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Original Article

Roles of Montane Forest inside National Park in Northern Thailand on Carbon and Macronutrient Storages

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ABSTRACT

The potential of carbon and macronutrient storages in a recovery montane forest (MF) inside the Doi Suthep-Pui National Park, Thailand, was assessed after 60 years of establishing the national park. Plant community analysis was carried out for studying the structure, species diversity and biomass production. Fifteen sampling plots, each of size 40 x 40 m^2, were arranged using a stratified random technique across an altitudinal range between 1,200 and 1,597 m above mean sea level (m. s. l.). Three 2 m soil pits were used for soil study. Biomass amounts of existing 171 plant species (129 genera and 70 families) were calculated using allometric equations and found that the total biomass of this forest was high as 438.78 megagrams per hectare (Mg/ha). Amounts of carbon (C), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) stored in the biomass were measured as the following order: 216.81 Mg/ha, 1,959.82, 273.55, 927.82, 3,895.57, and 580.72 kg/ha. Botanical names are referred to Smitinand (2014). *Castanopsis acuminatissima* had the highest amounts of biomass, carbon, and macronutrients, followed by *Schima wallichii*, *Pinus kesiya*, *Castanopsis diversifolia*, *Syzygium* sp., *Magnolia floribunda*, respectively. The species in Fagaceae family contributed to the highest value, 28.47%, followed by Theaceae, Lauraceae, Myrtaceae, respectively. Amounts of C, N, available P, extractable K, Ca, and Mg in Ao layers were estimated at 12.99 Mg/ha, 637.16, 36.37, 146.17, 483.49 and 66.34 kg/ha, respectively while those in the soil were 492.56 Mg/ha, 3,188.37, 71.53, 4,622.26, 5,123.67 and 373.36 kg/ha. Thus, their ecosystem storages were determined as fellow: 722.36 Mg/ha, 5,785.34, 345.46, 5,741.24, 9,502.72 and 1,020.39 kg/ha. The nutrient stocks in the Ao layers and soil were excess for the annual uptake of tree species in the MF.

Keywords: Carbon storage, Macronutrients, Montane forest, National park, Forest biomass

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INTRODUCTION

The highland watersheds in northern Thailand are mostly covered by forests of different types which give variable functions of forest hydrology as very dry, moderately dry, and humid areas. These result in different timing of streamflow (Chang, 2006) and appearing ephemeral, intermittent and perennial streams occurred in the watersheds. The areas above 500m m. s. l. altitude have recognized as the highlands by the Department of Land Development, and the forest covers are so called highland forests. Three forest groups are considered as evergreen, semievergreen and deciduous forests which include two deciduous forests (dry dipterocarp forest, DDF, and mixed deciduous forest, MDF), two semievergreen forests (dry evergreen forest, DEF, and pine-dipterocarp forest, PDF) and two evergreen forests (pine-montane forest, PMF) and montane forest, MF). The DDF is an opened forest on xeric site from a peneplain of 50 m altitude to slopes and rides of up to 1,300 m a.s.l. (Smitinand *et al.*, 1980) while the MDF distributes up to about 800 m (Santisuk, 1988). The PDF including *Pinus merkusii* and *Pinus kesiya* distributes on dry (xeric) site with 500 to 1,300 m altitude (sometimes classified as a subtype DDF). Here, it is separated to be a semievergreen type by the fact that mature evergreen pine trees are normally taller than dipterocarp species, as the upper most crown canopy in the forest with 30 to 40 m heights while the dipterocarps are lower canopy layer, 20 to 30 m tall. The PMF distributes in areas of higher moisture than the PDF (1,000 to 1,900 m altitude). The pine forest is sometimes divided into two subtypes: the PDF and the PMF.

The mesic sites at elevations between 1,000 and 2,565 m are covered by the MF indicated by tree species in Fagaceae family with two subtypes, lower montane forest (LMF; 1,000 to 1,500 m) and upper montane forest (UMF; 1,500-2565 m) (Santisuk, 1988; Khamyong *et al*., 2004, 2016). The forest site moisture is usually moderate to high throughout a year with no forest fires. This forest has the most efficient roles as head good watersheds of the country. It is found that the evergreen tree canopies could condense water vapor from the clouds moving through the trees (Nagakawa *et al*, 1998) with an average annual rainfall of 2,142 mm and releasing 1,383 m (65%) of water into streams (Withawatchutikul *et al.*, 2011). It had the deep soil which contained a large amount of organic matter and the low density (Seeloy-ounkeaw, 2014). These could make water seepage through well and store a lot of water. Within 2 m soil depth, it could store water at 9,584 m^3/ha which supporting maximum rainfall of 958.4 mm (Khamyong *et al.*, 2014). The MF inside and outside of the national park is different according to the national forest management. The forests inside national parks are conservation forests (CF) whereas the outside forests are the national reserved forests (NRF). By the law, forest utilization is prohibited inside the national parks whereas the people can use some limited forest products in the NRF). The villages settled inside the national parks are boundary for controlling people activities. In contrast to the MF outside the national park, the forest in many areas has been degraded and is in the scattered distribution caused by shifting cultivation, permanent agriculture and selective tree cutting. The Doi Suthep-Pui National Park covers an area of 261.06 km^2 in Chiang Mai province, northern Thailand. Its highest mountain is the Doi Pui (1,655 m), followed by Doi Suthep (1,601 m), Bhubing Palace (1,400 m), etc. Some parts of the MF had been disturbed through forest clearing for shifting cultivation by hill tribes and some villages are boundary inside this national park (Department of National Park, Wildlife and Plant Conservation, 2011).

The carbon cycle in forest ecosystem is related to the problem of global warming because the forest is considered as carbon sink (Landsberg and Gower, 1997; Waring and Running, 2007). The role of the MF on the carbon storage is therefore important. The cycling macronutrients are important to support growths of plant species in the forest. Nitrogen element in plants is mainly in proteins including amino acids, the nucleic acids, many enzymes, and energy transfer materials such as chlorophyll, ADP (adenosine diphosphate) and ATP (adenosine triphosphate). Phosphorus is an essential component of living cells, reproductive organs as seeds, cell division in growing tissues, energy transfer (ADP, ATP) during photosynthesis, deoxyribonucleic acids (genetic inheritance), ribonucleic acid (RNA) related to protein synthesis, etc. Potassium in plants is in the form of organic and inorganic salts. It aids in the uptake and movement of other nutrients within the plant and helps to maintain the osmotic concentration to keep the cells turgid. Calcium is a structural component of cell walls and makes strengthening stem and other plant organs while magnesium is a component of chlorophyll related to photosynthesis, producing seeds and enzymes involved in carbohydrate metabolism (Brady and Weil, 2010).

This research aims to investigate the potential of a recovery MF inside the Doi Suthep-Pui National Park in northern Thailand after 60 years of establishing national park (in 1959) on carbon and macronutrient storages in plant biomass, Ao layers and soil related to its environmental roles particularly mitigating global warming. These useful data can support the national forest management and watershed restoration.

MATERIALS AND METHODS

1. Study area

This research was conducted at the Doi Sutep-Pui National Park, Chiang Mai province. It is about 15 km to the west of Chiang Mai city. The altitude ranges between 1,200 and 1,597m m. s. l. The park is consisted of two areas; the first area locates in districts of Muang, Mae Rim and Hang Dong, and the second area is in Mae Taeng district. The geological data indicate that many rocks are found in the area including igneous rocks (granite), sedimentary rocks and metamorphic rocks. Five forest types are found in the park: dry dipterocarp forest, mixed deciduous forest, dry evergreen forest, pine forest and lower montane forest.

2. Plant community study

The method of plant community analysis was used for vegetation study. Fifteen sampling plots, each 40 x 40 m^2, were used, and arranged randomly in the MF having an altitude range between 1,200 and 1,597m m. s. l. In each sampling plot, the stem girths at breast height (GBH, 1.3 m above ground) and heights of all the tree species with height over 1.5 m were measured. The species included trees, shrubs, and vines. All plots were located using the Global Positioning System (GPS). The recorded field data of tree species were calculated for quantitative characteristics and Shannon-Wiener Index (SWI) of species diversity using equations given by Krebs (1985). Forest condition index (FCI) was based on an equation of Seeloy-ounkeaw *et al.* (2014) used for the plot of 40×40 m^2 in size. For immature trees, the stem girth class of tree species was divided into 25 cm intervals for the GBH up to 100 cm, and the 100 cm interval was used for mature trees having the GBH over 100 cm. This equation assumed a greater importance of the mature trees due to their number of individuals and stem sizes.

3. Plant biomass estimation

The collected data of stem-GBH and tree heights of all tree species were used for calculating standing biomass amounts in stem, branch, leaf and root organs of broad-leaved species (and pine root) using allometry equations studied by Tsutsumi *et al.* (1983).

$W_S = 0.0509(D^2H)^{0.919}$ (r^2=0.978)
$W_B = 0.00893(D^2H)^{0.977}$ (r^2=0.890)
$W_L = 0.0140(D^2H)^{0.669}$ (r^2=0.714)
$W_R = 0.0313(D^2H)^{0.805}$ (r^2=0.981)

Where W_S, W_B, W_L and W_R are the stem, branch, leaf, and root biomass, respectively. The biomass amounts of stem, branch and leaf of one were calculated using equations studied by Nongnuang *et al*. (2012). The biomass is in kg., diameters in cm., and heights in m.

$W_S = 0.0503 (D^2H)^{0.8775}$ (r^2=0.9749)
$W_B = 0.0012 (D^2H)^{1.0996}$ (r^2=0.4982)
$W_L = 0.4536 (W_B)^{0.7933}$ (r^2=0.6324)

4. Carbon and macronutrient storages in plant biomass

After the biomass amounts of tree species were estimated, carbon and macronutrients stored in the biomass could be determined by multiplying the biomass with nutrient contents in different plant organs. Based on the estimates of Tsutsumi *et al*. (1983), average nutrient contents in stem, branch, leaf, and root organs of 46 tree species in Thailand were used to calculate carbon and macronutrient storages in the plant biomass: carbon (C): 49.90%, 48.70%, 48.30% and 48.12%, nitrogen (N): 0.34%, 0.64, 1.83% and 0.53%, phosphorus (P): 0.05%, 0.08%, 0.13% and 0.02%, potassium (K): 0.16%, 0.34%, 0.91% and 0.27%, calcium (Ca): 0.74%, 1.26%, 2.12% and 0.88%, and magnesium (Mg): 0.08%, 0.27%, 0.92% and O.08%, respectively.

5. Carbon and macronutrient storages in Ao layers and soil

The study selected three plots for the vegetation study for investigating Ao layers and soil characteristics in the forest. Three subplots, each of 1 x 1 m^2, were used for collecting organic matter from Ao layers (L-, F- and H- layers) in each of the 40 x 40 m^2 plot. Soil sampling was carried out by making three pits in these plots, 1.5 m width x 1.5 m long x 2 m depth in size, and soil samples were collected along the depth using a 100 cm^3 corer from the thirteen soil depths with three replications: 0-5, 5-10, 10-20, 20-30, 30-40, 40-60, 60-80, 80-100, 100-120, 120-140, 140-160, 160-180 and 180-200 cm including A and B horizons. The soil samples were collected along soil profiles for analyzing physical and chemical properties. Carbon contents in soil samples were analyzed in a laboratory before estimating carbon amounts in the three soil pits (Page, 1982).

RESULTS AND DISCUSSION

1. Plant species composition and diversity in the MF

Table 1 shows the features of 15 sampling plots, each of size 40 x 40 m^2, used for plant community survey in the MF. These plots were located at different altitudes, 1,200 to 1,597m m.s.l. with various slope aspects and 5 to 26% slope gradients. The most dominant tree species varied among the plots; 5 plots each for *Castanopsis acuminatissima* and *C. diversifolia*, 3 plots for *Pinus kesiya*, and one plot each for *Xanthophyllum flavescens* and *Magnolia floribunda.* Species richness varied between 40 and 95 species while the tree densities were 466 to 903 trees per plot.

The quantitative characteristics of plant species in the forest are given in Table 2. In 15 sampling plots, a total of 171 species in 129 genera and 70 families was found. These included 49 big-sized trees, 38 medium-sized trees, 44 small trees, 18 shrubs and 14 climber species as a species list in Appendix 1.

1.1 Plant frequency

Four species had the highest frequency value (100%); *Castanopsis acuminatissima*, *Phoebe paniculata*, *Symplocos* sp. and *Diospyros glandulosa*. The species with 80 to 93.33% frequencies included *Castanopsis diversifolia*, *Schima wallichii*, *Syzygium* sp., *Litsea* sp., *Helicia nilagirica*, *Ardisia polycephala*, *Elaeocapus braceanus*, *Styrax benzoides, Anneslea fragrans, Olea* *salicifolia*, *Ilex umbellulata*, *Turpinia cochinchinensis*, *Elaeocarpus serrata*, *Pyrenaria diospyricarpa* and *Eurya nitida*. These were common species in the MF.

1.2 Plant density

Average density of all species in the forest was 4,031.25 trees/ha. Species with the highest density was *C. acuminatissima* (655 trees/ha), followed by *Litsea sp.* (218), *P. paniculata* (170), *C. diversifolia* (143), *Ardisia polycephala* (136), *S. wallichii* (130), etc.

1.3 Plant dominance

The dominance of tree species was calculated from the stem basal area (SBA) by measurement of stem girths at the breast height. *C. acuminatissima* had the highest dominance (27.20%), followed by *C. diversifolia* (12.0%), *Schima wallichii* (9.56%), *Pinus kesiya* (8.99%), *Syzygium* sp. (5.95%), *Helicia nilagirica* (2.70%), *Phobe paniculata* (2.14%), *Anneslea fragrans* (1.32%), *Litsea* sp. (1.05%), *Styrax benzoides* (1.27%), *Litsea salicifolia* (0.89%), *Symplocos* sp (0.56%), *Diospyros glandulosa* (0.32%), *Ilex umbellulata* (0.28%), *E. braceanus* (0.21%), *Ardisia polycephala* (0.20%) and *Olea salicifolia* (0.15%). These 17 species accounted for 74.80% of the total dominance.

1.4 Ecological important value index (IVI)

The IVI combines the relative frequency, relative density and relative dominance into a measure that can be used to determine the ecological influence of each species in the MF. The species with the highest IVI was *C. acuminatissima* (15.06% of all species), followed by *C. diversifolia* (5.71%), *Schima wallichii* (4.79%), *Syzygium* sp. (3.46%), *Pinus kesiya* (3.38%), *Phobe paniculata* (2.68%), *Litsea* sp. (2.68%), *Helicia nilagirica* (2.31%), *Litsea salicifolia* (1.75%), *Ardisia polycephala* (1.72%), *E. braceanus* (1.58%), *Symplocos* sp. (1.55%). *Styrax benzoides* (1.51%), *Anneslea fragrans* (1.40%) *Olea salicifolia* (1.35%), *Diospyros glandulosa* (1.26%) and *Ilex umbellulata* (1.16%). These 17 species accounted for 53.30% of the total value.

1.5 Evaluating species diversity and forest condition

The Shannon-Wiener Index (SWI) indicated that the plant species diversity in the MF was different among plots, 3.72 to 5.16 (4.52±0.43 on average) (Table 1), while the forest condition index (FCI) values in 15 plots were measured in a range between 13.48 and 30.52 (21.72±5.41 on average). The species diversity and forest condition were therefore high for this forest. The big-sized tree individuals resulted in the high FCI values. However, plot size and number of plots used for the plant community study are important factors to be considered when the SWI values are compared among forests of different sites. It is difficult to compare the SWI among research works as there are the different use of plot size and number of plots. Seeloy-ounkeaw *et al.* (2014) studied the MF in conservation (CF) and utilization (UF) community forests of Karen village using 50 plots, each of size 40x 40 m^2, for each forest. A total of 256 plant species in 166 genera and 73 families with 4.49±0.64 SWI and 17.3±6.87 FCI was found for the CF while the UF had the lower values, 132 species (93 genera and 52 families) with 3.43±0.50 SWI and 10.54±4.60 FCI. As for the UMF at Mt. Inthanon summit, the highest mountain in Thailand, with 2,000-2,565 m altitude had the SWI value as 4.2 when 50 plots of the size 40 x 40 m^2 were used (Khamyong *et al*., 2004). Its species diversity was lower than the LMF.

Table 1 Plant communities within 15 sampling plots in the MF

Plot no.	Altitude (m)	Slope (%)	Slope aspect	Most dominant species	Species (/plot)	Density (/plot)	Big tree (/plot)	SWI	FCI
1	1,597	20	S48° E	*Castanopsis acuminatissima*	40	635	15	3.72	22.86
2	1,596	17	S30° W	*Pinus kesiya*	41	573	12	4.04	13.48
3	1,587	20	S40° E	*Pinus kesiya*	52	662	19	4.82	25.51
4	1,579	26	S30° W	*Castanopsis acuminatissima*	53	466	21	4.25	16.03
5	1,570	10	S70° W	*Pinus kesiya*	51	472	15	4.38	14.82
6	1,558	25	S20° W	*Castanopsis diversifolia*	51	622	13	4.66	17.77
7	1,535	12	S50° W	*Castanopsis diversifolia*	62	664	15	4.81	16.25
8	1,349	5	S41° E	*Castanopsis acuminatissima*	52	576	22	4.04	23.01
9	1,332	5	N70° E	*Castanopsis acuminatissima*	63	903	20	4.51	26.67
10	1,331	25	S45° E	*Castanopsis acuminatissima*	59	722	17	4.52	28.08
11	1,311	5	N34° W	*Xanthophyllum flavescens*	69	626	16	5.14	23.94
12	1,306	10	N90° W	*Castanopsis diversifolia*	67	757	27	4.98	18.86
13	1,303	6	N21° W	*Castanopsis diversifolia*	59	679	16	4.07	30.52
14	1,211	12	S41° E	*Castanopsis diversifolia*	71	667	14	4.75	19.89
15	1,200	7	S72° E	*Magnolia floribunda*	95	651	18	5.16	28.05
				Mean	51	645		4.52	21.72
				S.D.	13.56	107		0.43	5.41

Note: The big tree has the stem GBH of 100 to 400 cm.

Table 2 Quantitative characteristics of plant species in the MF

No.	Name	Freq.	Density	SBA	Relative value (%)			IVI	
		%	tree/ha	m²/ha	Freq.	Dens.	Domi.	300	%
1	*Castanopsis acuminatissima*	100	655.00	96,289.81	1.69	16.25	27.23	45.17	15.06
2	*Castanopsis diversifolia*	93.33	142.50	42,507.13	1.58	3.53	12.02	17.14	5.71
3	*Schima wallichii*	93.33	130.44	33,797.81	1.58	3.24	9.56	14.38	4.79
4	*Syzygium* sp.	80	123.31	21,039.00	1.36	3.06	5.95	10.37	3.46
5	*Pinus kesiya*	40.00	18.75	31,803.69	0.68	0.47	8.99	10.14	3.38
6	*Phobe paniculata*	100	170.00	7,572.06	1.69	4.22	2.14	8.05	2.68
7	*Litsea* sp.	93.33	217.94	3,702.69	1.58	5.41	1.05	8.03	2.68
8	*Helicia nilagirica*	93.33	106.69	9,548.25	1.58	2.65	2.70	6.93	2.31
9	*Litsea salicifolia*	73.33	125.00	3,160.94	1.24	3.10	0.89	5.24	1.75
10	*Ardisia polycephala*	93.33	136.25	718.69	1.58	3.38	0.20	5.17	1.72
11	*Elaeocarpus braceanus*	93.33	119.19	748.44	1.58	2.96	0.21	4.75	1.58
12	*Symplocos* sp.	100	96.25	1,993.19	1.69	2.39	0.56	4.65	1.55
13	*Styrax benzoides*	86.67	72.06	4,484.94	1.47	1.79	1.27	4.53	1.51
14	*Anneslea fragrans*	86.67	57.06	4,656.31	1.47	1.42	1.32	4.20	1.40
15	*Olea salicifolia*	80	102.50	518.94	1.36	2.54	0.15	4.05	1.35
16	*Diospyros glandulosa*	100	70.44	1,145.38	1.69	1.75	0.32	3.77	1.26
17	*Ilex umbellulata*	86.67	69.56	982.88	1.47	1.73	0.28	3.47	1.16
18	Species 18 to 171								48.37
	Total	5900	2,412.938	264,670.1	100	100	100	300	100

2. Amounts of plant biomass in the MF

Table 3 and 4 show data of standing plant biomass of all species within 15 sampling plots in the MF. The biomass amounts varied between 236.86 and 827.02 Mg/ha (438.78 Mg/ha on average). It was partitioned to stem, branch, leaf, and root organs as the following order: 286.22, 96.38, 5.54 and 50.64 Mg/ha. The stem biomass contributed the highest percentage (65.20%), followed by branch (22.0%), root (11.50%) and leaf (1.30%). *C. accuminatissima* had the highest biomass, followed by *S. wallichii*, *P. kesiya*, *C. diversifolia*, *Syzygium* sp., *M. floribunda*, etc.

Table 3 Variation of plant biomass amounts among 15 sampling plots in the MF

Plot	Biomass (kg/ha)				
	Stem	**Branch**	**Leaf**	**Root**	**Total**
1	171.19	54.66	4.09	33.44	263.37
2	205.29	65.98	4.84	39.79	315.90
3	182.80	58.27	4.31	35.66	281.04
4	250.49	82.51	5.18	45.96	384.13
5	188.11	59.84	4.42	36.77	289.14
6	197.86	62.11	5.01	39.89	304.86
7	153.42	47.35	4,17	31.93	236.86
8	432.39	150.28	7.12	71.38	661.16
9	345.06	116.11	6.40	60.36	527.93
10	410.67	145.96	6.36	65.34	628.33
11	308.68	106.18	5.59	52.70	473.15
12	342.23	113.05	6.90	62.22	524.39
13	541.37	196.59	7.33	81.73	827.02
14	251.61	84.97	4.88	44.35	385.82
15	312.17	101.82	6.58	58.09	478.66
Mean	286.22	96.38	5.54	50.64	438.78
S.D. (%C.V.)	±112.68 (39.40)	±42.72 (44.40)	±1.14 (20.60)	±15.26 (30.20)	±171.51 (39.10)
%	65.20	22.0	1.30	11.50	100

Table 4 Amounts of standing plant biomass of species in the MF

No.	Scientific name	Biomass (kg/ha)					%
		W_S	W_B	W_L	W_R	Total	
1	*Castanopsis acuminatissima*	81,614.8	27,389.13	1,525.40	14,376.28	124,905.64	28.47
2	*Schima wallichii*	38,089.6	13,537.82	547.01	5,964.36	58,138.83	13.25
3	*Pinus kesiya*	28,900.4	9,865.95	458.57	4,822.68	44,047.66	10.04
4	*Castanopsis diversifolia*	27,369.7	8,880.79	577.71	5,128.39	41,956.67	9.56
5	*Syzygium* sp.	15,300.4	5,050.93	295.16	2,755.97	23,402.48	5.33
6	*Magnolia floribunda*	7,538.71	2,812.17	86.73	1,070.10	11,507.70	2.62
7	*Xanthophyllum flavescens*	5,681.51	2,159.40	61.26	777.29	8,679.46	1.98
8	*Calophyllum polyanthum*	5,231.93	2,008.58	49.70	691.18	7,981.40	1.82
9	*Phoebe paniculata*	5,130.66	1,568.82	147.13	1,091.47	7,938.09	1.81
10	*Duabanga grandiflora*	5,136.43	1,970.61	48.46	678.57	7,834.06	1.79
11	*Lithocarpus auriculatus*	4,380.42	1,620.73	51.44	629.71	6,682.31	1.52
12	*Litsea monopetala*	4,266.53	1,547.12	51.68	630.49	6,495.83	1.48
13	*Lepisanthes ferruginea*	4,206.07	1,592.99	42.11	570.26	6,411.43	1.46
14	*Helicia nilagirica*	4,023.40	1,158.90	138.62	946.64	6,267.56	1.43
15	*Adinandra integerrima*	3,583.75	1,248.29	53.82	578.54	5,464.39	1.25
16	*Elaeocarpus serrata*	2,577.89	874.33	43.86	439.02	3,935.11	0.90
17	*Dalbergia ovata*	2,472.80	800.57	52.24	463.66	3,789.26	0.86
18	*Styrax benzoides*	2,159.46	611.39	81.98	528.86	3,381.69	0.77
19	*Anneslea fragrans*	2,023.90	597.15	62.63	453.55	3,137.23	0.71
20	*Acrocarpus fraxinifolius*	2,053.49	743.53	24.86	303.96	3,125.84	0.71
21	species 21 to 171	34,479.32	10,339.33	1,143.72	7,738.98	53,701.29	12.24
	Total (kg/ha)	286,221.37	96,378.52	5,544.09	50,639.94	438,783.92	100
	Total (Mg/ha)	286.22	96.38	5.54	50.64	438.78	
	%	65.23	21.96	1.26	11.54	100	

3. Amounts of carbon and macronutrients in plant biomass

Table 5 shows data of carbon and macronutrient amounts stored in standing plant biomass of species in the MF.

Carbon (C): Total amount of C in the plant biomass was 216,806.56 kg/ha or 216.81 Mg/ha. With the same trend as biomass, *C. accuminatissima* had the highest stored C (61.72 Mg/ha), followed by *S. wallichii* (28.73), *P. kesiya* (21.77), *C. diversifolia* (20.73), *Syzygium* sp. (11.56), *M. floribunda* (5.69), etc. The stored C in the six species was accounted for 69.28% of all species.

Nitrogen (N): Total amount of N in the plant biomass was 1,959.82 kg/ha. *C. accuminatissima* had the highest amount of stored N (556.89 kg/ha), followed by *S. wallichii* (257.77), *P. kesiya* (195.36), *C. diversifolia* (187.65), *Syzygium* sp. (104.36), *M. floribunda* (50.89), etc. The remainders had values less than 50 kg/ha.

Phosphorus (P): Total amount of P in the biomass was 237.55 kg/ha. *C. accuminatissima* had the highest stored P (67.58 kg/ha), followed by *S. wallichii* (31.78), *P. kesiya* (23.90), *C. diversifolia* (22.57), *Syzygium* sp. (12.63), *M. floribunda* (6.35), etc.

Potassium (K): Total amount of K in the biomass was 972.82 kg/ha. Again, *C. accuminatissima* had the highest stored K (276.40 kg/ha), followed by *S. wallichii* (128.05), *P. kesiya* (96.98), *C. diversifolia* (93.09), *Syzygium* sp. (51.78), *M. floribunda* (25.30), etc.

Calcium (Ca): Total amount of Ca in the biomass was 3,895.57 kg/ha. *C. accuminatissima* had also the highest stored Ca (1,107.90 kg/ha), followed by *S. wallichii* (516.52), *P. kesiya* (390.34), *C. diversifolia* (371.81), *Syzygium* sp. (207.37), *M. floribunda* (102.48), etc.

Magnesium (Mg): Total amount of Mg in the biomass was 580.72 kg/ha. *C. accuminatissima* had the highest stored Mg (164.78 kg/ha), followed by *S. wallichii* (76.83), *P. kesiya* (57.84), *C. diversifolia* (55.29), *Syzygium* sp. (30.80), *M. floribunda* (15.28), etc.

Table 5 Amounts of C and other macronutrients stored in plant biomass of the MF

No.	Name	Nutrient (kg/ha)					
		C	N	P	K	Ca	Mg
1	*Castanopsis acuminatissima*	61,718.94	556.89	67.58	276.40	1,107.90	164.78
2	*Schima wallichii*	28,733.91	257.77	31.78	128.05	516.52	76.83
3	*Pinus kesiya*	21,768.21	195.36	23.90	96.98	390.34	57.84
4	*Castanopsis diversifolia*	20,729.28	187.65	22.57	93.09	371.81	55.29
5	*Syzygium* sp.	11,563.45	104.36	12.63	51.78	207.37	30.80
6	*Magnolia floribunda*	5,688.16	50.89	6.35	25.30	102.48	15.28
7	*Xanthophyllum flavescens*	4,290.32	38.38	4.80	19.09	77.39	11.56
8	*Calophyllum polyanthum*	3,945.51	35.22	4.43	17.52	71.16	10.62
9	*Phoebe paniculata*	3,920.50	35.96	4.23	17.83	70.46	10.57
10	*Duabanga grandiflora*	3,872.70	34.56	4.34	17.19	69.84	10.42
11	*Lithocarpus auriculatus*	3,302.99	29.55	3.68	14.69	59.47	8.86
12	*Litsea monopetala*	3,210.80	28.70	3.56	14.26	57.71	8.57
13	*Lepisanthes ferruginea*	3,169.36	28.29	3.55	14.07	57.11	8.51
14	*Helicia nilagirica*	3,094.54	28.65	3.31	14.20	55.64	8.38
15	*Adinandra integerrima*	2,700.59	24.22	2.98	12.03	48.48	7.20
16	*Elaeocarpus serrata*	1,944.61	17.49	2.13	8.68	34.89	5.18
17	*Dalbergia ovata*	1,872.15	16.94	2.04	8.41	33.57	4.99
18	*Styrax benzoides*	1,669.40	15.56	1.78	7.71	30.08	4.56
19	*Anneslea fragrans*	1,549.24	14.25	1.66	7.06	27.82	4.17
20	*Acrocarpus fraxinifolius*	1,545.06	13.81	1.71	6.86	27.77	4.12
21	specie 21to 171	26,516.83	245.34	28.56	121.62	477.76	72.18
	Total	216,806.56	1,959.81	237.56	972.81	3,895.56	580.69

Table 6 Contribution of families to C and other macronutrients stored in plant biomass of the MF.

No.	Name	Nutrient (kg/ha)					
		C	N	P	K	Ca	Mg
1	Fagaceae	88,924.91	803.05	97.25	398.54	1,596.15	237.44
2	Theaceae	28,879.02	259.18	31.93	128.75	519.17	77.25
3	Pinaceae	21,768.21	195.36	23.90	96.98	390.34	57.84
4	Lauraceae	12,541.31	114.85	13.61	56.97	225.69	33.91
5	Myrtaceae	11,718.97	105.77	12.79	52.48	210.16	31.21
6	Pentaphyllaceae	5,977.59	54.52	6.48	27.04	107.40	16.06
7	Magnoliaceae	5,688.28	50.89	6.35	25.30	102.48	15.28
8	Sapindaceae	4,647.38	41.54	5.18	20.65	83.67	12.46
9	Apocynaceae	4,304.67	38.51	4.89	19.16	77.65	11.60
10	Fabaceae	4,057.93	36.80	4.43	18.26	72.93	10.89
11	Callophyllaceae	3,945.51	35.22	4.43	17.52	71.16	10.62
12	Lythraceae	3,872.70	34.56	4.34	17.19	69.84	10.42
13	Proteaceae	3,602.05	33.28	3.86	16.49	64.75	9.74
14	Elaeocarpaceae	2,156.62	19.53	2.36	9.69	38.75	5.79
15	Styracaceae	1,669.40	15.56	1.78	7.71	30.08	4.56
16	Phyllanthaceae	1,349.10	12.50	1.45	6.20	24.32	3.68
17	Juglandaceae	1,217.77	11.22	1.31	5.56	21.90	3.29
18	Betulaceae	996.71	8.95	1.09	4.44	17.86	2.65
19	Ericaceae	937.76	8.90	0.99	4.41	16.98	2.61
20	Sapotaceae	870.06	7.97	0.94	3.95	15.62	2.34
21	family 21 to 70	7,680.59	71.66	8.24	35.52	138.67	21.11
	Total	216,806.54	1,959.82	237.55	972.82	3,895.57	580.72

In Table 6, tree species in the family of Fagaceae had the highest contribution to the stored C (41.01%), followed by Theaceae (13.32%), Pinaceae (10.04%), Lauraceae (5.78%), Myrtaceae (5.41%), Pentaphyllaceae (2.76%), Magnoliaceae 2.62%), etc. The percentage distribution patterns of other macronutrients were the same as the stored C. The amount of C stored in plant biomass was the highest among macronutrients, followed by Ca, N, K, Mg, and P, respectively. It is considered that either above-ground or below-ground (root) litterfalls are sources of carbon and other macronutrients in the forest floor (Ao layers) and soil. The amounts of above-ground litterfall in the MF during the year 1998 and 2,000 were varied with year and forest sites: 6.254, 5.141,10.629 Mg/ha at the upper slope and ridge site; 7.490, 7.107, 8.885 Mg/ha at the lower slope site, and 9.697, 10.226 and 11.313 Mg/ha at the valley site. The average amount was 8.60 Mg/ha/yr for all sites. About half (4.3 Mg/ha) of the litterfall was organic carbon recycled to forest floor and soil. The recycling N, P, K, Ca, and Mg were calculated as values in the following order: 95.60, 4.53, 45.37, 80.70 and 17.73 kg/ha/yr. These amounts were the fluxes of nutrient movement and balance from plants to compartments of Ao layers and soil (Khamyong, 2015).

4. Amounts of carbon and macronutrients in Ao layers

Since the MF usually has no forest fires, some amounts of above-ground litter are therefore accumulated on the forest floor as Ao layers. The MF covers the highland with a relatively cool weather throughout a year, and thus litter decomposition is normally slow and results in some accumulating organic layers. It was estimated that the average amount of organic matter on the forest floor on May 27th, 2018, was 37.48 Mg/ha including the dry matter of litter (L)-layer, fragmented (F)-layer, and humus (H)-layer. According to average contents of C, N, P, K, Ca, and Mg in the organic layers as 34.65%, 1.70%, 0.097%, 0.39%, 1.29% and 0.177%, respectively (Khamyong and Anongrak, 2016), amounts of these nutrients accumulated in Ao layers could be calculated as the following order: 12.99 Mg/ha, 637.16, 36.37, 146.17, 483.49 and 66.34 kg/ha.

5. Amounts of soil carbon and macronutrients

In Table 7, three soil pits under the MF derived from a deep weathered granitic rock was a deep fertile soil (1.43 m to 2.0 m or more) including A and B horizons excluding C horizon, and classified to be Order Ultisols, Suborder Humults, according to a high clay accumulation in subsoils and their acid properties as very strongly to extremely acid in surface soils and strongly to very strongly acid in subsoils (Soil Survey Staff, 1999). Soil physical and chemical properties have had influence on storages of carbon and macronutrient storages. The bulk densities were low in surface soils caused by the high contents of organic matter, and moderate in subsoils. As a result, textures of surface soils were mainly sandy clay loam while those of subsoils were clay loam or clay.

Organic matter (OM): Total amounts of OM in three soil pits varied between 714.74 to 1,000.50 Mg/ha, 849.24 Mg/ha on average. It was very high in surface soils and decreasing subsoils. This caused by decomposing organic layers on forest floor (Ao layers) which provided humus into the surface soils, and then slowly moved into the deeper soils, B horizon.

Carbon (C): The amounts of soil C were a similar trend as OM (organic C is 58% of OM) that were high in surface soils and decreasing subsoils. The average C amount of three pits was 492.56 Mg/ha.

Nitrogen (N): The amounts of total N were high in surface soils and decreased to subsoils because it is an important component of OM. The average amount in the soil profile was 3,188.37 kg/ha.

Phosphorus (P): The amounts of available P were high at surface soils and very low in subsoils, 71.53 kg/ha on average. The soil P came from either decomposing Ao layers or weathering parent rocks.

Potassium (K): The amounts of extractable K were not varied with soil depths. It was 4,622.26 kg/ha on average. The soil K can be easily moved throughout soil profiles in the form of K^+. It was also come from both decomposing Ao layers and weathering rocks.

Calcium (Ca): The amounts of extractable Ca were also not varied along soil profiles. This element came from both decomposing Ao layers and weathering rocks. The average total amount of three soil pits was 4,622.26 kg/ha.

Magnesium (Mg): The amounts of extractable Mg were not varied along the soil depths. The total amount of three soil pits was 4373.36 kg/ha on average.

The OM, C and N in soils were come from above-ground litterfall, and most of them accumulated within 100 cm soil depths, 92.0% of the total. Only 8.0% of them were stored at the depths of 100 to 200 cm. As for other macronutrients including available P, and extractable K, Ca and Mg in soils, their sources were from both decomposing plant litter and weathering parent rocks. Thus, the patterns of storage along soil profiles were differed from organic C and N.

Table 7 Amounts of organic matter, carbon, and macronutrients in three soil profiles under the MF.

Soil pit No.	Depth (cm.)	OM	CCP		NCP		Extractable nutrients (kg/ha)			
		Mg/ha	Mg/ha	%CP	kg/ha	%CP	P	K	Ca	Mg
1 (1,597m)	0-10	248.81	144.31	29.89	692.80	23.96	19.18	258.47	187.03	27.64
	10-20	175.26	101.65	50.94	676.20	47.35	10.43	167.05	233.66	27.79
	20-30	123.28	71.50	65.75	482.40	64.04	5.01	338.52	225.46	23.13
	30.40	66.07	38.32	73.69	265.60	73.23	3.00	438.79	266.35	26.23
	40-60	81.05	47.01	83.43	342.00	85.06	6.19	484.00	555.24	39.16
	60-80	74.11	42.98	92.33	155.20	90.43	4.66	1,241.13	641.13	52.19
	80-100	15.65	9.08	94.21	72.80	92.95	3.53	1,324.01	586.91	44.92
	100-120	15.83	9.18	96.11	77.20	95.62	2.05	715.57	616.33	30.30
	120-140	14.82	8.60	97.89	76.00	98.25	0.04	664.51	603.63	23.07
	140-160	13.65	7.92	99.53	39.00	99.60	0.04	472.10	469.76	23.32
	160-166	3.94	2.29	100.00	11.94	100.00	0.02	145.93	142.47	6.50
	Total	832.47	482.83	100.00	2,891.14	100.00	54.15	6,250.08	4,527.96	324.24
2 (1,596 m)	0-10	262.35	152.16	26.22	795.35	20.49	37.25	324.17	481.98	79.11
	10-20	166.62	96.64	42.87	641.30	37.01	9.80	242.00	336.55	48.85
	20-30	135.97	78.86	56.46	541.80	50.97	6.23	215.65	316.93	49.29
	30.40	114.69	66.52	67.92	471.90	63.13	5.73	238.98	329.37	49.55
	40-60	126.41	73.32	80.56	540.80	77.07	10.78	428.48	743.94	69.53
	60-80	68.07	39.48	87.36	299.20	84.78	11.59	412.34	898.76	50.38
	80-100	31.26	18.13	90.49	162.40	88.97	12.67	529.63	813.30	63.50
	100-120	29.35	17.02	93.42	131.40	92.36	6.88	616.09	789.93	27.90
	120-140	22.57	13.09	95.68	130.20	95.71	0.04	637.24	691.10	8.81
	140-160	17.22	9.99	97.40	84.00	97.87	0.04	352.13	547.89	8.61
	160-180	13.46	7.81	98.75	40.80	98.92	0.08	280.26	490.01	7.96
	180-200	12.54	7.27	100.00	41.80	100.00	0.04	252.10	419.00	4.39
	Total	1,000.50	580.29	100.00	3,880.95	100.00	101.14	4,529.06	6,858.76	467.86
3 (1,211 m)	0-10	206.65	119.86	28.91	768.00	27.50	25.58	297.61	230.57	60.55
	10-20	126.20	73.20	46.66	484.00	44.82	8.75	185.01	242.38	39.74
	20-30	107.00	62.06	61.54	425.00	60.04	3.99	178.63	238.34	32.45
	30.40	79.04	45.84	72.60	351.00	72.61	3.09	177.13	253.94	31.16
	40-60	71.34	41.38	82.58	296.00	83.21	4.62	389.06	546.27	42.48
	60-80	40.48	23.48	88.24	138.40	88.17	5.33	445.58	610.62	40.66
	80-100	29.58	17.16	92.38	136.00	93.04	5.17	431.60	586.19	41.45
	100-120	26.94	15.62	96.15	109.20	96.95	2.73	463.92	609.04	22.86
	120-140	25.02	14.51	99.65	73.60	99.59	0.04	472.25	589.98	15.42
	140-160	2.48	1.44	100.00	11.82	100.00	0.01	46.87	76.95	1.24
	Total	714.74	414.55	100.00	2,793.02	100.00	59.29	3,087.65	3,984.29	327.99
	(3 pits)	**849.24**	**492.56**	**100.00**	**3,188.37**	**100.00**	**71.53**	**4,622.26**	**5,123.67**	**373.36**

Note: The CP is cumulative percentages of storage along soil depth.

6. Ecosystem carbon and macronutrient storages

Three compartments of carbon and macronutrients in the MF ecosystem are considered: standing plant biomass, organic layers on forest floor (Ao layers) and soil system. The data are given in Table 8.

Carbon storage: The total C stock in the MF was 712.87 Mg/ha. This included C in the biomass (216.81 Mg/ha, 30.01%), Ao layers (12.99 Mg/ha, 1.80%), and soil (483.07 Mg/ha, 68.19%).

Nitrogen storage: The amount of total N in this forest was 5,642.89 kg/ha; 1,959.81 kg/ha (33.88%) in the biomass, 637.16 kg/ha (11.01%) in Ao layers, and 3.045.92 kg/ha (55.11%) in soil.

The total amounts of other macronutrients in the ecosystem could not provide here because the total amounts in soils were not determined. Sungpalee *et al.* (2015) reported that above-ground biomass increment of plant species with 372.70 Mg/ha of biomass at Mt. Doi Inthanon was 6.129 Mg/ha/yr and had the recruitment of 0.018 Mg/ha/yr. The total annual increment for the MF thus was 1.65% of existing biomass. As for this study, the biomass of 438.78 Mg/ha should have the biomass increment at 7.24 Mg/ha/yr. Therefore, the annual uptake of C, N, P, K, Ca, and Mg by plant species could be calculated using average contents of these nutrients in plant organs as the following order: 3.62 Mg/ha/yr, 60.82, 5.07, 30.41, 90.50 and 24.62 kg/ha/yr. The amounts of available forms (AF) of P, K, Ca and Mg in soil and Ao layers were excess for the annual uptake of tree species. The annual uptake amounts (AUA) of these nutrients were less than available forms in soil: P, AUA = 5.07 kg/ha/yr, AF = 107.90 kg/ha; K, AUA = 30.41 kg/ha/yr, AF = 4,768.43 kg/ha; Ca, AUA = 90.50 kg/ha/yr, AF = 5,607.16 kg/ha; and Mg, AUA = 24.62 kg/ha/yr, AF = 439.70 kg/ha. The plants receive carbon from CO_2 in the atmosphere whereas about 2% (60.92 kg/ha) of total soil nitrogen are generally occurred in the available forms (Stevenson *et al.*, 1982) with some amounts released from decomposing Ao layers were large enough for the annual plant requirement. Plants also uptake other macronutrients from the soil where their stocking amounts were also large enough. It is reported that the UMF at Mt. Inthanon summit had the higher biomass (703.80 Mg/ha) and could store the larger amounts of other macronutrients (Khamyong and Anongrak, 2016). The carbon allocated in the plant biomass, Ao layers and soil were accounted to 55.20%, 3.10% and 41.70%, respectively. The soil under the LMF of this study was deeper than the UMF and contained the larger amounts of carbon and nitrogen. The lesser acid soil in the LMF allows more availability of P, K, Ca, and Mg (Brady and Weil, 2010). Thus, the stored amounts of these macronutrients were very large in this LMF soil.

Table 8 Amounts of carbon and macronutrients in the MF ecosystem

Nutrient compartments	C	N	P	K	Ca	Mg
	Mg/ha	kg/ha	kg/ha			
Plant Biomass	216.81	1,959.81	237.56	972.81	3,895.56	580.69
%	30.01	33.88	68.77	16.94	40.99	56.91
Forest floor	12.99	637.16	36.37	146.17	483.49	66.34
%	1.80	11.01	10.52	2.55	5.09	6.50
Soil	492.56	3,188.37	71.53	4,622.26	5,123.67	373.36
%	68.19	55.11	20.71	80.51	53.92	36.59
Ecosystem	**722.36**	**5,785.34**	**345.46**	**5,741.24**	**9,502.72**	**1,020.39**
%	100	100	100	100	100	100
Plant annual uptake	**3.62**	**60.82**	**5.07**	**30.41**	**90.50**	**24.62**

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

CONCLUSION

The MF inside the Doi Suthep National Park is a recovery forest after 60 years of establishing the national park. Forest management through strict laws of the national park including prohibiting selective tree cutting and shifting cultivation as well as controlling inside village activities and fire protection is important for the stimulating rates of forest succession, plant growths and recovery. Moreover, favorable environmental factors in the MF such as receiving a large amount of annual rainfall, a high site moisture condition, a deep well-developed fertile soil, cool weather, no forest fires, ecotourism, etc., can promote the forest recovery which resulted in the high species diversity as well as biomass production. These further resulted in the high carbon and macronutrient stocks in the ecosystem of this montane forest.

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Appendix 1 Species list, growth form and number of tree individuals (15 plots) in the MF.

Family	No.	Scientific name	No. of trees	Life form
1. Actinidiaceae	1	*Saurauia roxburghii* Wall.	9	Shr
2. Caprifoliaceae	2	*Viburnum inopinatum* Craib	1	ST
3. Anacardiaceae	3	*Semecarpus cochinchienensis* Engl.	25	MT
	4	*Choerospondias axillaris* (Roxb.) B.L. Burtt & Hill	2	ST
	5	*Rhus javanica* L. *var. chinensis* (Mill.) T. Yamaz.	32	ST
	6	*Spondias lakonensis Pierre*	6	ST
4. Annonaceae	7	*Goniothalamus laoticus* (Finet & Gagnep.) Ban	1	MT
	8	*Miliusa thorelii* Finet & Gagnep.	2	Shr
	9	*Uvaria rufa* Blume	10	C
5. Apocynaceae	10	*Alstonia scholaris* (L.) R. Br.	1	B
6. Aquifoliaceae	11	*Ilex umbellulata* (Wall.) Loes.	167	ST
7. Araliaceae	12	*Schefflera bengalensis* Gamble	6	C
	13	*Trevesia palmata* (Roxb. ex Lindl.) Vis.	3	Shr
	14	*Aralia armata* (Wall. ex G. Don) Seem.	8	Shr
8. Arecaceae	15	*Areca montana* Ridl.	33	Palm
9. Asteraceae	16	*Vernonia volkameriaefolia* Wall. ex DC.	20	Shr
10. Berberidaceae	17	*Mahonia duclouxiana* Gagnep.	7	ST
11. Betulaceae	18	*Betula alnoides* Buch-Ham ex G. Don	2	BT
	19	*Carpinus viminea* Wall. ex Lindl.	2	MT

12. Bignoniaceae	20	*Markhamia stipulata* (Wall.) Seem. *var.pierrei*	8	MT

Appendix 1 (Continued)

Family	No.	Scientific name	Family	No.
		(Dop) Sprague Santisuk		
	21	*Stereospermum neuranthum* Kurz	2	MT
13. Burseraceae	22	*Canarium euphyllum* Kurz	59	BT
	23	*Protium serratum* Engl.	4	BT
14. Cornaceae	24	*Alangium chinense* (Lour.) Harms	3	ST
15. Cannabaceae	25	*Celtis tetrandra* Roxb.	2	MT
16. Celastraceae	26	*Siphonodon celastrineus* Griff.	6	ST
	27	*Eunymus cochinchinensis* Pierre	11	ST
17. Combretaceae	28	*Combretum punctatum* Blume	1	C
18. Dilleniaceae	29	*Dillenia parviflora* Griff.	22	BT
19. Dipterocarpaceae	30	*Shorea roxburghii* G. Don	1	BT
20. Ebenaceae	31	*Diospyros glandulosa* Lace	169	ST
21. Elaeocarpaceae	32	*Elaeocarpus serrata* L.	49	BT
	33	*Elaeocarpus braceanus* Watt. ex C.B. Clarke	286	MT
22. Ericaceae	34	*Lyonia ovalifolia* (Wall.) Drude var. *ovalifolia*	81	ST
	35	*Vaccinium sprengelii* (G.Don) Sleumer	122	Shr
23. Euphorbiaceae	36	*Mallotus phillippensis* (Lam.) Mull. Arg	9	ST
	37	*Ostodes paniculatus* Blume var. *paniculata*	24	ST
	38	*Macaranga denticulata* (Blume) Mull. Arg.	1	ST
	39	*Mallotus paniculatus* (Lam.) Mull. Arg	93	ST
24. Fabaceae	40	*Acrocarpus fraxinifolius* Wihgt ex Arn.	1	BT
	41	*Archidendron clypearia* (Jack) I. C. Nielsen	33	ST
	42	*Cassia fistula* L..	5	BT
	43	*Dalbergia assamica* Benth.	56	C
	44	*Dalbergia velutina* Benth.	67	C
	45	*Entada glandulosa* Pierre ex Gagnep.	26	C
	46	*Paraderris elliptica* (Wall.) Adema	44	MT
25. Icacinaceae	47	*Dalbergia ovata* Graham ex Benth. var. *ovata*	46	MT
26. Fagaceae	48	*Pittosporopsis kerrii* Craib	1,572	BT
	49	*Castanopsis acuminatissima* (Blume) A.DC.	342	BT
	50	*Castanopsis diversifolia* (Kurz) King ex Hook. f.	1	BT
	51	*Castanopsis echinocarpa* Miq.	121	BT
	52	*Lithocarpus mekonggensis* (A. Camus) C.C. Huang& Y.T. Zhang	18	BT
	53	*Lithocarpus auriculatus* (Hickel & A. Camus) Barnett	24	BT
	54	*Lithocarpus elegans* (Blume) Hatus. ex Soepadmo	2	BT
	55	*Lithocarpus sootepensis* (Craib) A. Camus	5	BT
	56	*Lithocarpus truncatus* (King ex Hook. f.) Rehder	17	BT
	57	*Lithocarpus fenestratus* (Roxb.) Rehder	2	BT
	58	*Quercus brandisiana* Kurz	7	BT
	59	*Quercus helferiana* A.DC.	59	BT
	60	*Quercus semiserrata* Roxb.	10	BT
27. Gnetaceae	61	*Quercus* sp.	11	C
28. Clusiaceae	62	*Gnetum montanum* Markgr.	1	MT
	63	*Garcinia costata* Hemsl. ex King	41	ST
	64	*Garcinia cowa* Roxb. ex Choisy	5	ST
	65	*Garcinia merguensis* Wight	8	MT
29. Calophyllaceae	66	*Garcinia speciosa* Wall.	21	BT
30. Juglandaceae	67	*Calophyllum polyanthum* Wall ex Planch. & Triana	111	BT
	68	*Engelhardtia spicata* Lechen ex Blume	23	BT

31. Lamiaceae	69	*Engelhardtia serrata* Blume	12	Shr

Appendix 1 (Continued)

Family	No.	Scientific name	Family	No.
	70	*Clerodendrum serratum* (L.) Moon	30	MT
32. Lauraceae	71	*Vitex canescens* Kurz	21	MT
	72	*Actinodaphne henryi* Gamble	148	BT
	73	*Beilschmiedia gammieana* King ex Hook. f.	78	BT
	74	*Cinnamomum bejolghota* (Buch-Ham) Sweet	15	BT
	75	*Cinnamomum parthenoxylon* (Jack) Meisn.	27	BT
	76	*Cryptocarya pallens* Kosterm.	300	ST
	77	*Litsea salicifolia* Nees ex Roxb.	5	BT
	78	*Litsea monopetala* (Roxb.) Pers.	11	BT
	79	*Litsea grandis* (Nees) Hook. f.	523	S
	80	*Litsea* sp.	23	BT
	81	*Phoebe lanceolata* (Nees) Nees	408	BT
	82	*Phoebe paniculata* (Nees) Nees	9	M
	83	*Phoebe cathia* (D. Don) Kosterm.	9	M
	84	*Phoebe* sp.	3	M
33. Lythraceae	85	*Lindera caudata* (Nees) Hook. f.	1	BT
34. Magnoliaceae	86	*Duabanga grandiflora* (DC.) Walp.	1	BT
	87	*Magnolia garrettii* (Craib) V.S. Kumar	28	BT
	88	*Magnolia floribunda* (Finet & Gagnep.) Figlar	2	BT
35. Malvaceae	89	*Magnolia hodgsonii* (Hook. f. & Thomson) H. Keng	2	MT
	90	*Pterospermum acerifolium* (L.) Willd	24	ST
36. Melastomataceae	91	*Sterculia balanghas* L..	161	ST
	92	*Memecylon plebejum* Kurz var. *ellipsoideum* Craib	3	ST
37. Meliaceae	93	*Memecylon plebejum* Kurz var. *plebejum*	7	BT
	94	*Melia azedarach* L.	2	BT
	95	*Toona ciliata* M. Roem.	3	ST
38. Moraceae	96	*Trichilla connaroides* (Wight & Arn.) Bentv.	10	MT
	97	*Artocarpus gomezianus* Wall. ex Trecul	2	BT
	98	*Artocarpus lacucha* Roxb. ex Buch-Ham.	1	MT
	99	*Ficus* sp.	3	MT
	100	*Ficus virens* Aiton	7	MT
39. Myricaceae	101	*Morus macroura* Miq.	1	ST
40. Myrtaceae	102	*Myrica esculenta* Buch-Ham. ex D. Don	3	MT
	103	*Syzygium* sp.	29	MT
41. Musaceae	104	*Syzygium albiflorum* (Duthie ex Kurz) Bahadur & R.	1	Shr
42. Oleaceae	105	*Musa acuminata* Colla var. *acuminata*	52	ST
	106	*Chionanthus ramiflorus* Roxb.	246	MT
43.Pentaphylacaceae	107	*Olea salicifolia* Wall. ex G. Don	75	ST
	108	*Eurya nitida* Korth.	35	MT
	109	*Eurya acuminata* DC.	22	BT
	110	*Adinandra integerrima* T. Anderson ex Dyer	137	ST
	111	*Anneslea fragrans* Wall.	35	BT
44. Phyllanthaceae	112	*Ternstroemia gymnanthera* (Wight & Arn) Bedd.	15	BT
	113	*Bischofia javanica* Blume	9	ST
	114	*Antidesma velutinosum* Blume.	65	Shr
	115	*Glochidion sphaerogynum* (Mull. Arg.) Kurz	107	Shr
	116	*Glochidion zeylanicum* (Gaertn.) A. Juss. *v*ar. Hook.f.) *Haines talbotii (Hook. Hainess)*	11	ST
	117	*Phyllanthus emblica L.*	100	ST
	118	*Baccaurea rammiflora* Lour.	37	ST

	119	*Bridelia glauca* Blume	1	ST

Appendix 1 (Continued)

Family	**No.**	**Scientific name**	**Family**	**No.**
	120	*Aporosa villosa* (Wall. ex Lindl.) Baill.	41	ST
45. Pinaceae	121	*Aporosa wallichii* Hook. f.	45	BT
46. Piperaceae	122	*Pinus kesiya* Royle ex Gordon	1	Shr
47. Pittosporaceae	123	*Piper suipigue* Buch-Ham ex D. Don	64	MT
48. Podocarpaceae	124	*Pittosporum nepaulense* (DC.) Rehder & E.H. Wilson	2	MT
49. Polygalaceae	125	*Podocarpus neriifolius* D. Don	10	BT
	126	*Xanthophyllum virens* Roxb.	72	BT
50. Primulaceae	127	*Xanthophyllum flavescens* Roxb.	54	ST
	128	*Myrsine sequinii* H. Lev.	82	Shr
	129	*Maesa montana* A. DC.	327	Shr
	130	*Ardisia polycephala* Wall. ex A. DC.	2	Shr
51. Proteaceae	131	*Ardisia attenuata* Wall. ex A. DC.	256	MT
	132	*Helicia nilagirica* Bedd.	41	ST
52. Rhizophoraceae	133	*Heliciopsis terminalis* (Kurz) Sleumer	36	MT
53. Rosaceae	134	*Carallia brachiata* (Lour.) Merr.	21	MT
54. Rubiaceae	135	*Eriobotrya bengalensis* (Roxb.) Hook. f.	6	Shr
	136	*Canthium berberidifolium* Geddes	51	Shr
	137	*Canthium parvifolium* Roxb.	19	Shr
	138	*Ixola* sp.1	18	Shr
	139	*Ixola* sp.2	8	Shr
	140	*Mussaenda sanderiana Ridl.*	13	ST
	141	*Rothmannia sootepensis* (Craib) Bremek.	42	ST
	142	*Tarennoidea wallichii* (Hooh. f.) Tirveng & Sastre.	67	ST
55. Rutaceae	143	*Wendlandia paniculata* (Roxb.) DC.	2	ST
	144	*Clausena excavata* Burm. f.	67	Shr
56. Santalaceae	145	*Euodia roxburghiana* (Cham.) Benth.ex Hook. f.	10	ST
57. Sapindaceae	146	*Scleropyrum pentrandrum* (Dennst.) Mabb.	1	MT
	147	*Sapindus rarak* DC.	23	Shr
	148	*Lepisanthes rubiginosa* Leenh.	20	MT
	149	*Nephelium hypoleucum* Kurz	8	MT
	150	*Paranephelium xestophyllum* Miq.	4	BT
58. Sapotaceae	151	*Lepisanthes ferruginea* (Radlk.) Leech.	91	MT
59. Simaroubaceae	152	*Sarcosperma arboreum* Hook. f.	3	MT
60. Staphyleaceae	153	*Picrasma javanica* Blume	131	ST
61. Styracaceae	154	*Turpinia cochinchinensis* (Lour.) Merr.	173	MT
62. Symplocaceae	155	*Styrax benzoides* Craib	2	Shr
	156	*Symplocos sulcata* Kurz.	231	ST
63. Theaceae	157	*Symplocos* sp.	15	ST
	158	*Camellia oleifera* C. Abel. var. *confusa* (Craib) Sealy	79	ST
	159	*Pyrenaria diospyricarpa* Kurz var. *diospyricarpa*	313	BT
64. Vitaceae	160	*Schima wallichii* (DC.) Korth.	12	C
	161	*Ampelocissus martinii* Planch.	5	C
65. Climber 1 to 4	162-166	Unknown species	34	C
66. Trees 1 to 6	167-171	Unknown species	9	Tree

Remark: Growth form (Life form): BT = big tree, MT = medium tree, ST = small tree, Shr = shrub, C = climber