Original research article

Nutrient Accumulation by Litterfall in Mangrove Forest at Klong Khone, Thailand

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ABSTRACT

Litter production is one of the major nutrient enrichments in a mangrove forest. Investigation on nutrient components in litter will lead to evaluation of nutrient accumulation. Therefore, this research aimed to 1) evaluate litter production in tropical mangrove forest at Klong Khone, Samut Songkhram province, Thailand; 2) investigate carbon, nitrogen and phosphorus contents in litter; and, 3) observe sediment quality and existing mangrove condition in the study area. Litter and sediment were collected at Klong Khone, Samut Songkhram province in September-October 2015. Litter samples were analyzed for biomass production, and composition of carbon, nitrogen and phosphorus. Sediment samples were analyzed for pH, salinity, water content, grain size composition, organic carbon, total nitrogen and total phosphorus. Results showed that leaf, branch, and fruit litter production were 65.02, 47.94 and 19.03 g DW/m^2/month, respectively. Carbon, nitrogen, and phosphorus content in the litter were 20.36, 0.37 and 4.47 mg/g DW leaf litter, respectively. The value of pH, salinity and water content of sediment ranged from 6.66-7.50, 3.30-9.28 ppt and 52.24-69.65%, respectively. Sediment was composed of fine sand (0.125-1 mm) 7.68%, silt (0.06-0.125 mm) 6.13%, and clay (smaller than 0.06 mm) 86.19%. By using statistical analysis (t-test), results showed no difference of all parameters between months. However, during the research, it was found that organic carbon decreased 2.37 mg C/g DW sediment; meanwhile nitrogen and phosphorus increased 0.44 mg N and 0.12 mg P /g DW sediment, respectively. Finally, carbon, nitrogen and phosphorus accumulation by litterfall were found to be 1877, 34 and 734 mg/m^2/month, respectively. These results will help in clarifying nutrient dynamic pathway by mangrove trees which play an important role in coastal and estuarine ecosystem restoration.

Keywords: Litter; Mangrove; Nutrient dynamic; Carbon sink; Sediment quality

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Introduction

Mangroves play the important role in a coastal and estuarine ecosystem through their highly primary productivity, sinks of sediment, nutrient and organic matter [1, 2]. However, many mangrove soils have extremely low nutrient availability [3]. Litterfall is the major nutrient input into mangrove areas. When leaves fall, nutrients are released through their decomposition and accumulated in sediment. These nutrients are resorbed by trees for growth. In addition, these plant litters are consumed by leaf-eating crabs [4], gastropods, worms [5], and some insects, such as termites [6], as their main food source. Therefore, nutrient enrichment by litter does not only promote nutrient recycling in mangroves, but also provides complex marine food web and house for aquatic nursery.

Although available nutrients can be influenced by many factors such as tidal inundation, sediment quality, fauna, and microbial activities [3], only litter production and its nutrient content (carbon, nitrogen and phosphorus) were emphasized in this research as its strongly input nutrients into mangrove ecosystem. The nutrient pool of a mangrove forest is stored in sediment, not in trees [7]. Litter brings nutrients back into sediment. More than 50% of carbon in sediment comes from litterfall [1, 2]. Nitrogen and phosphorus are known as limited factors for mangrove trees due to lack of nutrient source. Again, litterfall as leaves, branches and fruit is a major input of nitrogen and phosphorus [3, 7]. There are several researches on mangrove nutrition which focused on litter production and abundant nutrients in litter and sediment [8-11], but there is little documented in tropical mangrove forests located in Thailand, especially Klong Khone, Samut Songkharm province.

Nutrient accumulation by litterfall in Klong Khone mangrove may differ from those researches since litter production and nutrition may be varied by plant species, latitude, salinity, tidal amplitude, pollution and characteristic of atmospheric conditions [12]. Therefore, this research aimed to explore litter production and its organic carbon (C), total nitrogen (N) and total phosphorus (P) content in this specific area. The results of this study will assist in clarification of the nutrient dynamic in mangroves, especially at Klong Khone, and also provide basic information for further study in ecological service especially carbon sink by mangrove and saving biodiversity through providing food source.

Materials and Methods

Study area

Klong Khone is watercourse from Maeklong River located at Samut Songkhram Province, Thailand. Klong Khone mangrove forest is located in Amphoe Muang district where the mangrove area is 7,986.25 rai or 1,277.8 ha [34]. The research was conducted in Klong Khone tropical mangrove forest at its run off area from September - October 2015. Six sample stations (KB 1-6) are shown in Fig. 1.

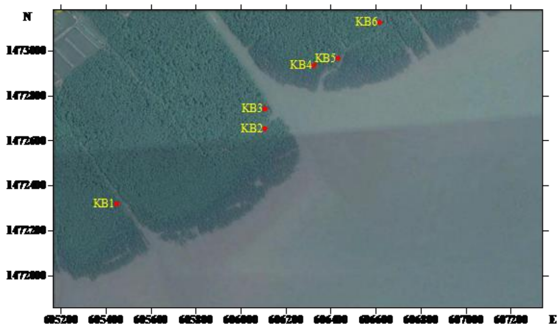

Fig. 1. Sampling station at Klong Khone, Samut Songkhram province, Thailand.

At each station, litter production and sediment were collected. In addition, the existing density of mangroves was defined by the number of trees in a plot 10x10 m which was located around litter traps. All trees in the plot were identified species and measured for stem diameter at breast height

(DBH). By employing these data, relative density (RD), relative dominance (RDo), relative frequency (RF), and importance value index (IVI) were calculated.

Litter analysis

Litter samples were collected by using litter traps (1x1 m, 30 cm depth) with 1 mm mesh. All traps were placed on September 16, 2015 and collected on October 17, 2015. Each trap was suspended above the ground around 1.5 m or above the maximum tide level (high tide). The litter trap was done in triplicate per station. After litter was collected, it was sorted into the component of leaves, branches and fruits. Each component was dried in a hot air oven at 105ºC for 3 days. Then, the sample was weighed by an analytical balance, and recorded as biomass of litter (g DW).

The dried litter was milled into fine particles. Finally, determination of nutrient content as C, N and P in each litter component was done by wet oxidation method [13], Kjeldahl method [14] and $HClO_4$ digestion [15], respectively.

Sediment analysis

In order to investigate nutrient accumulation, sediment near the litter trap was sampled before and after litterfall collection in September and October, respectively. The sediment was sampled at 0-1 cm depth from sediment surface by gravity core. All samples were stored in a refrigerator (-4ºC) waiting for further analysis. Each sample was analyzed for C, N and P by using the same procedure as a determination of nutrient content in litter. In addition, sediment characteristics such as pH, salinity, water content, and grain size were investigated. In order to examine pH and salinity of each sediment sample, 10 g of fresh sediment was sampled and stirred with 20 ml of distilled water until well-mixed [35]. After that, the samples were placed in room temperature until all sediments settled down. Finally, pH and salinity were conducted from supernatant by using Cybercan PC 300 (EUTECH Instruments, Singapore) and refractometer, respectively. Water content known as percentage of water in the sediment was determined by subtraction of dry weight (after dried in hot air oven at 105ºC for 3 days) from wet weight. Grain size was analyzed by using a sieve with pore size 1, 0.125 and 0.06 mm to represent composition of sand, silt and clay, respectively [35]. Finally, all parameters were investigated the differentiation between before and after collected litterfall by using statistical analysis (t-test) in Microsoft Excel 2010.

Results and Discussion

Mangrove density and species

Total tree density in the study area was 1,700 trees/ha, and the highest IVI was *Avicennia alba* followed *by Rhizophora mucronata*, and *Sonneratia caseolaris*, respectively (Table 1). DBH of *Avicennia alba, Sonneratia caseolaris*, and *Rhizophora mucronata* were found to be 21.3 ± 11.0, 26.4 ± 0.0, and 6.4 ± 2.6 cm, respectively. Tidal current at the study area is semi-diurnal. As shown in Fig. 2, there were seedlings only at KB 5 and 6 where were plantation areas for ecotourism, while the highest tree density was found in KB 3 at 2,800 trees/ha.

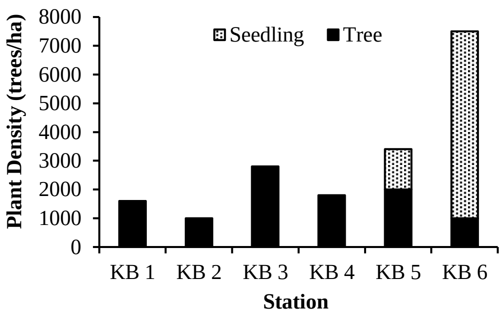

Fig. 2. Mangrove densities at Klong Khone, Samut Songkhram province, Thailand.

Table 1. Relative density (RD), relative dominance (RDo), relative frequency (RF), and importance value index (IVI) of mangrove tree at Klong Khone, Samut Songkhram province, Thailand.

Species	RD (%)	RDo (%)	RF (%)	IVI
Avicennia alba	46.08	87.87	41.67	176
Sonneratia caseolaris	0.98	2.62	8.33	12
Rhizophora mucronata	52.94	9.51	50.00	112

Our results showed that the tree densities found in this study were in the range of mangrove forests in Thailand [16-19] and other tropical regional countries [9, 20, 21] (Table 2). Mangrove density tended to increase from year 2012 which was recorded as 1,580 trees/ha [19]. This finding may be because local people have developed increased awareness of mangrove forest value on its accretion. Environmental friendly tourism was promoted to increase their income, and planting mangrove trees is the most popular recreation activity. Since, the tree species may differ compared to others due to this reforestation activity.

Litter production

In this research, litterfall was 132 g DW/m^2/month. Components of leaf, branch and fruit were found to be 49.27, 36.32 and 14.42% of total litter production (Fig. 3). Total litter biomass may not differ between years, but variation during the year can be found [8]. The variation can be caused by many factors such as climate characteristics, air temperature, wind speed and rainfall [8, 11, 22]. Our result on litter production may over estimate due to only collecting during the rainy season when high litter production is recorded [8, 11, 22]. However, litter production found in this study was comparable with other researches located in tropical mangrove forests (Table 2), and the highest composition of litter was leaf which generally was found by other researchers [8, 11, 22].

In addition, litter production may be varied by mangrove characteristics such as tree species, age, DBH, and density. Bernini and Rezende [22] found that mangrove forests with high density of *R. mangle* produced the highest litter followed by *A. germinans* and *Lagucularia racemosa*, respectively. As shown in Table 2, higher litter productions were found in mangrove forests with high density of *Rhizophora* spp. In this study, the highest litter production was found in KB 1 where the dominant species is *R. mucronata*. Although the highest tree density was found in KB 3, the litterfall was extremely lower than KB 1 (Fig. 2). This may be due to difference in the age of trees. As shown in Table 3, the average DBH of trees in KB 1 was smaller than KB 3. This demonstrates that trees in KB 1 are younger than KB 3. Our results also showed that litter production in KB 4 was higher than KB 5 (Fig. 2) with smaller DBH (Table 3). Hence, it can be stated that younger trees produced more litter than the older. This fact was found by Clough et al. [23] who documented that in mangrove forest with dominant *R. apiculata* in Ca Mau, Vietnam, litter productions declined with forest ages (6-36 years). Similar results were also found by Ye et al. [11] where the younger mangrove forest with dominant *Kandelia obovata* (24 years) had significantly higher production of total, leaf and branch litter than the older forest (48 years).

Considering similar plant species, high tree density resulted in high litter production [9, 20]. This agrees with our research. As shown in Fig. 3, the lowest litter production (13.33 g DW m^2/month) was found in KB 6 with the lowest tree density (Fig. 2). Although density of trees in KB 4 was found to be greater than KB 2, litter production was similar (Fig. 3). This could be caused by difference in tree species and, subsequently, difference in litter production and components. Composition of fruit litter found in KB 4 and KB 2 was 45.33 and 8.60 % of total litterfall, respectively. This may be due to a much higher density of *Avicennia alba* in KB 4 (Table 3). In total litter production, *Avicennia* sp. produced less than *Rhizophora* sp., but in composition they produced a larger amount of fruit litter. Meanwhile, *Rhizophora* sp. produced more branches and leaves than other mangrove species [22].

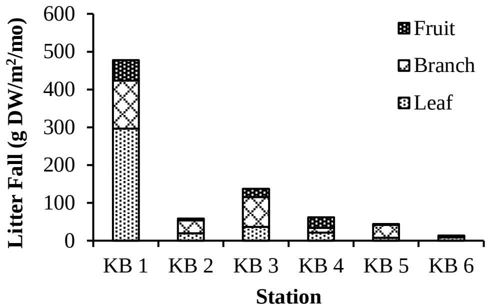

Fig. 3. Litter production at Klong Khone, Samut Songkhram province, Thailand.

Table 2. Tree species, density (trees/ha) and litterfall ($g/m^2/year$) of some tropical mangrove forests.

Region	Species	Tree density	Litterfall	Ref.
Thailand	*Avicennia alba, Rhizophora mucronata, Sonneratia caseolaris*	1700	1583	This study
	A. alba	320-1752	619-752	[16]
	Avicennia sp., *Rhizophora* sp., *Sonneratia* sp.	1877	1093	[17]
	Ceriops tagal	2987	875	[18]
Brazil	*R. mangle*	3200	1230	[9]
	R. mangle, A. germinans, Laguncularia racemosa	1800-4400	900	[20]
Australia	*R. stylosa*	1900-3000	1396	[21]

Table 3. Trees species, density and stem diameter at breast height (DBH) of each sampling station found in this study.

Station	Species	Density (trees/ha)	DBH (cm)
KB 1	*Rhizophora mucronata*	1200	2.96 ± 0.93
	Avicennia alba	400	18.53±10.80
KB 2	*R. mucronata*	300	3.82 ± 2.20
	A. alba	700	22.91 ± 5.07
KB 3	*R. mucronata*	2700	7.88 ± 1.62
	Sonneratia caseolaris	100	26.41 ± 0.00
KB 4	*R. mucronata*	100	6.36 ± 0.00
	A. alba	1700	14.67 ± 6.42
KB 5	*R. mucronata*	1000	7.10 ± 2.21
	A. alba	1000	28.57±16.37
	*R. mucronata**	1000	< 1.5
	*A. alba**	400	< 1.5
KB 6	*R. mucronata*	100	6.36 ± 0.00
	A. alba	900	20.36 ± 8.20
	*R. mucronata**	6500	< 1.5

Note: * is seedling species

Nutrient accumulation by litterfall

Results from a nutrient analysis in each litter component reveal that carbon contents in leaf, branch and fruit were 20.46 ± 8.40, 22.11 ± 8.66 and 17.26 ± 5.30 mg C/g DW litter, respectively. Nitrogen contents in leaf, branch and fruit were 0.37 ± 0.20, 0.34 ± 0.08 and 0.36 ± 0.14 mg N/g DW litter, respectively. Phosphorus contents in leaf, branch and fruit were 4.47 ± 2.16, 3.80 ± 1.41 and 4.77 ± 1.07 mg P/g DW litter, respectively. Finally, by multiplying nutrient content in litter with biomass of each litter component, total carbon, nitrogen and phosphorus accumulation by litterfall were 1877, 34 and 734 $mg/m^2/month$, respectively. The depositions of these nutrients were varied by litter biomass of which the highest value was found in KB 1 (Fig. 4).

Our results on nutrient accumulation by litterfall were much lower than other researches [11, 24-26]. Lower nutrient content in the litter may be due to lack of nutrients available in the ecosystem. In the study area, litterfall was only the main nutrient source. Klong Khone is a small canal from Maeklong River so the nutrient import from the river is not high. As shown in Table

4, nutrients in sediment found in this study are lower than other mangroves in Thailand where organic matter, nitrogen and phosphorus were found in a range of 56.0-10.52, 3.4-6.3 and 0.6-0.7 mg/g DW, respectively [27]. However, C/N ratio in each litter component is found to be similar to the others [11, 24]. Our result showed that C/N ratios of leaf, branch and fruit were 55.58, 64.72 and 48.32, respectively. This demonstrates that although the amount of available nutrients is different, the portion of nutrient absorption is similar [3].

As shown in Fig. 4, in total litter production, the highest carbon and nitrogen content was found in branches, but the highest phosphorus was found in leaves. Carbohydrate and protein are more highly assimilated in branches which are the hardest part to decompose. A mangrove branch contains lignin, a strong organic compound which is toxic to some living organisms; subsequently, it is difficult to biodegrade. To increase the decomposition rate, an enhanced microorganism resulting from fertilization with phosphorus is necessary [25]. On the other hand, the leaf is the easiest part to decompose [8]. Carbon and nitrogen leaching was found during the early phase of leaf litter decay [24]. Litter decomposition rates can be varied by climate characteristics, plant species, leaf anatomy, and chemical composition such as nutrient and lignin concentration. Due to high air temperature in the study area which is a tropical mangrove forest, nitrification reaction is much faster than phosphorus degradation [3]. Therefore, phosphorus content still remains in litter tissue, unlike carbon and nitrogen. Phosphorus in leaves will be degraded by microorganisms in sediment. The dissolved reactive phosphate, available in a form for trees growth, originates from binding of phosphorus to refractory organic material and oxidized Fe in the sediment [28]. Hence, our results confirm that leaf litter is a phosphorus pool in mangrove ecosystem.

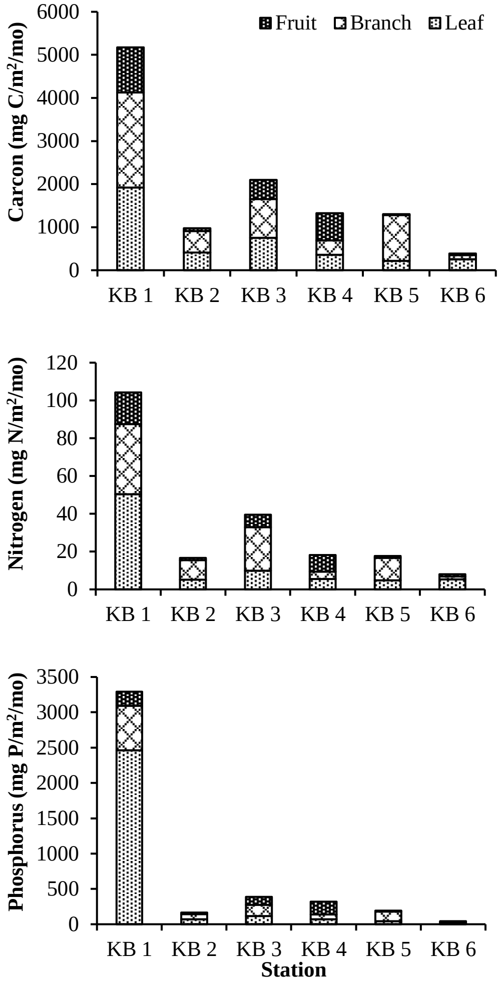

Fig. 4. Accumulation of carbon (top) nitrogen (middle) and phosphorus (below) by litterfall (mg/m^2/mo) in September-October 2015 at Klong Khone, Samut Songkhram province, Thailand.

Table 4. Sediment characteristic in September and October 2015.

Sediment quality	September	October
pH	7.29 ± 0.16	6.89 ± 0.16
Salinity (ppt)	6.77 ± 2.56	6.32 ± 0.82
Water content (%)	57.63 ± 6.49	59.81 ± 3.11
Grain size composition		
0.125-1 mm	4.20 ± 1.74	7.68 ± 4.86
0.06-0.125 mm	4.69 ± 2.61	6.13 ± 2.53
< 0.06 mm	91.11 ± 3.20	86.19 ± 5.97
Carbon (mg C/g DW)	13.00 ± 3.35	10.63 ± 2.88
Nitrogen (mg N/ g DW)	0.89 ± 0.16	1.33 ± 0.28
Phosphorus (mg P/g DW)	0.25 ± 0.09	0.37 ± 0.07

Even though statistical analysis (t-test, $\alpha = 0.05$) showed that there was no significant difference in sediment characteristics between before and after collected litterfall, some evidences on nutrient accumulation trends can be found. As shown in Table 4, pH was slightly lower in October. This demonstrated that there were decomposition activities by micro-organisms. Soil microorganisms produced an organic acid component as a byproduct of their digestion process [36]. During the research, salinity and water content were similar but grain size composition of fine sand (0.125-1 mm) was found to be a little higher in October (Table 4). This demonstrates that not only microorganisms degraded the litter but also other macrofauna. These benthic fauna consumed the litter and released some excretions as their faeces [4-6]. These faeces can be compacted with the fine sediment particles; subsequently, larger grain size can be found. Moreover, carbon content in sediment decreased 2.37 mg C/g DW from September to October. In contrast, nitrogen and phosphorus increased 0.44 mg N and 0.12 mg P/g DW, respectively.

In this study, results in litter production showed that the highest nutrient component in litter was carbon (Fig. 4); however, carbon content in sediment was found to be lowered. This carbon loss in sediment may be due to rapid decomposition and significant usage by microorganism [29]. High atmospheric temperature causes a higher metabolic rate of bacteria. The research by Alongi et al. [30] demonstrated that the rate of total carbon metabolism in summer was higher than in autumn, in a range from 518-624 mmol C/m^2/day, and the carbon mineralization efficiency increased with increases in tidal elevation. In addition, litter can be directly consumed by macrofauna such as leaf-eating carp, gastropod and worms [5], and also support meiofauna growth such as copepods [31]. Trees also significantly absorb dissolved organic matter for their growth. High absorption of organic matter could also be found in plantation areas. The study on dissolved organic matter (DOM) fluxes in cropland and adjacent forest by Fujii et al. [32] showed that DOM is constantly low due to high absorption by trees. This agrees with research by Jaiarree et al. [33] who documented that organic carbon was found to decrease 47% after 12 years of cultivation of maize fields in Thailand. Hence, loss of carbon in sediment can be found in mangrove due to significant usage by a variety of living organisms (microbial, fauna and trees) with limited carbon source.

The amount of nitrogen and phosphorus in the sediment increased during the study period due to higher immobilization rate and an earlier onset of mineralization. After microbial organisms consume organic carbon for their growth, they assimilate nitrogen and phosphorus into their cell as a compartment of protein, nucleic acid, lipid and ATP. This assimilation is a result from net immobilization such as binding of external nitrogen and phosphorus in microbial biomass [8, 25]. Tide elevation can cause higher nitrogen mineralization [30]. Finally, consistent increasing of nitrogen and phosphorus was found as long-term accumulation into the detritus by litter decomposition [24].

Conclusion

In tropical mangrove forest at Klong Khone, Samut Songkhram, province, Thailand, total litter production was 132 g DW/m^2/month with tree density 1700 trees/ha. The dominant plant species were *A. alba*, *R. mucronata*, and *S. caseolaris*. The highest litter component was leaf followed by branch and fruit, respectively. Total litter production, and nutrient (carbon, nitrogen, and phosphorus) content demonstrated nutrient accumulation by litterfall as 1877, 34 and 734 mg/m^2/month. Changes in nutrients in sediments revealed decreased carbon and increased nitrogen and phosphorus over time. Our results suggest that long-term accumulation of nitrogen and phosphorus by litter decomposition can be a significantly important nutrient pool in a mangrove ecosystem. This result can promote mangrove litter as an ecological service by providing food sources and ecological value by increasing biodiversity. Finally, it can be a global benefit for climate change as a carbon sink and storage of approximately 0.23 ton/ha/year by litterfall.

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References

[1] Robertson AI, Alongi DM. Tropical mangrove ecosystems. American Geophysical Society. Washington D.C.; 1992.

[2] Conell DW, Hawker OW. Pollution in tropical aquatic systems. Boca Raton: CRC Press; 1992.

[3] Reef R, Feller IC, Lovelock CE. Nutrition of mangroves. Tree Physiol 2010;30:1148-60.

[4] Robertson AI. Leaf-burying crabs: Their influence on energy flow and export from mixed mangrove forests (*Rhizophora* spp.) in northeastern Australia. J Exp Mar Biol Ecol 1986;102: 237-48.

[5] Kristensen E, Bouillon S, Dittmar T, Marchand C. Organic carbon dynamics in mangrove ecosystems: a review. Aquatic Botany 2008;89:201-19.

[6] Nagelkerken I, Blaber SJM, Bouillon S. The habitat function of mangroves for terrestrial and marine fauna: a review. Aquatic Botany 2008;89:155-85.

[7] Alongi DM, Clough BF, Dixon P, Tirendi F. Nutrient partitioning and storage in arid-zone forests of the mangroves *Rhizophora stylosa* and *Avicennia marina*. Trees-Struct Funct 2003;17:51-60.

[8] Tam NFY, Wong Y, Lan C, Wang L. Litter production and decomposition in a subtropical mangrove swamp receiving wastewater. J Exp Mar Biol Ecol 1998:226:1-18.

[9] Silva CAR, Oliveira SR, Rêgo RDP, Mozeto AA. Dynamics of phosphorus and nitrogen through litter fall and decomposition in a tropical mangrove forest. Mar Environ Res 2007:64:524-34.

[10] Bernin E, Rezende CE. Litterfall in a mangrove in Southeast Brazil. PANAMJAS 2010;5(4):508-19.

[11] Ye Y, Chen YP, Chen GC. Litter production and litter elemental composition in two rehabilitated *Kandelia obovata* mangrove forests in Jiulongjiang Estuary, China. Mar Environ Res 2013;83:63-72.

[12] Kathiresam K, Bingham BL. Biology of mangroves and mangrove ecosystems Adv Mar Biol 2001;40:81-251.

[13] Allison LF. Organic carbon. In: Black CA, editor. Method of soil analysis Part 2, Agronomy No.9. Wisconsin: American Society of Agronomy Madison; 1965.

[14] Bremner JM, Mulvaney CS. Nitrogen-total. In: Page AL, Miller RH, Keeney DR, editors. Methods of soil analysis Part 2, Agronomy No.9. Wisconsin: American Society of Agronomy Madison; 1982.

[15] Olsen SR, Sommer LE. Phosphorus. In: Page AL, Miller RH, Keeney DR,

editors. Methods of soil analysis Part 2, Agronomy No.9. Wisconsin: American Society of Agronomy Madison; 1982.

[16] Kruajan S. Quantity and quality of organic matter in mangrove forest with the emphasis on *Avicennia alba* dominated. TIJSAT 2011;1:27-37.

[17] Poungparn S, Aksornkoae S, Komiyama A. Mangrove forest as a prominent sink of atmospheric carbon: The study on NPP. Bangkok: Research report funded by Office of the Higher Education Commission and Thailand Research Fund; 2011.

[18] Pattanasing N. Biomass production, litter fall and litter decomposition Prednai community mangrove forest of Trat province [M.S. thesis]. Bangkok: Kesetsart University; 2012.

[19] Attawattana B. Existing condition of mangrove forest at the upper gulf of Thailand (Samut Prakan, Samut Sakhon, Samut Songkhram, and Phetchaburi Provinces), Bangkok: Technical paper of Office of Defense to manage coastal erosion and coastal areas; 2012.

[20] Bernini E, Chagas T, Lage-Pinto F, Calegario G, Rezende E. Phytosocio logy and litterfall in the mangrove estuary of the Itabapoana river, Southeast Brazil. PANAMJAS 2014;9(2):88-102.

[21] Alongi DM. Patterns of mangrove wood and litter production within a beach ridge-fringing reef embayment, Northern Great Barrier Reef Coast. Estuar Coast 2011;34:32-44.

[22] Bernini E, Rezende CE. Litterfall in a mangrove in Southeast Brazil. PANAMJAS 2010;5(4):508-519.

[23] Clough B, Tan DT, Phuong DX, Buu DC. Canopy leaf area index and litter fall in stands of the mangrove *Rhizophora apiculata* of different age in the Mekong Delta, Vietnam. Aquatic Botany 2000;66:311-320.

[24] Devis III SE, Corronado-Molina C, Childers DL, Day Jr. JW. Temporally dependent C, N, and P dynamics associated with the decay of *Rhizophora mangle* L. leaf litter in oligotrophic mangrove wetlands of the Southern Everglades. Aquatic Botany 2003;75: 199-215.

[25] Keuskamp JA, Hefting MM, Dinge mans BJJ, Verhoeven JTA, Feller IC. Effects of nutrient enrichment on mangrove leaf litter decomposition. Sci Total Environ 2015;508:402-410.

[26] Yamashita N, Ohta S, Sase H, Luangjame J, Visaratana T, Kievuttinon B, Garivait H, Kanzaki M. Seasonal and spatial variation of nitrogen dynamics in the litter and surface soil layers on a tropical dry evergreen forest slope. Forest Ecol Manag 2010;259:1502-12.

[27] Sungjan K. Variation of organic matter and nutrient in mangrove sediments dominated by *Avicennis alba* BI. TIJSAT 2011;2:28-39.

[28] Nielson T, Anderson F.Ø. Phosphorus dynamics during decomposition of mangrove (*Rhizophora apiculata*) leaves in sediments. J Exp Mar Biol Ecol 2003;293:73-88

[29] Chen R, Twilley RR. A simulation model of organic matter and nutrient accumulation in mangrove wetland soils. Biogeochemistry 1999;44:93-118.

[30] Alongi DM, Pfitzner J, Trott LA, Tirendi F, Dixon P, Klumpp DW. Rapid sediment accumulation and microbial mineralization in forests of the mangrove *Kandelia candel* in the Jiulongjiang Estuary, China. Estuar Coast 2005;63:605-18.

[31] Gee JM, Somerfield PJ. Do mangrove diversity and leaf litter decay promote meiofaunal diversity? J Exp Mar Biol Ecol 1997;218:13-33.

[32] Fujii K, Funakawa S, Hayakawa C, Sukartiningsih, Kosaki T. Fluxes of dissolved organic carbon and nitrogen in cropland and adjacent forests in a clay-rich Ultisol of Thailand and a sandy Ultisol of Indonesia. Soil Till Res 2013;126,:267-75.

[33] Jaiarree S, Chidthaisong A, Tangtham N, Polprasert C, Sarobol E, Tyler SC. Soil organic carbon loss and turnover resulting from forest conversion to maize fields in Eastern Thailand. Pedosphere 2011;21(5):581-90.

[34] Department of Marine and Coastal Resources 2016, KM: Knowledge Management database. [cited 2013 Dec 3]. Available from: http://marinegis center.dmcr.go.th/km/mangrove_samut songkhram/#.WEJ66LJ97IV

[35] Beck R. Soil analysis handbook of reference methods, Soil and Plant Analysis Council. Boca Raton: CRC Press; 1999.

[36] Chandrasekaran S. Production of organic acids by soil micro-organisms. Plant Soil 1969;30: 299-304.