Carbon and Nutrient Storages in an Upper Montane Forest at Mt. Inthanon Summit, Northern Thailand

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ABSTRACT

Investigation on carbon and nutrient storages in the ecosystem of an upper montane forest (UMF) was carried out at Mt. Inthanon, the highest mountain in Thailand. A method of plant community analysis was used for studying vegetation structure and plant species diversity. Fifty sampling plots, 40×40 m^2 in size, were arranged using a stratified random technique over the forest from about 2,000 m to 2,565 m above mean sea level. Forest biomass of 47 woody species was calculated using allometric equations. The total plant biomass was estimated to be 703.8 Mg/ha. The total amounts of stored carbon, nitrogen, phosphorus, potassium, calcium and magnesium in the biomass were calculated to be 347.91 Mg/ha, 4,038.79 kg/ha, 459.07 kg/ha, 2,001.37 kg/ha, 7,112.48 kg/ha and 1,515.47 kg/ha, respectively. *Quercus eumorpha* had the highest amount of nutrient storage, followed by *Syzygium angkae*, *Shima wallichii*, *Litsea martabarnica*, *Lindera caudata*, etc. The annual amounts of recycling through litterfall for these nutrients were in the following order: 3,425.31 kg/ha, 121.21 kg/ha, 5.54 kg/ha, 33.04 kg/ha, 303.06 kg/ha and 10.41 kg/ha. Their total amounts in organic layers were measured to be 19.46 Mg/ha, 594.30 kg/ha, 36.51 kg/ha, 101.78 kg/ha, 488.59 kg/ha and 56.64 kg/ha, respectively. The total amounts of carbon, nitrogen, extractable P, extractable K, extractable Ca and extractable Mg in a one meter soil profile were evaluated to be as follows: 262.47 Mg/ha, 10,209.41 kg/ha, 87.71 kg/ha, 227.24 kg/ha, 270.76 kg/ha and 64.69 kg/ha, respectively. Thus, the total ecosystem storages of carbon and nitrogen were in the following order: 629.84 Mg/ha and 14,842.50 kg/ha. The storages of the two nutrients were high in this forest as it is an abundant forest that has not had forest fire and low levels of soil erosion.

Keywords: Mt. Inthanon/ Upper montane forest/ Carbon storage/ Nutrient storages
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1. INTRODUCTION

Forests in northern Thailand are typically classified into five types: the dry dipterocarp forest (DDF), mixed deciduous forest (MDF), dry evergreen forest (DEF), pine forest (PF) and montane forest (MF). The montane forest (MF) has been divided into two subtypes, lower (LMF) and upper montane (UMF) forests, according to species composition, altitude and ecological nature (Santisuk, 1988). The LMF and UMF cover at the altitude range of about 1,000-1,500 and 1,500-2,565 m.m.s.l., respectively. Species composition and vegetation structure of the UMF at the summit of Mt. Doi Inthanon were reported by Khamyong et al. (2004). This forest consisted mainly of the temperate tree species and was lesser in species richness compared to the LMF.

The UMF at Mt. Inthanon summit is an old growth forest, and considered as topographic climax forest since it covers the high mountain above 2,000 m.m.s.l. Some parts of the forest were disturbed in the past because of the cultivation shifting, and now, the area of remaining abundant forest is only about five square kilometers. Thus, it is a rare forest ecosystem of the country. The microclimate as well as the forest vegetation is attractive to tourists due to the low temperature, the cloud or fog covering in rainy season and also winter, and to the flowering of some rare species particularly the *Rhododendron* species. In the UMF, the plant species composition and diversity were different from the LMF. Khamyong et al. (2004) reported that by using 50 sampling plots of area 40×40 m^2, they recorded 47 tree species (39 genera, 26 families) in the sampling plots with a tree density of 934 trees/ha. *Quercus eumorpha* had the highest dominance and importance value, followed by *Syzygium angkae*, *Litsea martabarnica*, *Helicia nilagirica*, *Lindera caudata*, *Schima wallichii*, *Osmanthus fragrans*, *Eurya accuminata* and *Myrsine semiserrata*, respectively. The value of Shannon-Wiener index of species diversity was relatively high, at 4.2.

In the forest ecosystem, carbon cycling is a functional process, which is important for the global carbon cycling and balance. Theories about the carbon cycling in forest ecosystems have been reviewed (Landsberg and Gower, 1997; Waring and Running, 1998). The cycling pathways involve three parts. The first part is carbon input mainly through photosynthesis. The second is the internal carbon cycling which consist of many processes such as litterfall, litter decomposition, mineralization, immobilization, soil respiration, etc. The carbon can be stored in plant biomass, animals, organic layers on the forest floor and soil. The third is carbon losses from the forest ecosystem especially through autotrophic and heterotrophic respiration, soil erosion, forest fire, and havesting of wood and non-wood products. Other nutrients also have the similar pathways.

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However, their cycling processes are different among the different kinds of nutrients (Kimmins, 2004). These plant nutrients especially nitrogen, phosphorus and potassium are macronutrients which influence on the growth of forest vegetation.

Forests have the different potentials of carbon and nutrient absorption, accumulation, and loss, which result in the variable amounts of carbon and nutrient storages in their ecosystems. Sahunalu (1994) reported that the net primary production in 52 sites of the DDF with six subtype communities in Thailand (for tree species over 10 cm dbh) varied with the sites, and had the mean value of 5.77 Mg/ ha/year, calculated to the carbon amount of 2.89 Mg/ ha/year. Few publications are available on the total ecosystem carbon and stocks in the forests of Thailand. Tsutsumi et al. (1983) found that total ecosystem carbon stock of mixed DEF-MDF at Nam Phom, Chaiyaphum province, northeastern region was 262.9 Mg/ha whereas the greater amount for the primary forest (LMF and MDF) was reported to be 357.62 Mg/ha on an average (Pibumrung et al., 2008). In the case of other nutrients, there are no data available.

Objective of this research is to explicate the amounts of carbon and macronutrient storages in an ecosystem of the UMF at the summit of Mt. Inthanon, including amounts in the plant biomass, the organic layers on forest floor and the soil.

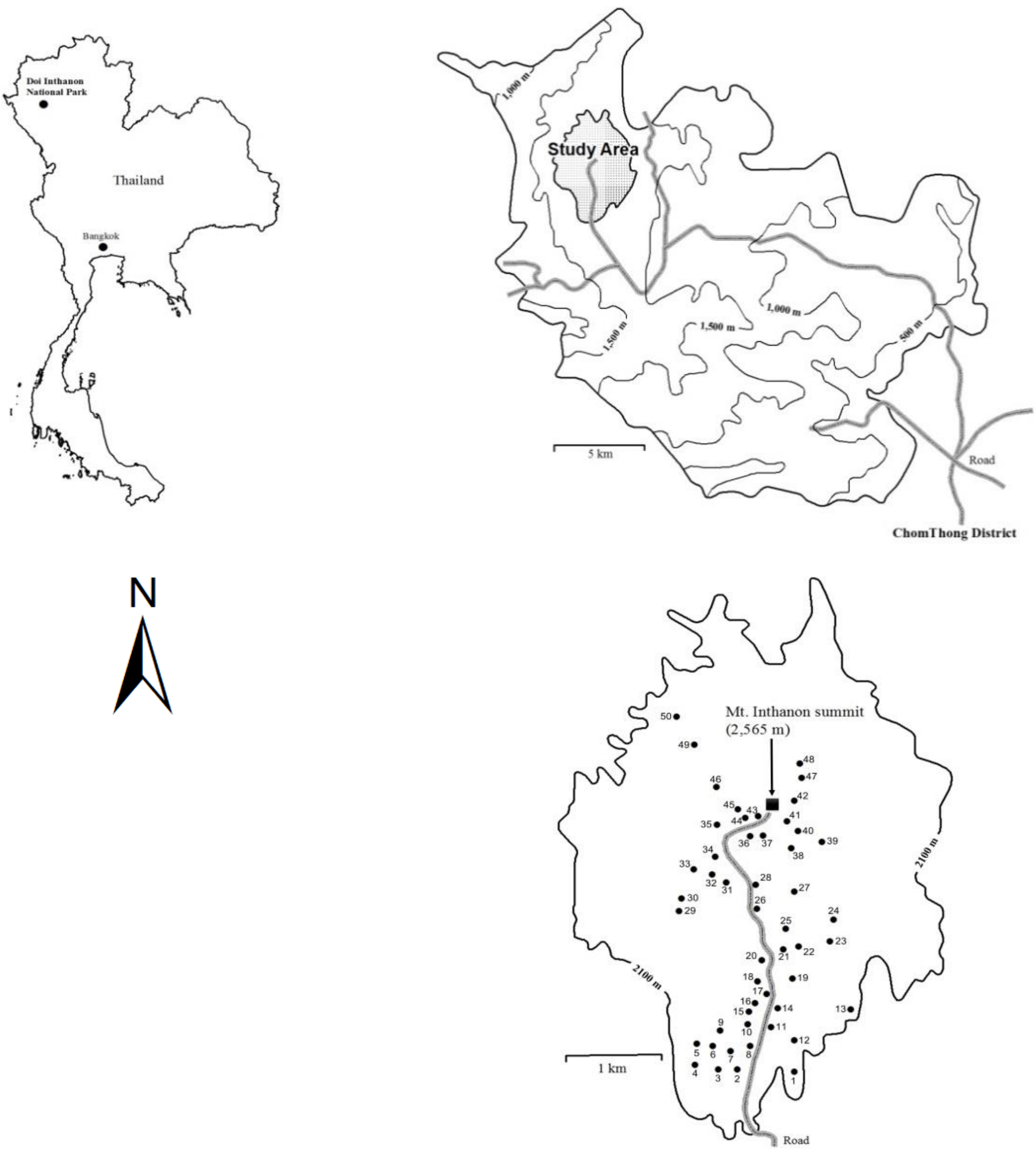

Figure 1. The Doi Inthanon National Park, orthern Thailand, and the 50 sampling plots at 2,080-2,565 m altitude inside the study area around the mountain summit

2. METHODOLOGY

2.1 Study area

Mt. Inthanon, the highest mountain in Thailand, is located in the Doi Inthanon National Park (18ºN24'-18º40'N, 98º24'-98º42'E), about 50 km southwest of the Chiang Mai city, northern Thailand. The National Park was established in 1972, and it covers an area of 482.4 km^2 which ranges across three districts: Chom Thong, Mae Wang, and Mae Chaem. Most of the park is mountainous and belongs to a southern extension of the Himalayan mountain range (MacDonald et al., 1993). The altitude range is between 400 m and 2,565 m at the summit of Mt. Inthanon.

The five major forest types, mentioned in the introduction, are found within the park. The different forest types overlap in their altitudinal ranges: DDF: 400-1,300 m, MDF: 400-800 m, DEF: 600-1,000 m, PF: 700-1,900 m and MF: 1,000-2,565 m. The climate has the monsoonal characteristic with about seven months of rainy season (May through November) and five months of dry season (December through April). At the summit of Mt. Inthanon, the average annual rainfall (1982-1999) was 2,228 mm (Department of National Parks, 2013). The average annual air temperature was 13 ºC, with absolute minimum of 1 ºC and absolute maximum of 23 ºC. During 1999-2012, the mean annual rainfall decreased to 1,986 mm, while the mean maximum and minimum air temperatures adversely increased to 17.37 ºC and 6.38 ºC, respectively (Northern Meteorological Center, 2013). In 2005, the maximum air tempera-ture in the UMF was the highest (19.5 ºC) in April and the lowest in December (11.5 ºC), whereas the minimum temperature varied between 2.5 ºC and 13.0 ºC (Khamyong et al., 2006).

The bedrock underlying the national park forms part of a geological formation mainly composed of gneissic granite that extends discontinuously along the western mountain range of northern Thailand (MacDonald et al., 1993). In this area, various soil types exist such as the Entisols, Inceptisols, Alfisols and Ultisols (Khamyong et al., 1996; Khamyong et al., 2006). The Ultisols are especially common within the park. In the UMF, the Ultisols are characterized by high accumulation of organic matter and extreme acidity, and they are classified as the Suborder Humults.

2.2 Vegetation survey and biomass estimation

The UMF was investigated for the plant species diversity accordance to a plant community analysis method. Fifty plots were established over the forest area using a stratified random sampling technique. All woody plants with a diameter at breast height (dbh) of 4.5 cm or more were identified for species. The dimensions of the plot were 40×40 m^2. Each plot was divided into 16 subplots of area 10 x 10 m^2. To select the position of the plots we used a topography map (1:50,000 scale); also it was difficult to use GPS to locate the plots as they were covered by very close dense forest canopy. In each plot, the sampling of the woody plants included measurement of the stem dbh by plastic tape and estimation of height. The selected plant ecological indices were calculated to provide insight into the diversity and structure of the forest. For all species, frequency, density, dominance and important value index (IVI) were calculated according to Krebs (1985). The results in details about the quantatiative floristic structure in the forest have been reported by Khamyong et al. (2004).

Allometric equations of tree species in the UMF could not be obtained from this study because of no permission of tree cutting in the national park, the biomass data of the woody plants were calculated using the allometric equations of Tsutsumi et al. (1983) who conducted their study on a dry evergreen-mixed deciduous forest at Chiyaphum province, northeastern Thailand. By the fact that broad leaved evergreen forest in Thailand is divided into moist, dry and hill (montane) evergreen forests, and many tree species and genera especially those in the families of Fagaceae, Lauraceae and Theaceae exist in all three forests (Santisuk, 1988).

The dominant tree species in the UMF especially *Schima wallichii*, shown in Table 1, has been reported as a species existed in the dry and moist evergreen forest. These equations are then used to estimate forest biomass in the UMF by this reason.

$$Ws = 0.0509\,(D^2H)^{0.919} \quad (r^2 = 0.978)$$
$$Wb = 0.00893\,(D^2H)^{0.977} \quad (r^2 = 0.890)$$
$$Wl = 0.0140\,(D^2H)^{0.669} \quad (r^2 = 0.714)$$
$$Wr = 0.0313\,(D^2H)^{0.805} \quad (r^2 = 0.981)$$

Where Ws, Wb, Wl and Wr are the stem, branch, leaf and root biomass, respectively.

2.3 Carbon and macronutrient storages in plant biomass

According to Tsutsumi et al. (1983), the average nutrient contents in the stem, branch, leaf, and root organs of 62 tree species are used for the calculation of nutrient amounts in tree biomass: C: 49.90%, 48.70%, 48.30% and 48.12%, N: 0.34%, 0.64%, 1.83% and 0.53%, P: 0.05%, 0.08%, 0.13% and 0.02%, K: 0.16%, 0.34%, 0.91% and 0.27%, Ca: 0.74%, 1.26%, 2.12% and 0.88%, and Mg: 0.08%, 0.27%, 0.92% and 0.08%, respectively.

2.4 Carbon and macronutrient amounts in litterfall

The annual amount of the above ground litterfall was estimated in 2005 using 30 litter traps which were of 60 cm in diameter. The traps were arranged in a 50×50 m^2 sampling plot. Ten litter traps were set every five meters along a slope for three lines (replications). Each line was ten meters apart. The monthly collection of litter in the traps was taken for one year. The litter was separated into leaves, branches and others, and then the composite litter samples were analyzed for the presence and amount of macronutrients.

2.5 Carbon and macronutrient storages in forest floor and soil

Estimation of dry matter of organic layers (Ao or O layers) on the forest floor was taken using five plots of area 20×20 cm^2 sampled randomly three times per year during different seasons. The samples were separated as L-, F- and H-layers, and the analysis for carbon and other nutrients was conducted in a laboratory.

Generally, soil characteristics in a forest vary with sites or topography particularly in the mountainous areas. However, this study selected a sloping area as one representive site of soil study in the UMF. Soil sampling was carried out by making three soil pits of 100 cm depth at the ridge, middle and lower slope sites since they were shallow soils with A-AB-Bt/BC profile and underlying gneissic bed rock within one meter. The samples were collected along each soil profile from the eight layers of 0-5, 5-10, 10-20, 20-30, 30-40, 40-60, 60-80 and 80-100 cm depths.

Table 1. Biomass of standing woody trees and climbers in the UMF after Khamyong et al. (2004)

Species	Biomass (kg/ha)				
	Stem	Branch	Root	Leaf	Total
1. *Quercus eumorpha*	122,092.0	43,202.7	19,200.3	1,739.1	186,233.5
2. *Syzygium angkae*	64,312.5	22,389.6	10,418.1	975.4	98,095.6
3. *Schima wallichii*	59,725.7	21,805.5	8,784.8	727.2	91,043.2
4. *Litsea martabanica*	29,019.2	9,282.9	5,566.1	639.3	44,507.6
5. *Lindera caudata*	25,786.5	8,399.7	4,766.5	522.7	39,475.4
6. *Helicia nilagirica*	23,297.6	7,324.5	4,615.8	549.5	35,787.5
7. *Oamanthus fragrans*	17,221.0	5,526.4	3,285.7	375.3	26,408.4
8. *Ilex umbellulata*	15,045.4	5,089.4	2,593.9	264.5	22,993.2
9. *Castanopsis accuminatissima*	12,669.0	4,320.6	2,137.8	209.4	19,336.8
10. *Eurya acumunata*	11,415.3	3,599.2	2,269.9	275.9	17,560.2
11. *Acer laurinum*	10,780.7	3,569.8	1,934.7	206.3	16,491.5
12. *Lithocarpus echinops*	9,811.4	3,481.0	1,525.6	134.7	14,952.7
13. *Lithocarpus aggregatus*	8,705.6	3,142.4	1,309.9	111.8	13,269.7
14. *Macropanax dispermus*	5,844.7	1,847.5	1,144.2	134.0	8,970.4
15. *Litsea beusekomii*	5,251.6	1,681.4	1,004.8	114.9	8,052.7
16. *Litsea* sp.	4,164.2	1,361.3	764.4	83.4	6,373.2
17. *Eleaocarpus sphaericus*	4,135.5	1,388.0	721.5	74.2	6,319.2
18. *Phoebe cathia*	3,915.2	1,459.1	557.0	45.1	5,976.5
19. *Lithocarpus garretianus*	3,683.9	1,493.3	436.8	27.4	5,641.4
20. *Rapanea yunnanensis*	3,494.8	993.7	843.5	126.9	5,458.8
21. *Phoebe* sp.	3,027.4	1,045.8	500.8	48.7	4,622.7
22. *Symingtonia populnea*	2,640.6	949.5	398.1	33.6	4,021.8
23. *Adinandra intergerrima*	2,467.1	835.8	422.2	42.4	3,767.5
24. *Myrrica esculata*	1,813.2	558.1	372.4	45.7	2,789.5
25. *Litsea paniculata*	1,770.4	592.2	310.3	31.9	2,704.8
26. *Myrsine semiserrata*	1,702.3	462.4	451.0	76.1	2,691.7
27. *Nyssa javanica*	1,655.2	559.9	286.8	29.7	2,531.6
28. *Quercus glabricupula*	1,217.0	411.5	208.2	20.7	1,857.3
29. *Viburnum kerrii*	785.6	246.6	155.8	18.5	1,206.7
30. *Symplocos macrophylla*	632.5	180.0	153.6	23.6	989.8
31. *Engelhardtia spiculatata*	558.6	181.0	104.0	11.4	855.0
32. *Vaccinium sperngellii*	395.5	109.4	101.1	16.3	622.3
33. *Rhododendron arboretum*	250.7	73.9	55.8	7.5	387.8
34. *Pyrenaria diospyricarpa*	230.2	70.4	48.6	6.4	355.7
35. *Camellia* sp.	213.5	66.2	43.9	5.6	329.2
36. *Jusminum dispermum*	133.3	35.5	36.4	6.3	211.5
37. *Sorbus grandulosa*	93.6	27.2	21.5	3.0	145.2
38. *Jusminum attenutum*	89.5	23.5	25.1	4.4	142.5
39. *Tarennoidea wallichii*	85.5	25.3	19.1	2.6	132.5
40. *Prunus phaeostigma*	73.9	19.9	19.7	3.3	116.8
41. *Melodinus cochinchinensis*	68.2	17.7	19.4	3.5	108.9
42. *Podocarpus nerifolius*	63.3	19.0	13.5	1.7	97.5
43. *Ficus* sp.	58.8	18.3	11.6	1.3	90.1
44. *Symplocos* sp.	32.6	8.7	8.7	1.5	51.5
45. *Trichilla conaloides*	5.9	1.6	1.6	0.3	9.4
46. *Polygala arillata*	0.9	0.2	0.3	0.1	1.5
47. *Aphanamixis polystachya*	0.5	0.1	0.2	0.0	0.9
Total	460,437	157,898	77,671	7,783	703,789

Each sample was analyzed for soil physical properties including bulk density, particle-size distribution and texture, and for soil chemical properties such as acidity (pH), organic matter, carbon, nitrogen and extractable forms of phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg). And also, the amounts of carbon and N, P, K, Ca, Mg macronutrients were evaluated.

3. RESULTS AND DISCUSSION

3.1 Plant species composition and diversity

Plant species composition and diversity in the UMF have already been discussed in detail in a previous study by Khamyong et al. (2004). A brief description based on the data obtained by them are included here. A total of 50 sampling plots of area 40×40 m^2 were used, in which there existed 47 species (39 genera and 26 families) in the forest. The most dominant species recoreded was *Quercus eumorpha* (Fagaceae family), and followed by *Syzygium angkae*, *Litsea martabarnica*, *Helicia nilagirica*, *Lindera caudata*, *Schima wallichii*, *Osmanthus fragrans*, *Eurya acuminata, Myrsine semiserrata* and *Ilex umbellulata*, respectively. There were six oak species in the forest. Three small trees were abundant namely: *Myrsine semiserrata*, *Rapanea yunnanensis* and *Symplocos* sp. The common woody climbers identified were *Melodinus cochinchinensis*, *Jusmimum dispermum* and *Jusminum attenuatum*.

The eleven most abundant species had a frequency above 86%, except *Rapanea yunnanensis* (50%) and *Acer laurinum* (54%) which had a relatively clumped distribution. The two species, *Helicia nilagirica* and *Lindera caudata*, had 100% frequency, followed by *Myrsine semiserrata*, *Litsea martabarnica*, *Quercus eumorpha*, *Osmanthus fragrans*, *Euyra acuminata*, *Syzygium angkae* and *Ilex umbellulata* with 96-86% frequency. These trees were the common species in this forest. The average tree density was 939.0 trees/ha. The species with high tree density/ha were *Helicia nilagirica* (108), *Litsea martabarnica* (107), *Quercus eumorpha* (98), *Syzygium angkae* (73) *Lindera caudata* (66), *Rapanea yunnanensis* (64), *Myrsine semiserrata* (62), *Eurya acuminata* (60), *Osmanthus fragrans* (51), *Ilex umbellulata* (34) and *Acer laurinum* (31). These eleven species accounted for 4/5 of the total individuals, they were all big trees, except for *Myrsine semiserrata* and *Rapanea yunnanensis*.

Nineteen species had a density of three individuals per ha or less, of these seven were considered to be rare species in the area (*Camellia* sp., *Melodinus cochinchinensis*, *Phoebe cathia*, *Prunus phaeosticta*, *Quercus grabicupula* and *Sorbus diospyricarpa*).

The dominance value was calculated on the basis of the stem basal area; the total basal area was 71.9 m^2/ha. *Quercus eumorpha* had the highest dominance (17.5 m^2/ha), followed by *Syzygium angkae* (10.1 m^2/ha) and *Schima wallichii* (8.5 m^2/ha), and these three species accounted for 50% of the total basal area. The remainder 44 species each had a basal area of 5 m^2/ha or less, and 27 species had a basal area of 0.5 m^2/ha or less.

Importance value index (IVI) combines the relative density, relative frequency and relative dominance into a measure that can be used to indicate the ecological influence of each species in the forest. The tree species with high IVI values were *Quercus eumorpha* (40.2), *Syzygium angkae* (26.8), *Litsea martabarnica* (23.9), *Helicia nilagirica* (23.3), *Lindera caudata* (18.5), *Schima wallichii* (18.0), *Osmanthus fragrans* (15.7), *Euyra acuminata* (14.6), *Myrsine semiserrata* (12.9) and *Ilex umbellulata* (11.6). These ten tree species accounted for 2/3 of the total IVI value.

3.2 Forest biomass

Table 1 shows the standing biomass of 47 tree species in the UMF. The total amount of plant biomass was calculated at 703.79 Mg/ha, including stem, branch, leaf and root organs of 460.44 Mg/ha, 157.90 Mg/ha, 7.78 Mg/ha and 77.67 Mg/ha, respectively. *Quercus eumorpha* contained the highest biomass (186.2 Mg/ha), followed by *Syzygium angkae* (98.1), *Shima wallichii* (91), *Litsea martabarnica* (44.5), *Lindera caudata* (39.5), *Helicia nilagirica* (35.8), *Osmanthus fragrans* (35.8), *Ilex umbellulata* (23.0), *Castanopsis acuminatissima* (19.3), *Eurya acuminata* (17.6), *Acer laurinum* (16.5), *Lithocarpus echinops* (15.0) and *Lithocarpus aggregatus* (13.3). The remainders had values less than 9.0 Mg/ha.

3.3 Carbon and macronutrient storages in UMF ecosystem

In this study, the storages of carbon and macronutrients in the UMF ecosystem involved three compartments: plant biomass, forest floor and soil (Table 2). The storages in the animal and ground covered species were not included. The ecosystem storages of P, K, Ca and Mg could not be given since the total amounts in soil were not measured, and only the available forms were studied.

3.3.1 Amounts of carbon, nitrogen and macro-nutrients in plant biomass

Carbon: The amounts of carbon storage in the standing biomass of 47 woody species in the UMF are given in Table 2. The total amount in the forest was calculated to be 347.85 Mg/ha. With the same trend as biomass, *Qurcus eumorpha* had the highest biomass carbon (92.1 Mg/ha), followed by *Syzygium angkae* (48.5), *Schima wallichii* (45.0), *Litsea martabarnica* (22.0), *Lindera caudata* (19.5), *Helicia nilagirica* (17.7), *Osmanthus fragrans* (13.0), *Ilex umbellulata* (11.4), *Castanopsis acuminatissima* (9.6), *Eurya acuminata* (8.7), *Acer laurinum* (8.2), *Lithocarpus echinops* (7.4), and *Lithocarpus aggregatus* (6.6), etc. The amount of carbon storage of the rest of the species is given in Table 2.

Table 2. Amounts of nutrient storages in biomass of different woody species in the UMF

Species	Nutrients (kg/ha)					
	Carbon	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
1. *Quercus eumorpha*	92,074.22	1,052.20	120.92	521.65	1,870.20	392.35
2. *Syzygium angkae*	48,496.98	557.78	63.81	276.46	987.48	208.53
3. *Schima wallichii*	45,015.39	507.24	58.87	251.60	909.37	188.06
4. *Litsea martabanica*	21,997.41	263.33	29.30	130.37	455.35	100.00
5. *Lindera caudata*	19,511.86	231.43	25.91	114.60	402.32	87.58
6. *Helicia nilagirica*	17,686.38	213.47	23.62	105.67	367.40	81.32
7. *Oamanthus fragrans*	13,052.22	156.04	17.38	77.26	270.04	59.23
8. *Ilex umbellulata*	11,366.32	132.60	15.02	65.70	232.79	49.85
9. *Castanopsis accuminatissima*	9,559.28	110.96	12.61	54.98	195.37	41.64
10. *Eurya acumunata*	8,678.17	104.85	11.59	51.90	180.39	39.95
11. *Acer laurinum*	8,151.79	96.00	10.80	47.55	167.60	36.23
12. *Lithocarpus echinops*	7,392.82	84.27	9.70	41.78	150.01	31.39
13. *Lithocarpus aggregatus*	6,560.92	74.28	8.59	36.84	132.78	27.59
14. *Macropanax dispermus*	4,433.37	53.35	5.91	26.41	91.98	20.30
15. *Litsea beusekomii*	3,980.00	47.62	5.30	23.57	82.37	18.08
16. *Litsea* sp.	3,150.23	37.30	4.18	18.47	64.92	14.11
17. *Eleaocarpus sphaericus*	3,123.76	36.54	4.13	18.10	64.05	13.75
18. *Phoebe cathia*	2,955.00	33.08	3.86	16.42	59.58	12.23
19. *Lithocarpus garretianus*	2,789.66	30.22	3.61	15.02	55.59	11.02
20. *Rapanea yunanensis*	2,696.31	34.35	3.66	16.99	57.39	13.34
21. *Phoebe* sp.	2,285.30	26.41	3.01	13.09	46.64	9.89
22. *Symingtonia populnea*	1,988.52	22.52	2.60	11.17	40.25	8.37
23. *Adinandra intergerrima*	1,862.44	21.69	2.46	10.75	38.12	8.15
24. *Myrrica esculata*	1,378.44	16.80	1.85	8.31	28.76	6.42
25. *Litsea paniculata*	1,337.06	15.66	1.77	7.76	27.44	5.90
26. *Myrsine semiserrata*	1,329.09	17.41	1.82	8.61	28.67	6.82
27. *Nyssa javanica*	1,251.43	14.62	1.65	7.24	25.66	5.50
28. *Quercus glabricupula*	918.20	10.69	1.21	5.30	18.80	4.02
29. *Viburnum kerrii*	596.26	7.20	0.80	3.56	12.40	2.74
30. *Symplocos macrophylla*	488.82	6.24	0.66	3.09	10.43	2.42
31. *Engelhardtia spiculatata*	422.61	5.02	0.56	2.49	8.73	1.90
31. *Vaccinium sperngellii*	307.31	3.98	0.42	1.97	6.61	1.55
33. *Rhododendron arboretum*	191.65	2.39	0.26	1.18	4.05	0.92
34. *Pyrenaria diospyricarpa*	175.71	2.16	0.24	1.07	3.69	0.83
35. *Camellia* sp.	162.67	1.99	0.22	0.98	3.41	0.76
36. *Jusminum dispermum*	104.42	1.38	0.14	0.68	2.27	0.54
37. *Sorbus grandulosa*	71.78	0.90	0.10	0.45	1.53	0.35
38. *Jusminum attenutum*	70.35	0.94	0.10	0.46	1.54	0.37
39. *Tarennoidea wallichii*	65.46	0.82	0.09	0.40	1.39	0.31
40. *Prunus phaeostigma*	57.67	0.76	0.08	0.37	1.26	0.30
41. *Melodinus cochinchinensis*	53.71	0.72	0.07	0.36	1.18	0.28
42. *Podocarpus nerifolius*	48.18	0.60	0.06	0.29	1.02	0.23
43. *Ficus* sp.	44.48	0.54	0.06	0.27	0.94	0.20
44. *Symplocos* sp.	25.43	0.34	0.03	0.16	0.56	0.13
45. *Trichilla conaloides*	4.64	0.06	0.01	0.03	0.11	0.02
46. *Polygala arillata*	0.74	0.01	0.00	0.01	0.03	0.00
47. *Aphanamixis polystachya*	0.40	0.01	0.00	0.01	0.03	0.00
Total	347,914.47	4,038.79	459.07	2,001.37	7,112.48	1,515.47

Nitrogen: The total amount of biomass nitrogen was 4,038.79 kg/ha. *Quercus eumorpha* had the highest biomass nitrogen (1,052.2 kg/ha), as well, followed by *Syzygium angkae* (557.78), *Schima wallichii* (507.24), *Lithocarpus martabarnica* (263.33), *Lindera caudata* (231.43), *Helicia nilagirica* (213.47), *Osmanthus fragrans* (156.04), *Ilex umbellulata* (132.60), *Castanopsis acuminatissima* (110.96), *Eurya acuminata* (104.85), *Acer laurinum* (96.00), *Lithocarpus echinops* (84.27), and *Lithocarpus aggregatus* (74.28), etc. The amount of nitrogen stored for the rest of the species is shown in Table 2.

Phosphorus: The amount of stored phosphorus in the biomass was 459.07 kg/ha. *Quercus eumorpha* had the highest amount (120.92 kg/ha) of phosphorus, as well, followed by *Syzygium angkae* (63.81), *Schima wallichii* (58.87), *Litsea martabarnica* (29.30), *Lindera caudata* (25.91), *Helicia nilagirica* (23.62), *Osmanthus fragrans* (17.38), *Ilex umbellulata* (15.02), *Castanopsis acuminatissima* (12.61), *Eurya acuminata* (11.59), *Acer laurinum* (10.80), *Lithocarpus echinops* (9.70) and *Lithocarpus aggregatus* (8.59), etc. The amount of phosphorus stored for the rest of the species is shown in Table 2.

Potassium: The total amount of biomass potassium was 2.001.37 kg/ha. Again, *Quercus eumorpha* had the highest amount (521.65 kg/ha), followed by *Syzygium angkae* (276.46), *Schima wallichii* (251.60), *Litsea martabarnica* (130.37), *Lindera caudata* (114.60), *Helicia nilagirica* (105.67), *Osmanthus fragrans* (77.26), *Ilex umbellulata* (65.70), *Castanopsis acuminatissima* (54.98), *Eurya acuminata* (51.90), *Acer laurinum* (47.55), *Lithocarpus echinops* (41.78), and *Lithocarpus aggregatus* (36.84), etc. The amount of potassium stored for the rest of the species is shown in Table 2.

Calcium: The total amount of biomass calcium was 7,112.48 kg/ha. Here, too, *Quercus eumorpha* had the highest amount (1,870.20 kg/ha), followed by *Syzygium angkae* (987.48), *Schima wallichii* (909.37), *Litsea martabarnica* (455.35), *Lindera caudata* (402.32), *Helicia nilagirica* (367.40), *Osmanthus fragrans* (270.04), *Ilex umbellulata* (232.79), *Castanopsis acuminatissima* (195.37), *Eurya acuminata* (180.39), *Acer laurinum* (167.60), *Lithocarpus echinops* (150.01), and *Lithocarpus aggregatus* (132.78), etc. The amount of calcium stored for the rest of the species is shown in Table 2.

Magnesium: The total amount of manesium stored in biomass was 1,515.47 kg/ ha. *Quercus eumorpha* had also the highest amount (392.35 kg/ha), as well. followed by *Syzygium angkae* (208.53), *Schima wallichii* (188.06), *Litsea martabarnica* (100.0), *Lindera caudata* (87.58), *Helicia nilagirica* (81.32), *Osmanthus fragrans* (59.23), *Ilex umbellulata* (49.85), *Castanopsis acuminatissima* (41.64), *Eurya acuminata* (39.95), *Acer laurinum* (36.23), *Lithocarpus echinops* (31.39), and *Lithocarpus aggregatus* (27.59), etc. The amount of magnesium stored for the rest of the species is shown in Table 2.

3.3.2 Litter fall and forest floor

In the year 2005, above ground litterfall in the UMF was collected monthly, and the dry matter amount of annual litterfall was estimated according to the method propounded by Kham-yong et al. (2006) (Table 3).The amount of annual litterfall in this forest was relatively high, at 8.05 Mg/ha, and it was separated into leaves, branches and others in the following order: 3.48 Mg/ha (43.18%), 2.47 Mg/ha (30.71%) and 2.10 Mg/ha (26.11%). The leaves provided the largest contribution. Leaf fall was high in the dry season, March-April. The number of fallen branches was high in the rainy season, May-October, since many storms with strong winds had damaged the branches. The other litter included fallen flowers and dead fruits.

Table 3. Amounts of dry matter in above ground litterfall of the UMF (2005)

Month (in 2005)	Leaves (kg/ha)	Branches(kg/ha)	Others (kg/ha)	Total (kg/ha)
1. January	173.68	210.43	187.79	571.90
2. Febuary	433.36	45.07	80.62	599.05
3. March	617.14	16.89	122.41	576.44
4. April	651.30	36.54	127.32	815.16
5. May	152.96	294.37	120.89	568.22
6. June	203.26	351.25	179.02	733.53
7. July	275.18	253.14	298.33	826.65
8. August	218.68	413.86	239.80	872.34
9. September	245.06	249.68	203.02	697.76
10. October	373.68	417.05	389.05	1,179.78
11. November	56.56	122.36	86.92	265.84
12. December	76.21	62.08	67.94	206.23
Total	3,477.05	2,472.72	2,103.1	8,052.90
	43.18	30.71	26.11	100%

Table 4. Average nutrient contents (%) in litterfall of the UMF

Litter fall	C	N	C/N	P	K	Ca	Mg
Leaves	43.20	1.73	24.97	0.07	0.40	4.49	0.18
Branches	45.20	1.21	37.36	0.04	0.30	3.45	0.09
Others	43.00	1.48	29.05	0.10	0.60	2.93	0.09

The contents of carbon and other macronutrients in litterfall were different with different kinds of macronutrients and plant organs (Table 4). In Table 5, the annual amount of carbon recycling from the above ground plant litter into the soil was calculated to be 3.43 Mg/ ha. The recycling amounts for nitrogen, phosphorus, potassium, calcium and magnesium were 121.21 kg/ha, 5.54 kg/ha, 33.94 kg/ha, 303.06 kg/ha, and 10.41 kg/ha, respectively. The percentages of recycling rates for OC, N, P, K, Ca and Mg were 1.0%, 3.0%, 1.21%, 1.70%, 4.26% and 0.69%, respectively, of the total stocks in the plant biomass.

The organic layers (Ao/O layers) on the forest floor including the litter (L), fragmented (F) and humus (H) layers were estimated for the dry matter or biomass.

Contents of organic carbon and macronutrients in these organic layers were different (Table 6). In Table 7, the total amount of dry matter was 33.55 Mg/ha, partitioned into the L-, F- and H-layers as thus: 1.54, 3.84, and 28.17 Mg/ha, respectively. Thus, the amounts of carbon, nitrogen, phosphorus, potassium, calcium and magenesium in the organic layers were 19.46 Mg/ha, 594.30 kg/ha, 36.51 kg/ha, 101.78 kg/ha, 488.59 kg/ha and 56.64 kg/ha, respectively.

Table 5. Amounts of nutrients in above ground litterfall in the UMF (2005)

Month (in 2005)	Amounts of nutrients in above ground litterfall (kg/ha)					
	Carbon	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
January	104.98	8.33	0.39	2.46	20.56	0.66
Febuary	242.25	9.24	0.40	2.35	23.37	0.89
March	326.89	12.69	0.56	3.25	31.88	1.23
April	352.63	13.58	0.61	3.48	34.23	1.32
May	247.09	8.00	0.35	2.22	20.57	0.65
June	315.85	10.42	0.46	2.93	26.50	0.85
July	384.99	12.24	0.59	3.65	29.83	1.00
August	419.60	12.38	0.56	3.55	31.13	0.98
September	305.59	10.26	0.47	2.95	25.56	0.85
October	520.68	17.27	0.82	5.08	42.57	1.40
November	115.50	3.74	0.18	1.12	9.31	0.29
December	89.27	3.08	0.15	0.90	7.55	0.26
	3,425.31	121.21	5.54	33.04	303.06	10.41

Table 6. Contents of nutrients (%) in organic layers on forest floor of the UMF

Ao layers	C	N	C/N	P	K	Ca	Mg
L-layer	42.28	1.61	26.26	0.06	0.49	1.19	0.22
F-layer	34.65	1.70	20.38	0.12	0.40	1.17	0.14
H-layers	27.02	1.79	15.09	0.11	0.28	1.51	0.17

Table 7. Amounts of dry matter and nutrients accumulated (kg/ha) in organic layers on forest floor of the UMF

Ao layers	Dry matter	C	N	P	K	Ca	Mg
L-layer	1,538.4	892.27	24.77	0.92	7.54	18.30	3.38
F-layer	3,842.1	2,228.41	65.32	4.61	15.37	44.95	5.38
H-layer	28,168.5	16,337.73	504.21	30.98	78.87	425.34	47.88
Total	33,548.9	19,458.36	594.30	36.51	101.78	488.59	56.64

3.3.3 Soil system

Soil characteristics have had an influence on storages of the carbon and macronutrients in the forest soil. The data regarding physical and chemical soil properties in the UMF are given in Table 8 and Table 9.

The physical properties include bulk density, particle size distribution and texture. The bulk densities were low to very low in the top soils, and low to moderate in the subsoils. For soil pit no. 1, the density at 0-10 cm depth was very low, at 0.61 Mg/m^3, varied between 0.65 Mg/m^3 and 0.82 Mg/m^3 at 5-40 cm, and increased from 1.25 Mg/m^3 to 1.54 Mg/m^3 at 40-100 cm. In the soil pit no. 2, the surface soil at 0-10 cm depth had low density, at 0.59 Mg/m^3, lower density between 0.67 Mg m^3 and 0.84 Mg/m^3 at 10-60 cm, and increased density between 1.0 Mg/m^3 and 1.04 Mg/m^3 at 60-100 cm. In the last soil pit, the density at 0-10 cm was very low, at 0.59 Mg/m^3, and varied between 0.61 Mg/m^3 and 0.98 Mg/m^3 at 10-100 cm. The first pit was located at the ridge while the second and third pits were situated at the middle and lower slope sites. The variation in the soil densities between the pits was because of the influence of the slope gradient. The low soil densities, particularly that of the surface soil were caused by the high organic matter.

In Table 8, sand particles in the soil pit no. 1, 2, and 3 were varied: 47.52-63.52%, 51.52-59.52% and 48.24-71.38%, respectively. Their silt particles were in the following order: 14.72-28.0%, 24.0-32.0% and 12.0-26.72%, whereas the clay particles varied between the following ranges: 16.48-36.48%, 14.48-18.48% and 14.49-28.48%, respectively. As a result, textures of the topsoils varied as sandy clay loam and sandy loam, while those of subsoils were loam, sandy loam, sandy clay, and sandy clay loam, and the soil type was classified into Order Ultisols, Suborder Humults.

In Table 9, the soil reaction in the soil pit no. 1 was extremely acid (pH=4.18-4.44) at the depth of 0-20 cm and very strongly acid at 20-100 cm depth (pH=4.62-4.89). In soil pit no. 2 and 3, the soil reaction was very strongly acid throughout soil profiles. The high accumulation of organic matter was what resulted in the large proportion of organic acids in the soil. In addition, the soil parent material is gneissic rock which is acidic. Therefore, the soil in the UMF is acidic.

The high organic matter content in the soil of this forest was accompanied by the high nitrogen content. The content proportion of extractable K was intermediate to relatively high in the surface soils, and low to very low in the subsoils whereas the content proportions of extractable P, Ca, Mg and Na were low throughout the soil profiles. These extractable macronutrients had a low content in the acidic soil.

Table 10 shows the amounts of organic matter, carbon, nitrogen and extractable macronutrients in the three soil profiles in the UMF. The amounts of organic matter in one-meter soil profiles varied between 409.46 Mg/ha and 530.18 Mg/ha (452.53 Mg/ha on average), and the amounts of organic carbon were calculated to be between 237.49 Mg/ha and 307.50 Mg/ha (262.47 Mg/ha on average).

Table 8. Some physical properties in three soil profiles under the UMF

Soil depth (cm)	Bulk density (Mg/m^3)			Particle size distribution (%)									Textural class		
				Sand			Silt			Clay					
Pit No.	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
0-5	0.61	0.63	0.55	63.5	57.5	71.4	16.0	26.0	14.1	20.5	16.5	14.5	SCL	SL	SL
5-10	0.62	0.55	0.63	48.2	59.5	69.5	26.7	24.0	12.0	25.0	16.5	18.5	SCL	SL	SL
10-20	0.65	0.67	0.61	49.5	51.5	53.5	28.0	32.0	18.0	22.5	16.5	28.5	L	L	SCL
20-30	0.73	0.69	0.70	57.5	53.5	56.4	26.0	32.0	18.7	16.5	14.5	25.0	SL	SL	SCL
30-40	0.82	0.82	0.79	51.5	55.5	48.2	22.0	30.0	26.7	26.5	14.5	25.0	SL	SL	SCL
40-60	1.25	0.84	0.82	48.2	59.5	50.2	18.7	26.0	26.7	33.0	14.5	23.0	SCL	SL	SCL
60-80	1.45	1.04	0.97	47.5	55.5	57.5	16.0	28.0	20.0	36.5	16.5	22.5	SC	SL	SCL
80-100	1.54	1.00	0.98	50.2	53.5	55.5	14.7	28.0	18.0	35.0	18.5	26.5	SC	SL	SCL

* SL = sandy loam, SCL = sandy clay loam, SC = sandy clay, L = loam

Table 9. Soil chemical properties in three soil profiles under UMF

Soil depth (cm)	pH	OM	C	N	C/N	P	K	Ca	Mg
		g/kg			mg/kg				
Soil pit No. 1 (ridge site)									
0-5	4.18	485.9	281.8	18.8	15.0	1.65	55.31	49.00	20.00
5-10	4.25	425.4	246.7	16.4	15.0	1.68	43.19	19.75	11.50
10-20	4.44	401.9	233.1	15.5	15.0	1.56	28.50	11.00	8.69
20-30	4.62	388.4	225.3	15.0	15.0	1.75	28.88	25.63	7.25
30-40	4.58	105.2	61.0	4.1	14.9	4.89	34.00	49.00	8.19
40-60	4.74	87.8	50.9	3.4	15.0	5.61	23.69	22.69	3.19
60-80	4.80	77.0	44.7	3.0	15.0	7.29	16.38	28.56	3.44
80-100	4.89	75.7	43.9	2.9	15.1	3.25	22.63	40.25	5.56
Soil pit No. 2 (upper slope site)									
0-5	4.73	465.4	269.9	18.0	15.0	9.15	52.8	75.31	17.94
5-10	4.64	451.6	261.9	17.5	15.0	8.75	38.1	31.5	10.31
10-20	4.73	403.7	234.1	15.6	15.0	9.20	25.4	43.13	7.69
20-30	4.77	366.8	230.1	15.3	15.0	10.5	28.9	37.31	8.69
30-40	4.81	102.7	59.6	4.0	14.9	14.3	21.5	31.5	7.04
40-60	4.86	101.3	58.8	3.9	15.1	15.3	22.3	16.88	5.38
60-80	4.92	89.6	52.0	3.5	14.9	21.75	21.9	25.63	4.19
80-100	5.02	78.7	45.6	3.0	15.2	30.63	19.7	19.75	3.69
Soil pit No. 3 (lower slope site)									
0-5	4.41	575.0	333.5	22.2	15.0	11.1	128.88	297.63	61.56
5-10	4.54	496.2	287.8	19.2	15.0	4.40	53.13	25.63	13.63
10-20	4.59	472.2	273.9	18.3	15.0	5.65	37.69	19.75	9.63
20-30	4.71	413.9	240.1	16.0	15.0	9.10	31.44	31.50	6.75
30-40	4.66	417.3	242.0	16.1	15.0	8.20	25.56	16.88	4.88
40-60	4.73	108.8	63.1	4.2	15.1	6.25	22.25	19.75	5.38
60-80	4.81	84.8	49.2	3.3	14.9	4.65	21.13	37.31	5.38
80-100	4.81	82.7	48.0	3.2	15.2	4.10	25.94	34.38	4.63

Table 10. Amounts of organic matter, carbon and nutrients in three soil profiles under the UMF

Soil pit No.	Depth (cm)	OM (Mg/ha)	Total C (Mg/ha)	Total N (Mg/ha)	Extractable nutrients (kg/ha)			
					P	K	Ca	Mg
1	0-5	97.18	53.36	3,757.63	0.50	16.87	14.95	6.10
(ridge site)	5-10	85.08	49.35	1,644.88	0.52	13.39	6.12	3.57
	10-20	80.38	46.26	1,554,01	1.01	18.53	7.15	5.65
	20-30	77.68	45.05	1,501.81	1.28	21.08	18.71	5.29
	30-40	21.04	12.20	406.77	4.01	27.88	40.18	6.71
	40-60	17.56	10.19	169.75	14.02	59.22	56.72	7.97
	60-80	15.40	8.93	148.87	21.13	47.49	82.83	9.97
	80-100	15.14	8.78	146.35	10.01	69.69	123.97	17.13
Total		409.46	237.49	9,330.07	52.48	274.15	350.63	62.39
2	0-5	93.08	54.00	3,599.09	2.88	16.62	23.72	5.65
(upper slope site)	5-10	90.32	52.39	1,746.19	2.41	10.47	8.66	2.84
	10-20	80.74	46.83	1,560.97	6.16	17.04	28.89	5.15
	20-30	79.36	46.03	1,534.29	7.25	19.92	25.75	5.99
	30-40	20.54	11.91	397.11	11.73	17.63	25.83	39.87
	40-60	20.26	11.75	195.85	25.70	37.38	28.35	9.03
	60-80	17.92	10.39	173.23	45.24	45.50	53.30	8.71
	80-100	15.74	9.13	152.15	61.25	33.38	39.50	7.38
Total		417.96	242.42	9,358.88	162.62	197.94	234.00	84.62
3	0-5	115.00	66.70	4,446.67	3.05	35.44	81.85	16.93
(lower slope site)	5-10	99.24	57.56	1,918.64	1.39	16.73	8.07	4.29
	10-20	94.44	54.78	1,825.84	3.45	22.99	12.05	5.87
	20-30	82.78	48.01	1,600.41	6.37	22.01	22.05	4.73
	30-40	83.46	48.41	1,613.56	6.48	20.19	13.33	3.85
	40-60	21.76	12.62	210.35	10.25	36.49	32.39	8.82
	60-80	16.96	9.84	163.95	9.02	40.39	72.39	10.43
	80-100	16.54	9.59	159.89	8.04	50.84	67.38	9.07
Total		530.18	307.50	11,939.30	48.05	209.64	227.66	47.06
Average (three pits)		452.53	262.47	10,209.41	87.71	227.24	270.76	64.69

3.3.4 Ecosystem storages of carbon and macro-nutrients

The carbon and nitrogen stocks in the ecosystem of the UMF are composed of three source compartments: carbon in the standing plant biomass, carbon in organic layers on the forest floor and carbon in the soil. In Table 11, the total carbon stock in the UMF ecosystem was high, at 629.84 Mg/ha: the carbon stock in the biomass was 347.91 Mg/ha (55.20%), in the Ao layers was 19.46 Mg/ha (3.10%), and in the soil was 262.47 Mg/ha (41.70%). The total nitrogen stock was also high, 14842.50 kg/ha: 4038.79 kg/ha (27.20%) in the biomass, 594.30 kg/ha (4.0%) in the florest floor and 10209.41 kg/ha (68.80% in the soil). The total amounts of other nutrients could not provide here because the total amounts in the soil were not determined.

Mt. Inthanon is the highest mountain in Thailand located in one of the most attractive National Park of the country to local and foreign tourists. An oldgrowth montane forest (UMF) at the mountain summit has a specific microclimate, wildlife especially birds, and plant species with the most attractive. This is a primary point of interest to study the potentials of carbon and macronutrient storages in this undisturbed forest whereas most forest in the lower area is mainly secondary forests. The biomass of tree species in this old-growth forest was high, at 703.79 Mg/ha. Most area of the forest is not disturbed from forest concession and shifting cultivation in the past. One reason is that hill tribe particularly Hmong people believe that it is the forest area of devil. Also, it is not suffered from forest fire caused by human activities as usual occurrence in lower area forests, and therefore some organic layers are accumulated on the forest floor. One cause of the remaining organic layers is the influence of slow decomposition rate due to low air temperature at the high altitude and the close forest canopy. The organic layers can protect the surface soil from carbon and nutrient losses by the soil erosion. Extremely acid of soil in the forest is a limiting factor of nutrient availability, and thus carbon and macronutrient losses to the stream water would be small as reported by Bormann and Likens (1979).

The UMF had a simple stratification with two-canopy layers of dense upper canopy layer and lower canopy layer, lack of emergent trees, abundance of epiphytes, few lianas, and very dense groundcovered species, *Strobilanthes* sp. The tree species in upper canopy layer were mainly *Quercus eumorpha*, *Syzygium angkae*, *Litsea martabarnica*, *Helicia nilagirica*, *Lindera caudata*, *Schima wallichii*, *Osmanthus fragrans* and *Eurya acuminata.* Some dominant tree species such as *Ilea umbellulata, Acer laurinum, Lithocarpus echinops, Lithocarpus aggregatus* and *Elaeocarpus sphaerirus* were abundant in some areas in the forest. The dense upper canopy layer caused scatterred individual distribution of saplings of the dominant species and some shrubby trees as *Myrsine semiserrata*, *Rapanea yunnanensis* and *Symplocos* sp. in the lower canopy layer, and occurrence of common climbers as *Melodinus cochinchinensis*, *Jusmimum dispermum*, *Jusminum attenuatum* and *Piper* sp. The canopy closure of forest can reduce light intensity, air temperature at the forest floor as well as soil erosion. The litter decomposition is thus slow down, and resulted in accumulated organic layers on forest floor as the carbon and macronutrient pools.

Table 11. Amounts of organic carbon and macronutrients in the UMF

Nutrient compartments	C		N		P	K	Ca	Mg
	Mg/ha	%	kg/ha	%	kg/ha			
Plant biomass	347.91	55.20	4038.79	27.20	459.07	2001.37	7112.48	1515.47
Forest floor	19.46	3.10	594.30	4.00	36.51	101.78	488.59	56.64
Soil	262.47	41.70	10209.41	68.80	-	-	-	-
Total	629.84	100	14842.50	100	-	-	-	-

* Amounts in soil of P, K, Ca and Mg are available forms (not total amounts).

As compared to the old-growth forests in other countries, the above ground biomass of 422 Mg/ha, 575 Mg/ha, and 415 Mg/ha were reported for temperate deciduous, temperate ever-green hardwood and tropical forests, respectively, whereas the biomass of cool temperate coniferous forests in Japan and the northern United States exceeded 600 Mg/ha (Art and Marks, 1971 referred by Kimmins, 2004). The higher value of 731 Mg/ha was reported for an old-growth subalpine forest in southeastern British Columbia (Krumlik, 1979), and the amounts varied from 734 Mg/ha to 1,773 Mg/ha for Douglas-fir western hemlock and noble fir forests in the Oregon Cascade Mountains (Zobel et al., 1976 referred by Kimmins, 2004), whereas the coast redwood forest in northern California which exceeded 1,000 years in age had a stem biomass along the lines of 3,461 Mg/ha (Waring and Franklin, 1979). Most forests in the lower areas of Thailand were disturbed by forest concession, illegal tree cutting and shifting cultivation. The amounts of plant biomass were lower than those in the UMF. Nongnuang (2012) reported that the fragmented pine-lower montane forest in Samoeng district, Chiang Mai province, registered a plant biomass between 117.39 Mg/ha and 253.3 Mg/ha, whereas the amounts were estimated to be 252.36 Mg/ha and 139.74 Mg/ha for the con-servation and utilization pine-montane community forests, respectively (Seeloy-ounkeaw, 2014).

Storages of carbon and macronutrient in the UMF are occurred in three compartmets; plant biomass, organic layers on forest floor and soil system. The UMF could store large amounts of carbon, nitrogen, phosphorus, potassium, calcium and magnesium in the biomass, to the tunes of 345.81 Mg/ha, 3,130.09 kg/ha, 382.16 kg/ha, 1,554.07 kg/ha, 6,245.23 kg/ha, and 928.39 kg/ha, respectively. Nongnuang (2012) reported that the fragmented pine-lower montane forest had lower amounts of these macronutrients, the amounts being 99.33 Mg/ha, 1,101 kg/ha, 154 kg/ha, 753 kg/ha, 1602 kg/ha and 359 kg/ha, respectively. The amounts of macronutrients in the conservation forest of Nong Tao village were in the following order: 124.68 Mg/ha, 1,135.21 kg/ha, 134.89 kg/ha, 563.13 kg/ha, 2,327.72 kg/ha and 333.34 kg/ha, whereas the values for the same for the utilization community forest were 69.01 Mg/ha, 312.95 kg/ha, 74.03 kg/ha, 315.39 kg/ha, 1,240.96 kg/ha and 1 86.26 kg/ha, respectively (Seeloy-ounkeaw, 2014).

Parts of these macronutrients were stored in the organic layers of forest floor under the UMF, the values of which are in the following order: 19.46 Mg/ha, 594.3 kg/ha, 36.51 kg/ha, 101.78 kg/ha, 488.59 kg/ha and 56.64 kg/ha, respectively. The storages of carbon and macro-nutrients were different from those of the dry dipterocarp, mixed deciduous and pine forests which usually have annual fires caused by human activities, which result in hardly any accumulation of organic layers. In dry season, all organic layers were almost disappeared after a few minutes of fire burning, and a thin organic layer occurred in rainy season might have a rapid decomposition particularly by termite eating. Nongnuang (2012) reported that the dry matters and the carbon amounts in the organic layers under the five fragmented pine-montane forests were lower than those of the UMF, at 5.86-7.64 Mg/ha and 2.15-2.73 Mg/ha, respectively.

The storages of carbon and nitrogen in the soil under the UMF were also high, at 262.47 Mg/ha and 10.21 Mg/ha, respectively. The amounts of extractable P, K, Ca and Mg were in the following order: 87.71 kg/ha, 227.24 kg/ha, 270.76 kg/ha and 64.69 kg/ha. Most of the carbon and nitrogen stored in the soil came from plant litterfall, and a part of soil nitrogen might be obtained through nitrogen fixation. For the other macronutrients, both plant litterfall and rock weathering were their sources. However, their amounts in the soil were given in available forms, not the total. Nongnuang (2012) reported that the fragmented forest could store high amounts of carbon, up to 95-276 Mg/ha. For the conservation community forest, the amounts of soil carbon and nitrogen were higher than those for the UMF, at 322.71 Mg/ha and 17.29 Mg/ha, respectively. The amounts of extractable P, K, Ca and Mg were in the following order: 65.70, 2261.19; 885; 330.81 and 705.95 kg/ha. Thus, the abundant pinelower montane community forest was found to be able to accumulate larger amounts of carbon and nitrogen. The stored carbon and nitrogen in the soil under the utilization forest were 84.27 Mg/ha and 5.95 Mg/ha, respectively whereas the amounts of extractable macronutrients were in the following order: 23.02, 3,146.04, 1,370.84, 658.24, and 558.49 kg/ha (Seeloy-ounkeaw, 2014). Selective tree cutting was allowed in this community forest under village regulations, which resulted in some degradation to the forest. The relationship between plants and soil in the forest ecosystem is usually dynamic as plants uptake most nutrients particularly macronutrients as nitrogen, phosphorus, potassium, calcium and magnesium from the soil to maintain the physiological processes and growth, whereas carbon is taken mainly from atmosphere through photosynthesis and then storaged as carbohydrates in plant tissues.

The total ecosystem storages of carbon and nitrogen in the UMF were higher than those in the other forests in Thailand, at 629.84 Mg/ha and 14.84 Mg/ha, respectively. The carbon allocation in the plant biomass (55.20%) was nearly the same to as that in the organic layers and the soil compartment (44.80%). As for nitrogen, its allocation in the UMF was lower as 27.20% in the plant biomass, and the remainder was contained in the organic layers (4.0%) and the highest in the soil (68.80%). Nongnuang (2012) reported that the five fragmented forests had the highest amounts of carbon in the soils (41.2-72.5%), followed by the plant biomass (26.8-57.7%) and the forest floor (0.7-1.2%). The conservation and utilization community forests had the ecosystem carbon amounts of 457.39 Mg/ha and 153.28 Mg/ha, respectively, whereas the amounts of ecosystem nitrogen were in the following order: 17.29 Mg/ha and 0.95 Mg/ha. The biomass carbon in the UMF was higher than that in the conservation community forest (the LMF), but the accumulated soil nitrogen was adversely lower. Other forest types had the lower storages of ecosystem carbon and nitrogen caused by forest degrade and utilization of the local people as mentioned by Nawapramote et al. (2014). The dry dipterocarp forest which experiences annual fire had total plant biomass, ecosystem carbon, and nitrogen of 106.60 Mg/ha, 124.64 Mg/ha and 1.37 Mg/ha, respectively (Wattanasuksakul, 2012).

4. CONCLUSIONS

The upper montane forest at the summit of Mt. Inthanon is an oldgrowth forest. Most of forest area is not suffered from forest concession, shifting cultivation and forest fire. Only about five square kilometers of this forest remains now, and it has been defined as the rare forest ecosystem of Thailand. The plant species in this forest are mainly temperate species which are different from those in the forests in the lower areas. The forest is preserved for the ecological values and, most important and particularly, for ecotourism with regard to the specific microclimate as well as because of the exceptional plant species diversity especially the *Rhododendron* spp. The UMF plays an important ecological role as the head watershed, and is capable of storing enormous amounts of carbon as well as other macronutrients. The carbon sink in the forest ecosystem plays a significant role in reducing atmospheric carbon dioxide and global warming.

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