January and The North East monsoon during February to April. The highest of high tides speed was 0.61 m sec^{-1} and the highest of low tides speed is 0.64 m sec^{-1} on

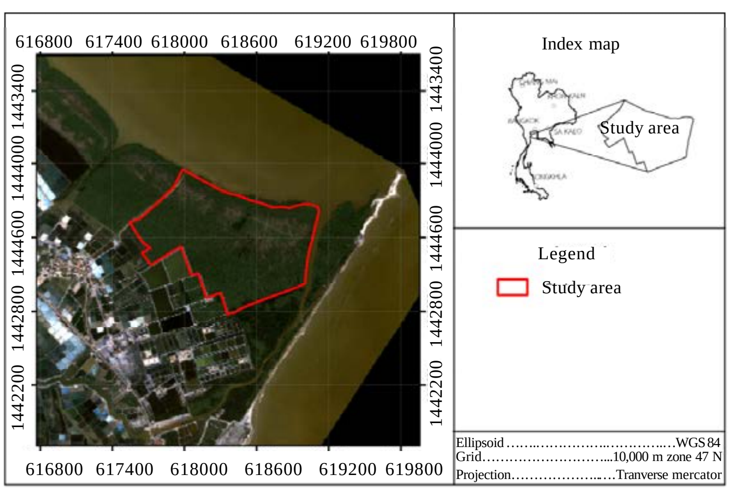

Fig. 1: The location of the study area, located within Laem Phak Bia sub-district, Ban Laem district, Phetchaburi province, Thailand (created from THEOS satellite image)

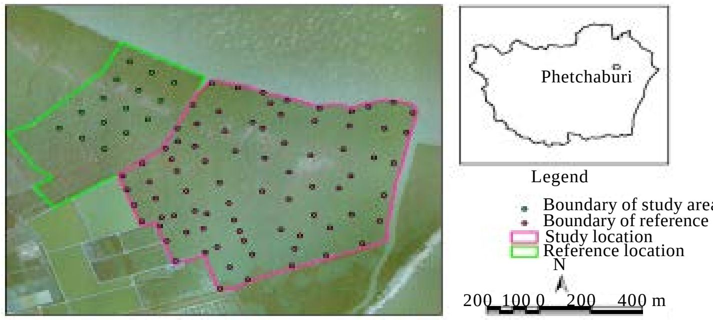

Fig. 2: Sampling plots in the study site and reference site (created from Landsat TM 5 satellite image)

December whereas the highest of high tides speed is 0.85 m per a second and the highest of low tides speed is 0.78 m per a second on May. The average of high-low tide rates are 2.78-7.36 km ha^{-1}. Surface water is the average of wind speed rating 5.9 and 6.9 km ha^{-1} during February, April, November and January, respectively. The highest wind speed is 40 km ha^{-1} which to create the average of wave heights are 0.14 and 0.18 m, respectively. The undercurrent is 0.3-1.8 m (Sawangchat, 2001). The study area is divided into two sites (Fig. 2). There is the study site and the reference site:

- The study site is the mangrove filtration system area where is directly affected from the municipal waste water. The area is about 7.46 km^2
- The reference site is the mangrove forest area where is indirectly affected from the municipal waste water at Ban Pranaen is located in the north of the cape. The area is about 2.87 km^2

Mangrove forest analysis

Mangrove sampling: The size of each sampling station is 30×30 m^2. A simple random sampling method used for selecting the locations of the sampling stations. Sampling plots showed in Fig. 2. Mangrove tree sampling carried out in wet (July-December 2009) and dry (January-June 2010) seasons for representation. The floristic parameters recorded are species names, tree heights (H), Diameters a Breast Height (DBH), crown cover area and Differential Global Positioning System (DGPS) coordinates in the Universal Transverse Mercator co-ordinate (UTM) system (Vaiphasa *et al*., 2006).

Tree sampling location: The King's Royally Initiated Laem Phak Bia Environmental Research and Development Project where located within Laem Phak Bia Sub-district, Ban Laem District, Phetchaburi Province**,** Thailand (100.10°E, 13.05°N) was selected as study area with a total area of approximately 10.33 km^2. The study area was divided into two sites:

- The study site; the mangrove forest filtration system was directly by municipal waste water is about 7.46 km^2
- The reference site; the natural mangrove forests was indirectly by municipal waste water is about 2.87 km^2 at Ban Pranaen was located in the north of the cape

Data field measurement: Data were collected in the field from July 2009 to June 2010. *Rhizophora mucronata* and *Avicennia marina* were the two dominant species mangrove trees in this area. Measurement of tree Diameter at Breast Height (DBH) performed by measurement tape, crown diameter. Tree heights measured by measuring pole and Haga hypometer. The size of sampling was sampled within 900 m^2 quadrate in the rectangular permanent sample plot by systematic system and spread around mangrove forest area. LAI was measured by a total leaf count technique (Ishil and Tateda, 2004) in each plot.

Tree sampling cutting: *Rhizophora mucronata* and *Avicennia marina* were selected to cut for 6 sets and cutting separated to small part with length 1 m by stratified clip technique. All cut samples were weighted and recorded their weighting prior to analyze the percentage of carbon content for each parts of tree samples.

Estimation of tree volume: Estimation of tree volume focused on two dominance species mangroves trees. They were calculated by using the independent variables of algometry equation in D^{2}H by following equations:

$$BA = \pi D^2/4$$

BA stand for Tree surface area. D stand for tree diameter at 1.3 cm. The calculation of tree sample volume used Smalian formula (Phongsuksawat, 2002).

$$Vs = ½(BA_1+BA_2)×L$$

Vs stand for the volume of tree log (m^3). BA_1, BA_2 stand for both two ends diameter (m^2) L stand for log length (m). For the last end log calculated the volume as following equation:

$$Vtop = 1/3×BA_{top}×L_{top}$$

Vtop stand for the end of tree stem (m^3). BA_{top} stand for the end side diameter (m^2). L_{top} stand for the length of the top end (meter).

Estimation of LAI value: Two LAI equations are developed by field data collection base on two dominance species mangroves trees which a method of the basic of Japanese national forest surveys and satellite data analysis (Ishii *et al*., 2001). The LAI measurements were calculated by measuring DBH and the total of leaf area at each tree in the field plots and analyzed the strongly relationship between leaf area, diameter at breast high and tree height. The results of two algometry equations were used in this research for calculation of LAI value.

Calculation of biomass: Each tree sampling was registered. Calculations of crown area and crown diameters were used. The crown area was considered an ellipse. The harvested trees were subdivided into following compartments: leaves, branches, stems and roots. Determination of dry weight compartments for each sampled individual were used simple linear regression between dry weight and fresh weight. These statistical procedures may be found by Zar (1996). The obtained regressions were grouped by compartments: leaves; branches, stems and roots. We pooled the data of two species mangrove trees from the various regressions to compute common regressions based on the comparison results (Soares and Schaeffer-Novelli, 2005) then determining the best regression model to estimate the total above ground biomass and compartments biomass follow by law of allometric method (Kittredge, 1944; Ogawa and Kira, 1977). Measurements of net productivity were bases on allometric techniques (Ong *et al*., 1984). Sampled plot twelve trees of two dominance spices mangrove trees were harvested. The allometric regression equations could be developed. The results of two allometric equations were used for biomass calculation.

Calculation of carbon content (%): The harvested trees samples were sent to laboratory at Department of Silviculture, faculty of forestry, Kasetsart University for analyze the percentage of carbon content by dry combustion method and using CN corder model MT-700 (Nualngam, 2002).

Calculation of above ground carbon sequestrations: The percentage of carbon content was analyzed by laboratory. They were taken into the calculation of above ground carbon sequestration from above ground biomass in term of each plot (Sridang, 2008) from equation:

$$\text{Total carbon} = \%\text{carbon}×\text{biomass}$$

Statistical analysis: Some main statistical parameters were analyzed: mean, standard deviation variance, coefficients of variation and extreme maximum and minimum values. ANOVA statistical analysis was used to test the significances almost of the parameters at $p< 0.05$. Regression analyses were also used to develop modeling for above ground carbon sequestration. These statistical parameters were performed by using EXCEL 2003 and statistical package for the Social Science (SPSS) program. The statistical relationships between the annual field data measurements and laboratory results were correlated to various regression models. The best equation model was selected by its highest coefficient of determination. Correlation and regression analysis were evaluated the association between two or more variables and expressing the nature of relationship and determination the degree of association between variables with coefficient of determination (R^2) (Lim, 2007).

Integrating ecological data into the spatial distribution mapping model: Spatial relationships between mangroves and the environment are well known (Clough *et al*., 1983). These relationships result in the mangrove zonations that are usually found in tropical mangrove forest (Tomlinson, 1986). Moreover, Vaiphasa *et al.* (2006) tested whether mangrove environment relationships can be exploited in order to improve mapping accuracy. The study confirmed that the mangrove environment relationships into the mapping process that can be used for mapping mangrove at the species level.

All of the results were used for the Kring method to produce the spatial distribution map of study and reference sites. For the spatial interpolation, a cell size of 100×100 m was chosen to divide the study area into a grid system. The final result of this spatial interpolation process was shown as values spatial distribution maps. Geostatistics (Matheron, 1963) uses the semi-variogram to quantify the spatial variation of a regionalized variable and provides the input parameters for the spatial interpolation method of Kriging (Krige, 1951). The Geostatistical analyses and the interpolated map were produced with the Geographic Information System (GIS) software.

RESULTS AND DISCUSSION

Tree parameters inventory data: From the research field work, the data demonstrated structures characteristics of mangrove trees follow as Table 1. Mean of tree height were 4.40 and 2.58 m for study site and reference site, respectively. These results showed significant of tree height which found that the study site higher than reference site approximately twice times and mean of DBH for study site and reference site were 9.07 and 6.23 cm, respectively. Finding of DBH showed the slightly higher value in study site and crown area (m) found that the similar value in study and reference sites with no significant of different were 4.10 and 4.25 m^2, respectively. Volumes of tree found slightly higher in study site than reference sites were 0.75 and 0.54 m^3, respectively (Table 1).

Estimation of LAI

LAI equations: Two LAI equations were developed by field data collection which a method of the basic of Japanese national forest surveys and satellite data analysis (Ishii *et al*., 2001). LAI measurements were calculated by measuring DBH and the total of leaf area in each tree and analyzed the strongly relationship between leaf area, DBH and tree height. The results of two algometry equations have shown in Table 2.

Table 1: Structural characteristics of the studies mangrove forests filtration system

Parameters	Study site	Reference site
Height (m)	4.40±2.68	2.58±2.66
DBH (cm)	9.07±5.33	6.23±6.06
Crown area (m)	4.10±3.07	4.25±4.94
Volume (m^3)	0.75±0.43	0.54±0.52

DBH: Diameter at breast height, values are Mean±SD

Table 2: Allometry equations for leaf area estimation of the two species of dominance mangrove trees

Species of mangrove trees	Allometry equations	R^2
Avicennia marina	$U = 0.0102\ (DBH^2H)^{2.2034}$	0.98 (n = 6)
Rhizophora mucronata	$U = 0.0499\ (DBH^2H)^{1.6692}$	0.88 (n = 6)

U: Leaf area (m^2), DBH: Diameters at breast height (cm), H: Height (m)

Table 3: Comparison of the average LAI values

	Leaf area index (LAI)		
Minimum	Maximum	Mean	References
0	17.7	4.8	This paper
3	5.7	-	Araujo *et al.* (1997)
2.2	7.4	4.9	Clough *et al.* (1997)
3.3	4.9	-	Clough *et al.* (2000)

Table 4: Statistic values of leaf area (m^2)

Sites	Seasons	Mean	SD	D	SD_D	t-value	Sig.
Study site[1]	Wet	11.94	11.64	9.91	15.46	5.73	0.000
	Dry	21.85	25.50				
Reference site[2]	Wet	7.34	9.40	6.96	9.05	2.34	0.010
	Dry	0.38	0.39				

[1]N = 80, [2]N = 15

LAI values: Two algometry equations were used to estimate value of mangrove LAI values. LAI ranged from 0.00-28.01, with a mean value of 4.75 and 0.00-10.86 and mean value of 1.909 in study site whereas Green *et al.* (1997) found mangrove LAI ranged between 0.8 and 7.0, with a mean of 3.96. In addition to, these results demonstrated that the LAI in study site was higher than reference site. From Fig. 3, results of seasonal variation showed that LAI was the highest in dry season in the both area. Finding of LAI was 0.00 value because of the death of mangrove trees which can see in clear spaces in Fig. 1. From Table 3, comparison of LAI results with the previous studies, it demonstrated that this research has the highest and lowest LAI value with the nearly value of mean. Values of this research has the maximum average with 17.67 and minimum average with 0.00 and a mean of 4.76 meanwhile study of Clough *et al.* (1983) showed previous publish of LAI values for mangrove from the west coast of peninsular Malaysia. They obtained indices ranging from 2.2-7.4 (mean 4.9) by direct measurement and a mean value of 5.1 when LAI was estimated indirectly from light transmission measurements over four transects. Values of LAI derived from satellite data of Caribbean mangroves (0.83-7.00, mean 3.96). Clough *et al.* (2000) has studied canopy LAI of the mangrove *Rhizophora apiculata* in the Mekong data, Vietnam. They found that LAI ranging from 3.3-4.9 shown in Table 3 whereas Ishil and Tateda (2004) found that these differences are due to a high plantation density and the absence of thinning.

LAI statistics values: From Table 4 showed statistic values of LAI. The results found that mean of LAI in study site from wet and dry seasons were 11.94 and 21.85, respectively and standard deviation was 11.64 and 25.50, respectively. Testing of LAI values different between wet and dry seasons by t-test. The LAI in dry season is significantly higher (t-test, p<0.01) than in wet season.

Meanwhile, mean of LAI in reference site from wet and dry season were 7.34 and 0.38, respectively and standard deviation was 9.40 and 0.39, respectively.

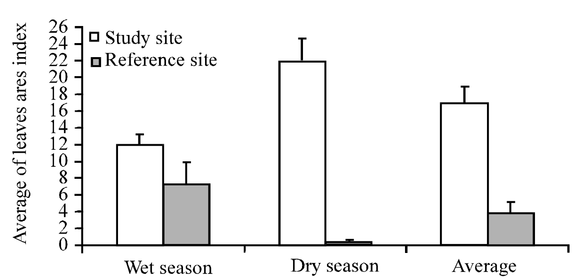

Fig. 3: Histograms of leaf area index

Testing of LAI values different between wet and dry season by t-test. The LAI in wet season is significantly higher (t-test, $p<0.05$) than in dry season (Table 4).

In Fig. 3 showed LAI values. The results discovered that LAI values in dry season higher than in wet season twice times. Accordingly, highs LAI value was indicated the ability of rates of energy exchange plants and the atmosphere (Gholz *et al*., 1991).

Estimation of above ground biomass

The percentage of carbon content in each part of tree: From Table 5 showed the average percentage of carbon content of *Rhizophora mucronata*. The results showed carbon content percentage found in each part of tree in both sites have similar values when compared carbon content percentage between study and reference sites also found similar value in all parts.

From Table 6 showed the average percentage of carbon content of *Avicennia marina*. The results found slightly difference between study and reference sites.

Comparison of the average percentage of carbon content between *Rhizophora mucronata* and *Avicennia marina*. The results showed that the average percentage of carbon content in all parts of *Rhizophora mucronata* have slightly higher than *Avicennia marina*.

Table 5: Average of carbon content (%) of *Rhizophora mucronata*

	Average of carbon content (%)	
Parts of tree	Study site	Reference site
Roots	45.35	46.51
Stems	45.99	44.04
Branches	45.87	43.73
Leaves	43.19	48.23

Table 6: Average of carbon content (%) of *Avicennia marina*

	Average of carbon content (%)	
Parts of tree	Study site	Reference site
Stems	44.55	44.18
Branches	43.45	42.92
Leaves	42.80	44.42

Table 7: Algometry equations for biomass estimation of the two species of dominance mangrove trees

Species of mangrove trees	Allometry equations	R^2
Avicennia marina	$W_L = 0.3161\ (DBH^2H)^{0.5119}$	0.97
	$W_B = 0.3737\ (DBH^2H)^{0.5186}$	0.97
	$W_S = 0.0019\ (DBH^2H)^{2.4514}$	0.97
	$DBH_{max} = 4.14$ cm, n = 6	
Rhizophora mucronata	$W_L = 0.459\ (DBH^2H)^{0.4487}$	0.90
	$W_B = 0.6797\ (DBH^2H)^{0.276}$	0.97
	$W_S = 0.9926\ (DBH^2H)^{0.2141}$	0.99
	$W_R = 0.2838\ (DBH^2H)^{0.8308}$	0.99
	$DBH_{max} = 3$ cm, n = 6	

DBH: Diameters at breast height (cm), H: Height (m), W_S: Biomass of stem (kg), W_B: Biomass of branches (kg), W_L: Biomass of leaf (kg), W_R: Biomass of tree roots (kg)

Algometry equations of the two species of dominance mangrove trees: Allometric equations of two species of mangroves trees were developed from the field data of two dominance species mangrove trees for the various regressions to compute common regressions based on the comparison results. Determining of the best regression model was selected to estimate the total above ground biomass and the compartments of biomass in each part follow by law of allometric method. The results of two allometric equations were created follow as Table 7.

Above ground biomass value: The results were calculated the average above ground biomass values from allometric equations. Estimation of the average above ground biomass have maximum valve with 154.62 and 35.09 t ha^{-1} for study and reference sites, respectively. These results discovered that the average above ground biomass in study site has higher than reference site about five times. From Fig. 4, the seasonal variation of total biomass found that significantly between wet and dry seasons. Comparison of above ground biomass between wet and dry seasons found that dry season higher than wet season approximately twice times. The significant result showed that the net productivity of mangrove forest depend on seasons. The net productivity of dry season has higher than wet season. According to the result of Aksornkoae *et al*. (1989), they found that the net productivity of dry season has higher than wet season about 40-50%. Moreover biomass of mangrove forest was varied in species and zone. The highest above ground biomass, 460 tonnes, was found in a forest dominated (Putz and Chan, 1986).

Above ground biomass (AGB) (tonnes per hectare) statistics values: Table 8 showed that above ground

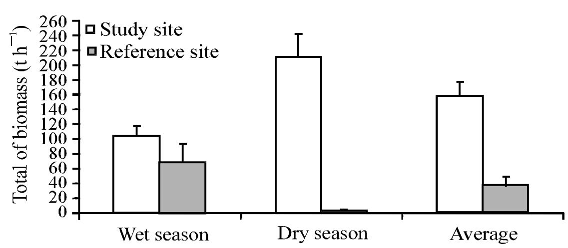

Fig. 4: Histograms of above ground biomass

Table 8: Statistics values of above ground biomass (AGB) (tonnes ha^{-1})

Sites	Seasons	Mean	SD	D	SD_D	t-value	Sig.
Study site[1]	Wet	102.30	121.33	104.63	183.50	5.1	0.000
	Dry	206.93	290.59				
Reference site[2]	Wet	67.68	90.560	65.18	88.21	2.86	0.013
	Dry	2.50	2.66				

[1]N: 80, [2]N: 15

206.93 t ha^{-1} in wet and dry season, respectively biomass statistic values. The results showed mean of above ground biomass in study site was 102.30 and and standard deviation was 121.33 and 290.59 t ha^{-1}, respectively. Testing of AGB values different between wet and dry seasons by t-test. The AGB in dry season is significantly higher (t-test, $p<0.01$) than in wet season.

Whereas, mean of Above Ground Biomass in reference site was 67.68 and 2.50 t ha^{-1} in wet and dry season, respectively and standard deviation was 90.56 and 2.66 t ha^{-1}, respectively. Testing of AGB values different between wet and dry season by t-test. The AGB in wet season is significantly higher (t-test, $p<0.05$) than in dry season.

Chukwamdee and Anunsiriwat (1997) estimated biomass of mangrove forest at Changwat Samut Songkhram. Their results showed above ground biomass sequestration with 75.96 tonnes mean while above ground biomass of more than 300 tonnes was also reported in mangrove forests in Indonesia (Komiyama *et al*., 1988). An above ground biomass of 341 tonnes was reported for an *Avicennia marina* forest (Mackey, 1993). The lowest above ground biomass reported was 7.9 tonnes for *Rhizophora mangle* forest in Florida, USA (Lugo and Snedaker, 1974).

Estimation of above ground carbon

Above ground carbon sequestration: Above ground biomass and the percentage of carbon content were conducted to estimate of above ground carbon sequestration. The highest of above ground carbon was found in study site with maximum 14.58 t ha^{-1} in wet season whereas found only 2.78 t ha^{-1} in dry season for reference site. From Fig. 5, above ground carbon sequestration of dry season has higher than wet season. Comparison of the average of above ground carbon between study and reference site in both seasons found the study site have higher above ground carbon than reference site and when we compared between wet and dry season seasons found that dry season have the average above ground carbon higher than wet season. Calculation of the total of above ground carbon in study area found the above ground carbon sequestration in this area was 320.11 tonnes. When we compared with the previously researcher, Fujimoto *et al*. (2004) found above ground carbon sequestration rate with 208 tonnes. Besides, Sridang (2008) estimated above ground carbon sequestration on mangrove forest, found an average of it about 71.10 tonnes. Then our results showed the above ground carbon sequestration higher than that.

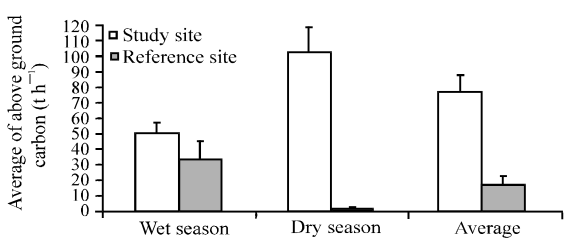

Fig. 5: Histograms of above ground carbon

Table 9: Statistics values of above ground carbon (AGC) (t ha^{-1})

Sites	Season	Mean	SD	D	SD_D	t-value	Sig.
Study site[1]	Wet	51.15	60.67	104.63	183.50	5.10	0.000
	Dry	103.38	145.31				
Reference site[2]	Wet	33.84	45.28	52.23	91.77	5.10	0.013
	Dry	1.24	1.32				

[1]N: 80, [2]N: 15

Above ground carbon (AGC) (tonnes ha^{-1}) statistics values: Mean of Above Ground Carbon in study site was 51.15 and 103.38 t ha^{-1} in wet and dry seasons, respectively. Standard Deviation was 60.67 and 145.31 t ha^{-1}, respectively. Testing of AGC values different between wet and dry season by t-test. The AGC in dry season is significantly higher (t-test, $p<0.01$) than in wet season.

Mean while mean of Above Ground Biomass in reference site was 33.84 and 1.24 t ha^{-1} in wet and dry seasons, respectively. Standard Deviation was 45.28 and 1.32, respectively. Testing of AGB values different between wet and dry seasons by t-test. The AGC in wet season is significantly higher (t-test, $p<0.05$) than in dry season.

From Table 9 showed above ground carbon statistics values. The results showed above ground carbon sequestration in study site has higher than reference site in both seasons. Especially, the rate of above ground carbon sequestration in dry season has the highest because sediment organic matter was rapidly and efficiently decomposed in mangrove forest for dry season. Accordingly, Bouillon *et al*. (2004) found that the degree of utilization of mangrove derived food sources depends partially on the degree of material exchange with adjacent system.

Integrating ecological data into the spatial distribution mapping model

Integrating leaf area index (LAI) into the spatial distribution mapping model: A technique was presented by thematic maps of mangrove LAI. It was derived accurately and precisely from remote sensed satellite data. The final result of this spatial interpolation process was shown as Fig. 6. From the spatial distribution map of LAI showed that LAI values have the highest lay on in

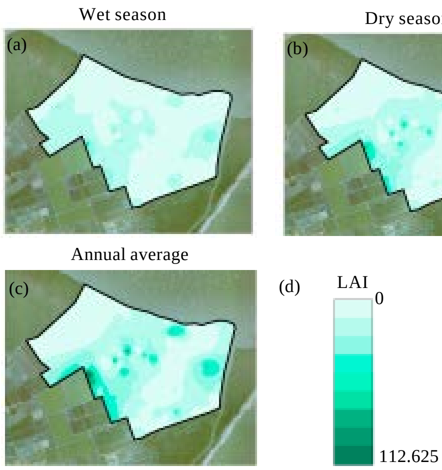

Fig. 6(a-d): Spatial distribution map of leaf area index values

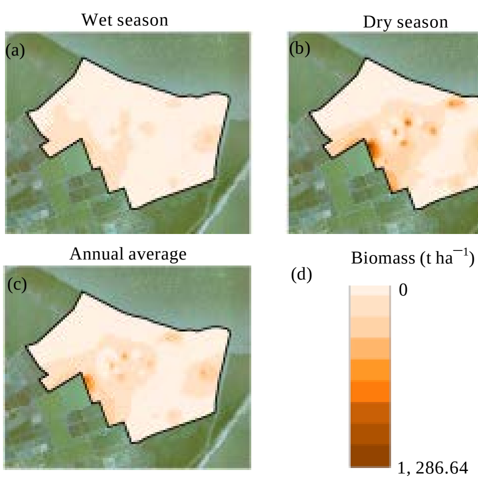

Fig. 7(a-d): Spatial distribution map of above ground biomass

Western and Eastern, respectively. The density of LAI found the highest in dry season. Trend of LAI spatial distribution showed low density of LAI in area where has less of tree and showed value of LAI with 0.00 in death of tree area.

Integrating above ground biomass into the spatial distribution mapping model: The final result of this spatial interpolation process was shown as Fig. 7. From the spatial distribution map of AGB showed that AGB values have the highest lay on in Western and Eastern, respectively. The density of AGB found the highest in dry

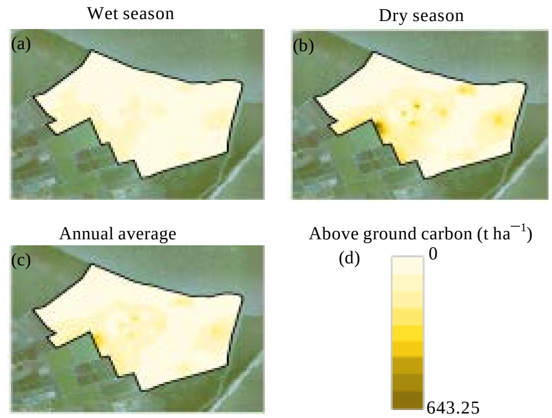

Fig. 8(a-d): Spatial distribution map of above ground carbon

season. Trend of AGB spatial distribution showed the same result of LAI values.

Integrating above ground carbon into the mapping model: Figure 8 showed the trend of the spatial distribution. This map found that above ground carbon values have the highest in fresh water outlet area where found the content of above ground carbon the highest in dry season whereas slightly in wet season same as the spatial distributions of LAI and above ground biomass.

CONCLUSION

The study of biological parameters of the two species of dominance mangrove trees in study area demonstrated that study site (mangrove filtration system) has higher biological values than the natural mangrove in the reference site when we calculate the above ground carbon sequestration, the results showed the positive potential for the above ground carbon sequestration. In this context, sequestration is the removal of CO_2, either directly from the atmosphere and disposing of it either permanently for geologically significant time periods. Out data suggest that mangrove forest filtration system was not only wastewater construction but the results of this study showed advantages on a function as the sink of carbon.

ACKNOWLEDGMENTS

This research was funded by The 90th Anniversary of Chulalongkorn University Fund (Ratchadaphiseksomphot Endowment Fund), Chulalongkorn University, Thailand. We are extremely thankful for the comments and suggestion from the reviewers. The authors would also like to thank the numerous workers of The Laem Phak Bia Environmental Study, Research and Development Project for their assistance in the field.

REFERENCES

Aksornkoae, S., J. Kongsangchai, S. Panichsuko, W. Srisawatt and S. Panichchart *et al*., 1989. Inventory and mornitoring on Mangroves in Thailand. Final Report, Submitted to the Official of the National Environment Board, Bangkok, Thailand.

Araujo, R.J., J.C. Jaramillo and S.C. Snedaker, 1997. Leaf area index and leaf size differences in two red mangrove forest types in South Florida. Bull. Mar. Sci., 60: 643-647.

Ayukai, T., 1998. Introduction: Carbon fixation and storage in mangroves and their relevance to the global climate change- a case study in hinchinbrook channel in northeastern Australia. Mangroves Salt Marshes, 2: 189-190.

Bouillon, J., M.D. Medel, F. Pages, J.M. Gili, F. Boero and C. Gravili, 2004. Fauna of the Mediterranean Hydrozoa. Sci. Mar., 68: 421-438.

Chukwamdee, J. and A. Anunsiriwat, 1997. Biomass estimation for *Anvicennia alba* at Chungwat Samut Songkrum. Proceedings of the 10th Thailand National Mangrove Ecosystem Seminar, August 25-28, 1997, Songkhla, Thailand, pp: 5-14.

Clough, B., D.T. Tan, D.X. Phuong and D.C. Buu, 2000. Canopy leaf area index and litterfall in stands of the mangrove *Rhizophora apiculata* of difference age in the Mekong delta, Vietnam. Aquat. Bot., 66: 311-320.

Clough, B.F., J.E. Ong and G.W. Gong, 1997. Estimating leaf area index and photosynthetic production in canopies of the mangrove *Rhizophora apiculata*. Mer, Ecol. Prog. Ser., 59: 285-292.

Clough, B.F., K.G. Boto and P.M. Attiwill, 1983. Mangrove and Sewage: A Reevaluation. In: Biology and Ecology of Mangroves: Tasks for Vegetation Science Series, Teas, H.J. (Eds.). Volume, 8, Dr. W. Junk Publishers, Lancaster, Lancashire, UK, pp: 151-162.

Domrongsutsiri, V., 2001. Application of remote sensing for estimating leaf area index and above-ground forest biomass at Phu Kradung Nation Park, Changwat Loei. Graduate School Kasetsart University, Bangkok Thailand.

Fujimoto, K., A. Imaya, R. Tabuchi, S. Kuramoto and H. Utsugi, 2004. Implementation plan for the global observing system for climate in support of the UNFCCC. Report GCOS-92 (WMO/TD No. 1219).

Gholz, H.L., 1982. Environmental limits on aboveground net primary production, leaf area and biomass in vegetation zones of the Pacific Northwest. Ecology, 63: 469-481.

Gholz, H.L., S.A. Vogel, W.P. Cropper, K. McKelvey, K.C. Ewel, R.O. Teskey and P.J. Curran, 1991. Dynamics of canopy structure and light interception in *Pinus elliottii* stands. North Florida. Ecol. Monogr., 6: 33-51.

Green, E.P., P.J. Mumby, A.J. Edwards, C.D. Clark and A.C. Ellis, 1997. Estimating leaf area index of mangroves from satellite data. Aquat. Bot., 58: 11-19.

In-on, P., 2003. Determination of organochlorine and organophosphorus pesticide residues in water, sediment and aquatic organisms in mangrove area influenced by wastewater overflow from petchaburi municipal wastewater treatment system. Master's Thesis, College of Environment. Kasetsart University.

Ishii, T., M. Nashimoto and H. Shimogaki, 2001. Large-Scale Mapping of Leaf Area Index using Remote Sensing Data. In: Soil-Vegetation-Atmosphere Transfer Schemes and Large-scale Hydrological Models, Dolman, A.J. (Ed.). International Association of Hydrological Sciences, USA., ISBN-13: 9781901502619, pp: 287-290.

Ishil, T. and Y. Tateda, 2004. Leaf area index and biomass estimation for mangrove plantation in Thailand. Proceedings of the IEEE International Geoscience and Remote Sensing Symposium, Vol. 4, September 20-24, 2004, Chiba, Japan, pp: 2323-2326.

Kittredge, J., 1944. Estimation of the amount of foliage of trees and stands. J. For., 42: 905-912.

Komiyama, A., H. Moriya, S. Prawiroatmodjo, T. Toma and K. Ogino, 1988. Forest Primary Productivity. In: Biological System of Mangrove, Ogino, K. and M. Chihara (Eds.). Ehime University, Japan, pp: 97-117.

Krige, D.G., 1951. A statistical approach to some basic mine valuation problems on the Witwatersrand. J. Chemical, Metallurgical Mining Society, 52: 119-139.

Lim, C., 2007. Estimation of urban tree crown volume based on object-oriented approach and LIDAR data. Master's Thesis, International Institute for Geo-Information Science and Earth Obseravation, Enschede, The Netherlands.

Lugo, A.E. and S.C. Snedaker, 1974. The ecology of mangroves. Ann. Rev. Ecol. Syst., 5: 39-46.

Mackey, A.P., 1993. Biomass of the mangrove *Avicennia marina* (Forsk.) Vierh. Near Brisbane, South Eastern Queensland. Aust. J. Mar. Freshwater Res., 44: 721-725.

Matheron, G., 1963. Principles of geostatistics. Economic Geol., 58: 1246-1266.

McNaughton, K.G. and P.G. Jarvis, 1983. Predicting Effects of Vegetation Changes on Transpiration and Evaporation. In: Water Deficits and Plant Growth, Kozlowski, T.T. (Ed.). Vol. 7. Academic Press, London, pp: 1-47.

Meyers, T. and U.K.T. Paw, 1986. Testing of a higher-order closure model for modeling airflow within and above plant canopies. Boundary-Layer Meteorol., 37: 297-311.

Meyers, T.P. and U.K.T. Paw, 1987. Modelling the plant canopy micrometeorology with higher-order closure principles. Agric. For. Meteorol., 41: 143-163.

Monteith, J.L., 1972. Solar radiation and productivity in tropical ecosystems. J. Applied Ecol., 9: 747-766.

Norman, J.M., 1980. Photosynthesis in Sitka Spruce (*Picea sitchensis*). Radiation penetration theory and a test case. J. Applied Ecol., 12: 839-878.

Nualngam, S., 2002. Role of reforestation on carbon sink and some soil properties at re-affforestion research and training station, changwat nakhon ratchasima. Master's Thesis, Graduate School Kasetsart University, Bangkok Thailand.

Ogawa, H. and T. Kira, 1977. Method of Estimating Forest Biomass. 16th Edn., The University of Toyko Press, Toyko.

Ong, J.E., 1993. Mangroves-a carbon source and sink. Chemosphere, 27: 1097-1107.

Ong, J.E., W.K. Gong, C.H. Wong and G. Dhanarajan, 1984. Contribution of aquatic productivity in a managed mangrove ecosystem in Malaysia. Proceedings of the UNESCO Asian Symposium on Mangrove Environmemt: Research and Management, August 25-29, 1980, Kuala Lumpur, pp: 209-215.

Phongsuksawat, P., 2002. Determination of tree biomass in the mangrove habital study area, changwat phangnga. Master Thesis, Kasetsart University, Bangkok, Thailand.

Pierce, L.L. and S.W. Running, 1988. Rapid estimation of coniferous forest leaf area index using a portable integrating radiometer. Ecol., 69: 1762-1767.

Putz, F.E. and H.T. Chan, 1986. Tree growth, dynamics and productivity in a mature mangrove forest in Malaysia. For. Ecol. Manage., 17: 211-230.

Sawangchat, S., 2001. Heavy metals concentration in water at Leam Pak Bier mangrove area, Phetchaburi province, receiving effluent from municipal wastewater treatment system. Master's Thesis, Graduate School Kasetsart University, Bangkok Thailand.

Schlesinger, W.H., 1990. Evidence from chronosequence studies for a low carbon-storage potential of soils. Nature, 348: 232-234.

Soares, M.L.G. and Y. Schaeffer-Novelli, 2005. Above-ground biomass of mangrove species. I. Analysis of models. Estuarine, Coastal Shelf Sci., 65: 1-18.

Sridang, S., 2008. Estimation of above-ground carbon sequestration on mangrove forest at koh lanta, krabi province using remote sensing techniques. Master Thesis, Graduate School Kasetsart University, Bangkok Thailand.

Tomlinson, P.B., 1986. The Botany of Mangroves. Cambridge University Press, Cambridge, UK., Pages: 419.

Vaiphasa, C., A.K. Skidmore and W.F. de Boer, 2006. A post-classifier for mangrove mapping using ecological data. ISPRS J. Photogrammetry Remote Sens., 61: 1-10.

Zar, J.H., 1996. Biostatistical Analysis. 3rd Edn., Prentice Hall Inc., Englewood Cliffs, New Jersey, USA.