CHAPTER 2

Plant Communities, Wood Production, Biomass Carbon and Nutrient Storages in Ecosystems of *Pinus kesiya* Plantations, Adjacent Fragmented Forests and Montane Forest

Abstract

Studies on pine growths, wood productions, plant succession, plant communities, biomass carbon and nutrient storages at Boakaew Watershed Management Station in 14-34 year-old pine plantations of 21 age-classes and fifteen adjacent fragmented forests remained in areas nearby pine plantations and the climax montane forest at the Doi Inthanon national park, Chiang Mai province, Thailand. Average growth increments of *Pinus kesiya* in these plantations were determined: height, 0.82 m.yr^{-1}; diameter at breast height, 1.28 cm.yr^{-1}; and tree volume, 6.23 m^{3}ha^{-1}yr^{-1}. The number of succession broad-leaved tree species in plantations varied from 17 to 72 species with different densities of 540-2,688 trees ha^{-1}. The densities of pine trees varied between 75-429 trees ha^{-1} whereas other species had greatly different densities, 131-2,331 trees ha^{-1}. Shannon-Wiener indexes of species diversity (SWI) in the plantations were varied from low to high values, varying 1.57-4.65. The succession broad-leaved tree species in pine plantations were mainly belong to the families of Fagaceae, Euphorbiaceae, Juglandaceae, Lauraceae, and Myrtaceae, etc. The carbon storages were different among different age stands, 46-140 MgC.ha^{-1}, and separated to 12-106 MgC.ha^{-1} for pine and 6-69 MgC.ha^{-1} for the others. The storages of nitrogen, phosphorus, potassium, calcium and magnesium were in ranges of 370-965, 44-127, 263-680, 480-1,329 and 75-279 kg.ha^{-1}. Totally, 103 species exited in the adjacent fragmented forests. Tree densities were greatly, varied 556-1,769 trees ha^{-1}. SWI was high, 5.28. Fagaceae was the most dominant family. The dominant trees were *Pinus kesiya* and *Castanopsis acuminatissima*, whereas some were dominated by *Schima wallichii* and *C. diversifolia*. Their total volumes were in range of 36.19-78.42 m^{3}ha^{-1}, and the timber volumes were 22.23.-51.04 m^{3}ha^{-1}. Carbon stocks in their biomass varied between 57.93-125.16 MgC.ha^{-1} (99.33 MgC.ha^{-1} in average) divided into stem, branch, leaf and root components of 64.86, 19.70, 1.60 and 12.60 MgC.ha^{-1}, respectively. Average amounts of nitrogen, phosphorus, potassium and magnesium in their biomass were in the order of 1,100.62; 154.37; 753.12; 1,601.87 and 358.75 kg.ha^{-1}. *P. kesiya* had the largest amounts of biomass carbon and nutrients. The lower amounts were occurred for *C. acuminatissima*, *S. wallichii*, *C. diversifoli*a and *Quercus brandisiana*. The climax montane forest composed of 122 species. Fagaceae Lauraceae and Cornaceae were the dominant families. The average tree density was 7,391 trees ha^{-1}. The tree species having the high density values were *Mallotus khasianus*, *Euodia triphylla* , and *C. calathiformis* , respectively. SWI was 5.72. The average total tree volume was 94.81 m^{3}ha^{-1}, and timber volumes were in the order of 48.69 m^{3}ha^{-1}. Biomass carbon stock of tree species at Doi Inthanon collected as 186 MgC.ha^{-1}, separated to stem, branch, leaf and root components as 130, 24, 2 and 29 MgC.ha^{-1}, respectively. Average amounts of

nitrogen, phosphorus, potassium and magnesium in their biomass were in the order of 2,057.32, 278.54, 1390.26, 3,002.04 and 652.86 kg.ha^{-1}. At the family level, carbon stock and nutrients in biomass outstandingly appeared in the family of Fagaceae followed by Lauraceae, Cornaceae, Guttiferae, Magnoliaceae, Nyssaceae, and Rubiaceae. However, natural succession resulted in accelerated development of plantation ecosystems to be a natural lower montane forest. However, it may need more many decades to develop the forest structure of successional pine plantations to be the montane forest.

2.1 Introduction

The tropical forest biome of Southeast Asia has been recognized as one of the richest sites in biological diversity of the world. Deforestation, forest fragmentation and degradation are considered as serious problems in this region. Loss of tropical forests may have long term effects including change in regional climate especially rainfall pattern, biological productivity, acceleration of soil erosion, disruption of watershed stability, and increase in atmospheric temperature as well as further impacts on global climate dynamics.

In Thailand, as in most tropical countries, deforestation and forest degradation are widely recognized as major threats to environmental stability, economic prosperity and social welfare, particularly amongst rural communities. Remaining forest has become fragmented into patches that are incapable of supporting viable populations of many tree species. (Lynam, 1997). In the northern highlands, which constitute the country's most important watershed, large areas of degraded forestland require urgent reforestation. In areas earmarked for economic forestry, conventional reforestation with monoculture plantations (mostly pines) will remain important. Some advantages of planting *P. kesiya* in the highland are that it can grow very fast on open site with strong solar radiation, fluctuated moisture and poor soil. The roles of adjacent fragmented natural forests on succession in the plantations are significant for forest management and development of pine plantation to natural forest. Adjacent fragmented forests can disperse fruits or seeds of many species for succession in plantations to increase biodiversity enrichment, and thus the plantations can be developed to be a natural forest.

Productive forest plantations are forest plantations predominantly intended for the provision of wood, fibred, and non-wood forest products, though they can also have protective, recreational, water flow regulation, soil loss prevention, restoring the soil nutrients, improving microclimatic, releasing O_2, carbon sequestration and other functions. Some forests classified as adjacent fragmented include trees of native species, most of which are used for productive purposes, but as these forests do not fall under the forest plantation definition.

The purposes of this chapter are to evaluate pine growths, wood productions, plant succession, biomass carbon and nutrient storages in different age-classed of *Pinus kesiya* plantations**,** adjacent fragmented forest and the climax montane forest as the useful information for restoration of forest plantation ecosystems which are developing to be the climax montane forest.

2.2 Research Area

The research was conducted in two areas; (1) *Pinus kesiya* plantations and adjacent fragmented forests at the Boakaew Watershed Management Station, and (2) the climax montane forest at Doi Inthanon national park, Chiang Mai province, Thailand (Figure 2-1).

2.2.1 Boakaew Watershed Management Station

Boakaew Watershed Management Station located at $18^{0}45'$-$21^{0}00'$N, $98^{0}25'$-$98^{0}40'$E, Chiang Mai province, Thailand, about 82 km north of Chiang Mai province. The elevation of research site ranges from 1,200 to 1,600 m. a.s.l. The climate is cool throughout a year. Mean monthly temperature is 20.9 ^{0}C, with a maximum of 25.4 ^{0}C in April and minimum of 16.4^{0} C in December. Average annual rainfall is 1,894 mm. The forest type is pine-lower montane forest (Figure 2-2).

The local people utilize the natural forest, either wood or non-wood products. Some tree species were cut for house construction, and some pine trees were fallen for collecting cones, and sold to merchant. Many oaks were cut for making fire wood.

The main causes of deforestation in Boakaew Watershed Management Station were forest clearing for agriculture and shifting cultivation. Forest rehabilitation in this area used the native pioneer fast growing species including *P. kesiya*, *Prunus cerasoides*, *Docynia indica* and *Betula alnoides* planted in pure stands to recover the degraded watershed land during 1975-1995 with the area of 2,285 ha (Table 2-1).

Table 2-1 Plantation areas of Boakaew Watershed Management Station

Planting	Age	Area	Species	Spacing
1975	34	226	*Pinus kesiya*	4 x 4
1976	33	144	*Pinus kesiya*	4 x 4
1977	32	115	*Pinus kesiya*, *Docynia indica*	4 x 4
1978	31	229	*Pinus kesiya*, *Docynia indica*	4 x 4
1979	30	160	*Pinus kesiya*, *Docynia indica*	4 x 4
1980	29	146	*Pinus kesiya*, *Docynia indica*	4 x 4
1981	28	128	*Pinus kesiya*, *Docynia indica*	4 x 4
1982	27	80	*Pinus kesiya*	4 x 4
1983	26	72	*Pinus kesiya*	4 x 4
1984	25	64	*Pinus kesiya*	4 x 4
1985	24	96	*Pinus kesiya*	4 x 4
1986	23	88	*Pinus kesiya*	4 x 4
1987	22	80	*Pinus kesiya*	4 x 4
1988	21	84	*Pinus kesiya*	4 x 4
1989	20	69	*Pinus kesiya*	4 x 4
1990	19	96	*Pinus kesiya*	4 x 4
1991	18	96	*Pinus kesiya*, *Prunus cerasoides*	4 x 4
1992	17	96	*Pinus kesiya*, *Prunus cerasoides*, *Docynia indica*	4 x 4
1993	16	128	*Pinus kesiya*, *Prunus cerasoides*, *Docynia indica*,	4 x 4
1994	15	48	*Pinus kesiya*, *Prunus cerasoides*, *Docynia indica*,	4 x 4
1995	14	40	*Pinus kesiya*, *Prunus cerasoides*, *Docynia indica*,	4 x 4
Total		2,285		

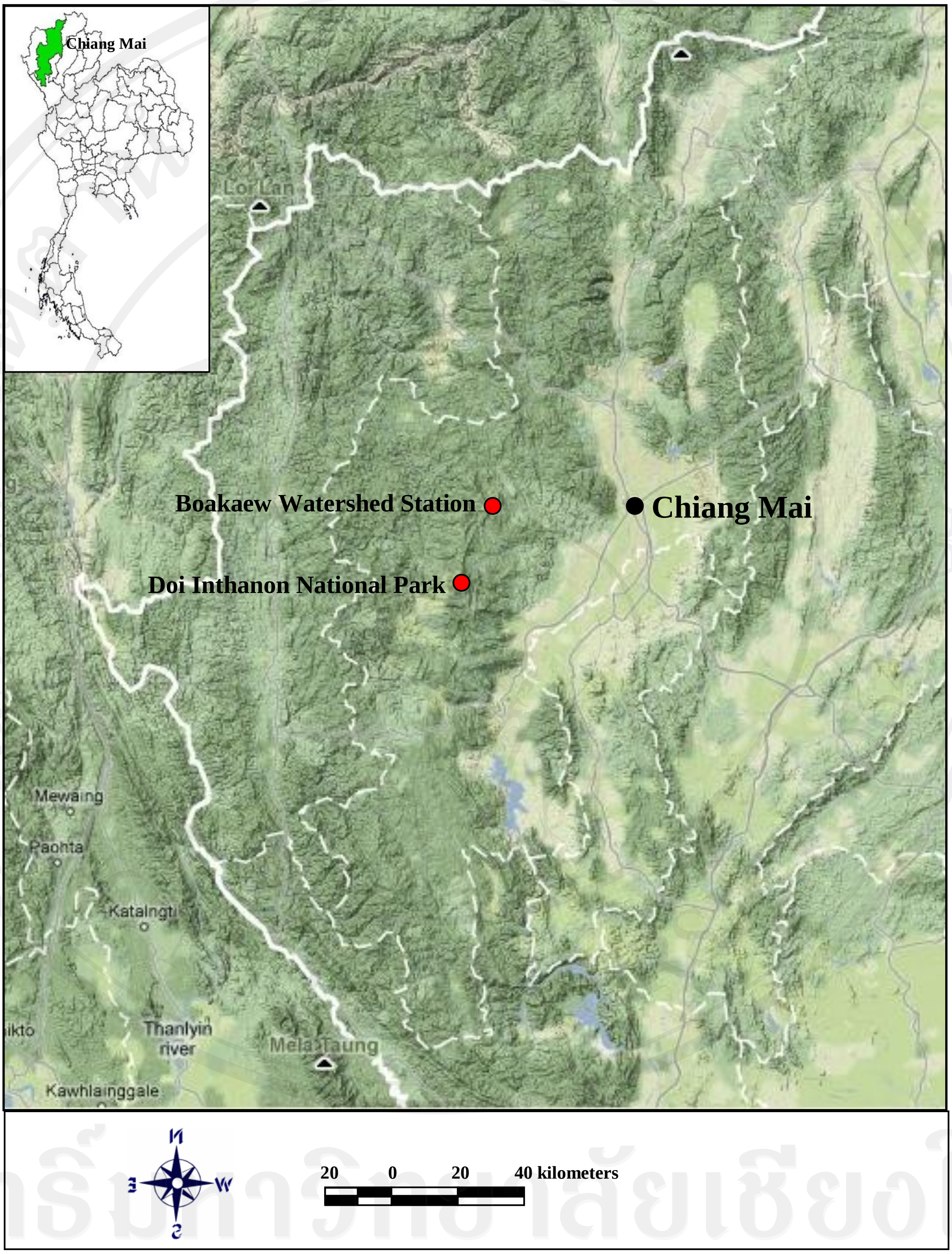


Figure 2-1 Location of study areas at Boakaew Watershed Station and Doi Inthanon national park

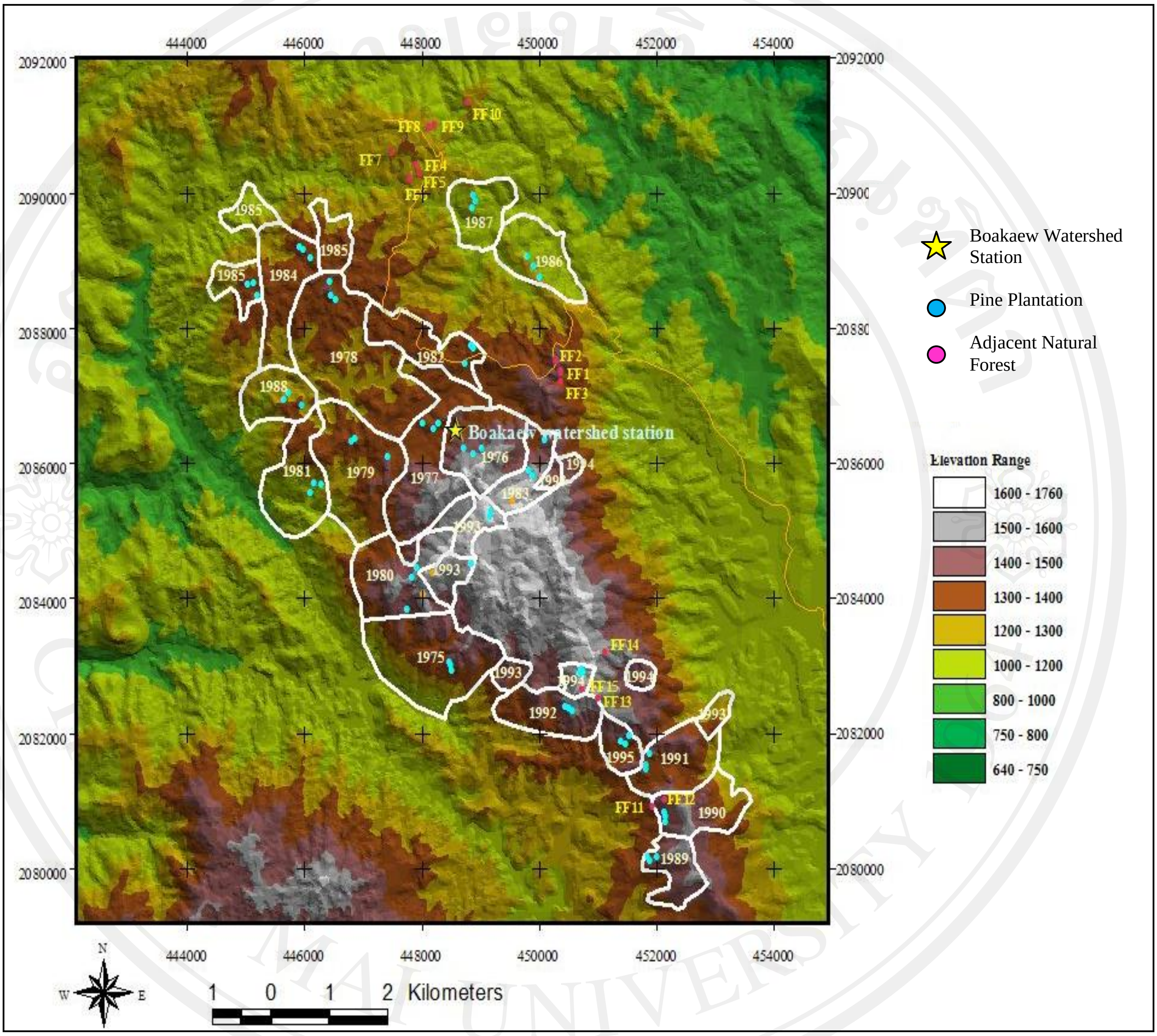


Figure 2-2 Location of pine plantations areas and adjacent fragmented forests at Boakaew Watershed Management Station

2.2.2 Doi Inthanon National Park

The study about climax montane forest was conducted in Doi Inthanon national park, 50 km southwest of Chiang Mai province, Thailand and stretches from 18°24′ N to 18°40′ N latitude, and 98°24′ E to 98°42′ E longitude. Its altitude ranges from 400 m at the entrance of the national park up to 2,565 m msl. at the summit. Administratively, it belongs to the Chom Thong and Mae Chaem districts of Chiang Mai province. The mountain and surrounding area, totally 482.4 square kilometers, was declared the country's sixth national park in 1972. At present, Doi Inthanon national park is administered by the National Park Division of Department of National Parks, Wildlife and Plant Conservation in the Ministry of Natural Resources and Environment (Figure 2-3).

Annual mean of monthly minimum temperature and maximum temperature at the Royal Project Doi Inthanon Station (1300 m msl; 1993–2006) is 16.4°C and 26.3°C, respectively. The warmest month is April with the monthly mean of maximum temperature of 21.4°C. The coldest month is December and the monthly mean of daily minimum temperature drop to 2.9°C. In December and January, ground frost frequently covers the exposed ridges near the summit where the lowest of -8°C has been recorded. The total amount of rainfall ranges from 1,822 to 2,536.7 mm/year with an average of 1,949 mm/year. A 15-ha permanent plot (500 x 300 m) was established within the lower montane forest zone, which had the most diverse vegetation at the site (18°31′24′′ N, 98°29′42′′E, *c*.1700 m msl.). Bedrock within the plot comprises post-Silurian and post-Permian granite and pre-Cambrian gneiss (Pampasit, 2000).

2.3 Materials and Methods

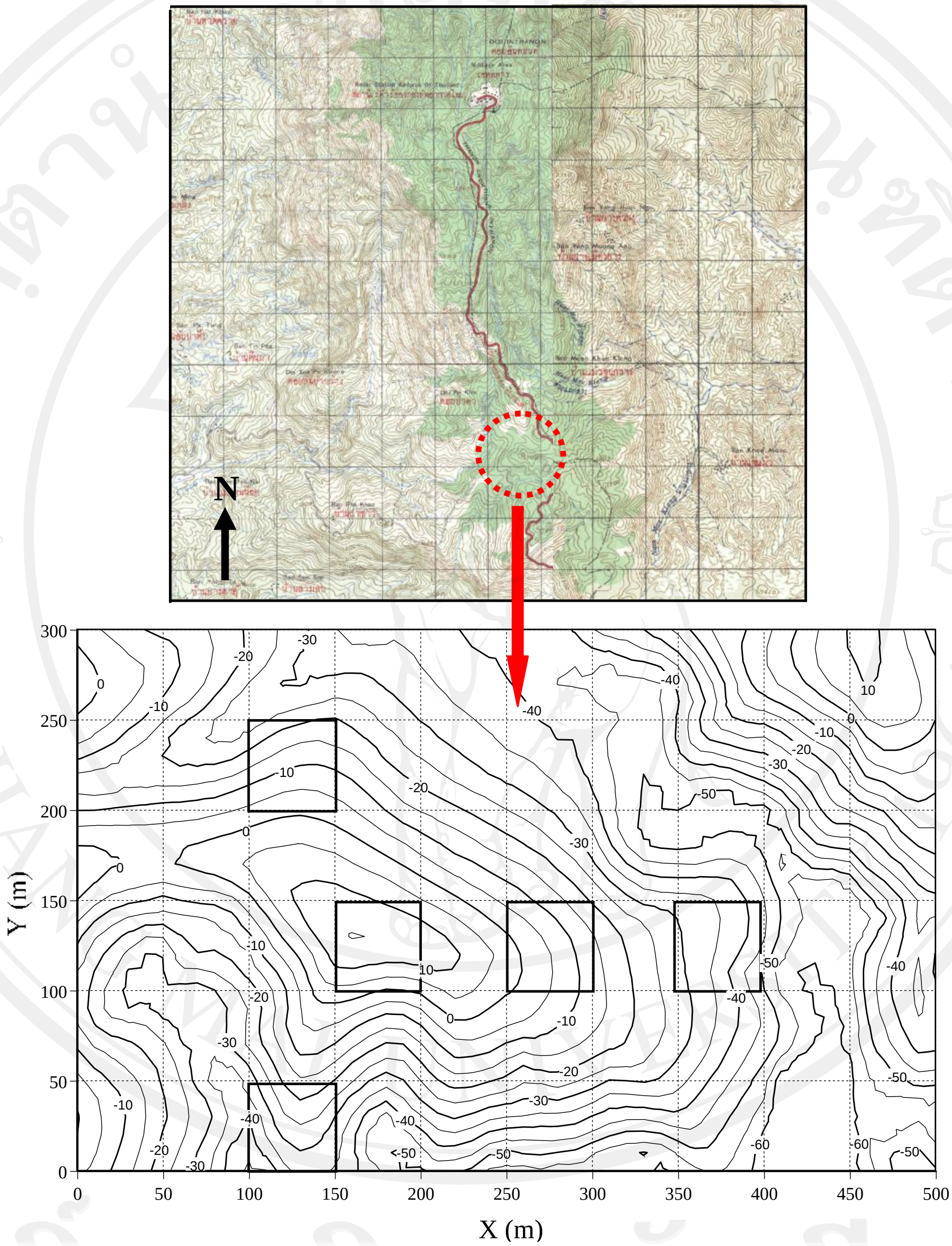
2.3.1 Vegetation Sampling

1) *Pinus kesiya* Plantations

Sixty three sampling plots of 40 x 40 m in size were used to study growths and wood productions of *P. kesiya* plantations. Twenty-one age-class plantations including 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33 and 34 years old were chosen. Three plots (replications) were used for each age-class plantation. In each plot, stem girth at breast high (gbh) and tree height of pine and other trees were measured. Timber log was estimated for all trees having $\geq$ 30 cm. gbh. Timber grade was classified as A (straight stem), B (some curl stem), and C (very curl stem). All plots were recorded for positions using GPS (Global Positioning System) at the center of plot, altitude, slope aspect and gradient. The slope gradient was measured every ten meters along the plot using abney.

2) Adjacent Fragmented Forests

Fifteen sampling plots of 40 x 40 m were used for vegetation survey in each of adjacent fragmented forests. Each plot was divided into 16, 10x10 m subplots, and all woody trees and climbers with $\geq$ 1.5 m height were measured for gbh (stem girth at breast height, 1.3 m above ground), and tree height. All plots were located using GPS and topographic map.



Topographic map of the Doi Inthanon Forest Dynamics Plot (15 ha).
Contours are 5 m. interval and figures are in relative elevation.
Numbers inside the map indicate relative elevation (meters) from the point, (X, Y) = (0 m, 150 m).

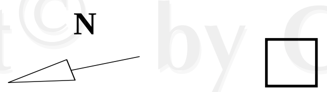


Figure 2-3 Location of a 15 ha permanent plot at Doi Inthanon natural park

3) Climax Montane Forest

Five sampling plots of 50x50 m grid points were used for vegetation survey in the 15 ha permanent plot. In each plot, all living trees ≥ 3.15 cm in gbh were measured. Timber log was estimated for all trees having ≥ 30 cm gbh. Timber grade was classified as A (straight stem), B (some curl stem), and C (very curl stem).

2.3.2 Calculation of Ecological Parameters

The data were calculated for ecological parameters of tree species and plant communities: frequency, density, dominance, important value index (IVI), and species diversity index (Krebs, 1985).

1) Plant Frequency

$$\text{Frequency} = \frac{\text{Number of occupied plots}}{\text{Number of all plots}} \times 100$$

$$\text{Relative frequency} = \frac{\text{Frequency of species } i}{\text{Sum of frequency values of all species}} \times 100$$

2) Plant Density

$$\text{Density} = \frac{\text{Number of individuals of species } i}{\text{Number of all quadrats}} \quad \text{(trees/plot)}$$

$$\text{Relative density} = \frac{\text{Number of individuals of species } i}{\text{Number of individuals of all species}} \times 100$$

3) Plant Dominance

The relative dominance of tree species was calculated from stem basal area.

$$\text{Relative dominance} = \frac{\text{Stem basal area of species } i}{\text{Sum of stem basal area of all species}} \times 100$$

4) Important Value Index (IVI)

The IVI is a composite index based on measures of relative frequency, relative density and relative dominance (Mueller-Dombois and Ellenberg, 1974). It is and integrated influence of a tree species in the forest. The value varies between 0 and 300. However, it can be expressed in term of relative IVI.

$$\text{IVI} = \text{Relative frequency} + \text{Relative density} + \text{Relative dominance}$$

$$\text{Relative IVI} = \frac{\text{IVI of species } i}{\text{Sum of IVI of all species}} \times 100$$

5) Index of Species Diversity

The Shannon-Wiener index (SWI) relates the proportional weight of the number of individuals per species to the total sample belonging to all species (Kreb, 1985).

$$H = -\sum_{i=1}^{S} (p_i)(\log_2 p_i)$$

Where, H = index of species diversity
S = total number of species
p_i = proportion of individuals of species *i* to total individuals of all species

2.3.3 Calculation of Tree Volume

The data of stem girth at breast high (gbh) and tree height in pine plantations, adjacent fragmented forests and climax montane forest were used for tree volume calculation.

Tree volume of pine trees were calculated using power equations of Pornleesangsuwan, (2012).

$$V = 0.00002\,(D^2H)^{1.0514} \qquad (R^2 = 0.9783)$$

Where, V = stem volume over bark (m^3)
D = diameter at breast height (cm)
H = total height (m)

Tree volume of other broad-leaved trees were calculated using equations of Sungpalee, *et al.* (2009).

$$V = 0.00007629674(DBH^2.H)^{0.914502}$$

Where, V = volume (cu.m.)
DBH = diameter at breast height (cm)
H = total height (m)

2.3.4 Calculation of Tree Biomass

(1) *Pinus kesiya* Plantations

The data of stem girth at breast height (gbh) and tree height of pine trees in a series of plantations were used for biomass calculation. Above-ground biomass of pine trees were calculated using equations of Nongnuang, (2010). The root biomass of pine trees was based on allometric equations of Tsutsumi *et al.* (1983), as follow:

$$W_S = 0.0503\,(D^2H)^{0.8775} \qquad R^2 = 0.9749$$
$$W_B = 0.0012\,(D^2H)^{1.0996} \qquad R^2 = 0.4982$$
$$W_L = 0.4536\,(W_B)^{0.7933} \qquad R^2 = 0.6324$$
$$W_R = 0.0313\,(D^2H)^{0.805} \qquad R^2 = 0.9810$$

Where, W_S = biomass of stem (kg)
W_B = biomass of branch (kg)
W_L = biomass of leaf (kg)
W_R = biomass of root (kg)
D = diameter (cm)
H = height (m)

(2) Adjacent Fragmented Forests

Biomass accumulations in adjacent fragmented forests and other succession broad-leaved trees in pine plantations were calculated using allometric equations of Tsutsumi *et al.* (1983), as follow:

$$W_S\ \text{(stem)} = 0.0509\,(D^2H)^{0.919} \qquad R^2 = 0.978$$
$$W_B\ \text{(branch)} = 0.00893\,(D^2H)^{0.977} \qquad R^2 = 0.890$$
$$W_L\ \text{(leaf)} = 0.0140\,(D^2H)^{0.669} \qquad R^2 = 0.714$$
$$W_R\ \text{(root)} = 0.0313\,(D^2H)^{0.805} \qquad R^2 = 0.981$$

Where, W = biomass (kg)
D = diameter (cm)
H = height (m)

(3) Climax Montane Forest

The biomass in living tree was estimated by using allometric equation proposed by Sungpalee *et,al.* (2009). The root biomass was base on allometric eqations of Tsutsumi *et al.* (1983), as follow:

$$W_S = 0.00007629674\,(D^2H)^{0.914502} \times \text{wood density}$$
$$W_B = 0.1489327\,(W_S)^{1.0355}$$
$$W_L = 0.1101134\,(W_S)^{0.73082}$$
$$W_R = 0.0313\,(D^2H)^{0.805}$$

Where, W_S = biomass of stem (kg)
W_B = biomass of branch (kg)
W_L = biomass of leaf (kg)
W_R = biomass of root (kg)
D = diameter (cm)
H = height (m)

2.3.5 Calculation of Stored Nutrients

Nutrient contents in various organs of tree species followed the data of Tsutsumi *et al.* (1983) in mix deciduous-dry evergreen forest. The mean contents in stem, branch, leaf and root were carbon: 49.9, 48.7, 48.3 and 48.2%; nitrogen: 0.53, 0.53, 1.59 and 0.53%; phosphorus: 0.08, 0.10, 0.13 and 0.02%; potassium: 0.37, 0.40, 1.10 and 0.27%; calcium: 0.76, 0.80, 1.50 and 0.88%; and magnesium: 0.17, 0.20, 0.90 and 0.10%.

2.4 Results

2.4.1 Plant Community Analysis

2.4.1.1 *Pinus kesiya* Plantations

Plant succession in pine plantations resulted in changes of plant communities in different age stands. Some pine trees might be died by the damage of disease, forest fire and competition (Oberhauser, 1997; Armitage and Wood 1980). Some might be cut for wood and non-wood products and provided gaps in plantations. Variations in species richness and composition were occurred in different age stands.

The data of species richness and plant composition in 14 to 34 year-old pine plantations of 21 age-class stands shown in Table 2-2 and Appendix Table 1-1. The number of succession tree species was different among 21 age-class pine stands, 17 to 72 species. Tree densities of these plantations varied between 540-2,688 trees/ha separated to be 75-429 trees ha^{-1} of *P. kesiya* and 131-2,331 trees ha^{-1} of broad-leaved species. The importance value index (IVI) of *P. kesiya* in plantations varied from 10.65 to 60.09% whereas the Shannon-Wiener indexes (SWI) were 1.57 to 4.65 (Table 2-2).

The succession broad-leaved species in pine plantations were almost same species existed in adjacent fragmented forests. Mother trees in plantations as well as adjacent fragmented forests had the potential role as sources of seeds/fruits in pine plantations. The natural succession in these plantations increased biodiversity enrichment, and thus the plantations could develop to be the climax montane forest. However, the seed dispersal was depended upon distance from the nearest seed source and altitude gradient (Geldenhuys, 1997; Khamyong *et al*., 2004). Therefore, great differences of plant communities in different age pine plantations were observed, and the similarity values of plant communities among the plantations varied in a wide range, 2-78%.

Table 2-2 Quantitative data of plant communities in a series of *Pinus kesiya* plantations

Code	Age (year)																				
	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
1. Alitude (m)	1,410	1,561	1,655	1,561	1,389	1,393	1,361	1,314	1,202	1,204	1,368	1,362	1,463	1,358	1,410	1,606	1,376	1,409	1,362	1,453	1,393
2. Number of Species	36	54	33	61	46	38	17	41	61	50	46	39	31	70	35	32	36	39	34	53	50
3. Number of Genus	30	47	29	51	40	32	16	34	49	37	42	33	26	56	30	30	30	35	29	48	42
4. Number of Families	20	31	22	34	26	22	13	23	28	23	27	23	19	28	21	16	21	26	23	31	26
5. Basal area (m^2/ha)	22.95	16.49	25.23	19.66	29.59	29.36	26.06	36.52	31.52	24.20	27.54	28.13	43.08	30.45	27.96	22.54	32.99	30.68	35.68	34.92	33.43
6. Dominant tree (%)																					
6.1 *Pinus kesiya*	52.20	29.23	89.38	24.51	59.75	72.12	93.30	62.89	52.18	50.59	53.54	68.22	69.47	57.40	81.25	65.07	66.56	38.88	66.49	90.89	46.25
6.2 Other broad-leaved trees	47.80	70.77	10.62	75.49	40.25	27.88	6.70	37.11	47.82	49.41	46.46	31.78	30.53	42.60	18.75	34.93	33.44	61.12	33.51	9.11	53.75
7. IVI (%)																					
7.1 *Pinus kesiya*	26.74	12.37	40.41	10.65	27.74	40.12	60.09	32.42	22.69	23.98	33.63	39.17	43.71	24.24	41.38	36.74	36.89	19.77	41.71	41.40	23.07
7.2 Other broad-leaved trees	73.26	87.63	59.59	89.35	72.26	59.88	39.91	67.58	77.31	76.02	66.37	60.83	56.29	75.76	58.62	63.26	63.11	80.23	58.29	58.60	76.93
8. Density (trees/ha)	627	1,556	1,252	2,256	1,279	890	544	1,350	2,688	1,694	788	963	710	2,250	583	598	625	783	540	1,119	1,060
8.1 *Pinus kesiya*	144	75	329	106	252	385	413	406	356	306	338	429	392	290	223	233	240	125	283	329	206
(1) gbh < 30 cm	2	0	0	15	2	2	2	4	21	40	2	10	0	0	2	0	0	0	0	0	2
(2) gbh 30-50 cm	0	6	4	8	6	15	15	30	52	60	40	64	2	10	0	15	2	2	0	0	13
(3) gbh 50-100 cm	71	46	244	73	158	317	329	277	239	169	281	330	225	213	69	140	111	48	134	93	102
(4) gbh 100-150 cm	67	23	75	10	85	52	67	95	45	35	15	25	160	67	140	79	114	73	149	228	83
(5) gbh > 150 cm	4	0	6	0	0	0	0	0	0	2	0	0	4	0	13	0	13	2	0	8	6
8.2 Other broad-leaved trees	483	1,481	923	2,150	1,029	504	131	944	2,331	1,388	450	533	319	1,960	360	365	385	658	256	790	854
(1) gbh < 30 cm	193	1,274	841	1,793	618	255	83	584	1,791	1,066	269	296	120	1,601	244	198	129	232	93	690	483
(2) gbh 30-50 cm	154	97	38	225	263	148	30	196	424	201	76	152	86	163	45	66	115	246	43	88	154
(3) gbh 50-100 cm	105	81	44	108	137	91	17	139	103	97	78	73	75	176	56	83	130	139	80	8	158
(4) gbh 100-150 cm	29	22	0	16	10	6	1	19	13	21	10	6	17	21	15	13	9	27	28	4	38
(5) gbh > 150 cm	2	7	0	8	0	4	0	6	0	2	17	6	21	0	0	4	2	14	13	0	21
9. Shannon-Wiener index of species diversity	3.35	4.26	3.31	4.50	4.08	3.26	1.57	3.94	4.65	4.19	3.49	3.29	2.67	4.63	3.63	3.35	3.28	3.76	2.85	3.51	4.13

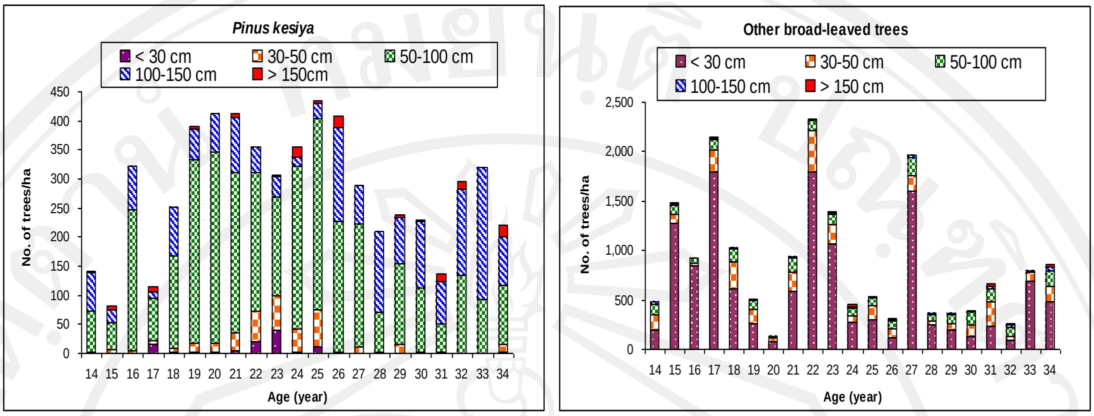


Figure 2-4 Tree densities of *Pinus kesiya* and succession broad-leaved trees with different stem-girth classes in 21 age-class plantations

2.4.1.2 Adjacent Fragmented Forests

The plant community characteristics of the fifteen adjacent fragmented forests were shown in Table 2-3 and 2-4. (Appendix Table 1-2)

(1) Species Richness

The total number of plant species existed in the forest is called species richness. In fifteen adjacent fragmented forests, totally 103 species in 82 genus and 44 families were found (Table 2-3). Dominant tree species were mainly *P. kesiya*, *C. acuminatissima* and *S. wallichii*. Codominant tree species were *Q. brandisiana*, *C. diversifolia*, *L. elegans*, *Q. vestita*, *T. gymnanthera*, *H. nilagirica*, *E. spicata*, etc. The small trees included mainly *T. rufescens*, *W. tinctoria*, and *V. sprengelii*. Many rare species in the forests were observed such as *M. henryi*, *S. albiflorum*, *S. cumini*, *T. chebula*, *C. armata*, *R. ignea*, *B. alnoides*, *A. gomezianus*, *C. iners*, etc. Some were true rare species and the others might be existed in more abundance in forests of lower areas. The dominant families were Fagaceae (13 species), Leguminosae (8), Lauraceae (8), Euphorbiaceae (7), Rubiaceae (6), and Theaceae (6).

The numbers of tree species per plot in fifteen adjacent fragmented forests were shown in Appendix Table 1-2. The values varied between 16 and 42 species (13-35 genus and 10-24 families). The species richness in each plot was rather low since most adjacent fragmented forests were situated at the summit of mountainous areas where forest sites were relatively dry. There were no correlation between the species richness and altitude gradient. The species richness was higher in mesic areas between 1,345-1,586 m altitude.

The species richness was typically high in LMF. Khamyong and Seramethakun (1998) reported that the same forest type at Mt. Doi Suthep in area of 1,200-1,300 m altitude consisted of 72 species (54 genus and 34 families), and it was increased to be 188 species (124 genus and 57 families) as the sampling area was expanded between 800-1,500 m (Khamyong, 2009). Loarpansakul (2000) found that the forest at the Queen Sirikit botanic garden consisted of 97 tree species (in 68 genus and 42 families), and it was high as 184 tree species (129 genus and 61 families) for the fragmented forests in Pang Ma Pha district, Mae Hong Son province (Seanchanthong, 2005). The species richness of montane forest at Mt. Doi Inthanon was declined with higher altitude by lower air temperature and cloud covering nearly throughout a year. It was low as 47 species in upper montane (UMF) forest at Mt. Doi Inthanon summit (Khamyong *et al*., 2004)

(2) Tree Frequency

There were five tree species having the frequency values over than 80% in fifteen adjacent fragmented forests including *W. tinctoria*, *P. kesiya*, *G. sphaerogynum*, *C. acuminatissima* and *S. wallichii*. These trees existed in most adjacent fragmented forests. The tree species having the lower frequencies (60-80%) were *P. emblica*, T. *rufescens*, *V. sprengelii*, *H. nilagiriga*, *A. fragrans*, *C. stellatum*, *T. gymnanthera*, *L. elegans*, *E. spicata*, *C. purpurea*, *Q. vestita*, *D. cultrata*, *S. albescens* and *S. benzoides*.

(3) Tree Density

The average tree density in the whole adjacent fragmented forests was 1,166 trees/ha. The shrubby tree, *T. rufescens* had the highest density (116 trees/ha), and followed by *W. tinctoria* (91), *V. sprengelii* (86), *P. kesiya* (69), *S. wallichii* (63) and *C. acuminatissima* (60).

Tree densities were greatly different among adjacent fragmented forests, 556-1,769 individuals/plot. The tree densities were low in areas of 1,230-1,260 m altitude, and higher between 1,300-1,560 m. It is found that some adjacent fragmented forests consisted of mainly intermediate-size and big trees whereas densely small trees were existed in the others. The human disturbance through selective tree cutting resulted in the big canopy gaps in some adjacent fragmented forests. This stimulated the natural regeneration, and many saplings were grown densely in the gaps. Thus, tree densities were higher in the disturbed forests.

(4) Tree Dominance

The dominance value was calculated on the basis of the stem basal area. *P. kesiya* had the highest relative dominance (24.10% of all species), and followed by *C. acuminatissima* (14.12%), *S. wallichii* (7.14%), *C. diversifolia* (5.84%), *Q. brandisiana* (5.28%), *T. rufescens* (4.10%) and *C. purpurea* (3.46%).

Table 2-3 Quantitative characteristics of tree species in fifteen adjacent fragmented forests

No	Species	No. of trees	Frequency (%)	Density (trees/ha)	Basal area (m^2/ha)	Relative (%)			IVI	
						Frequency	Density	Dominance	(300)	(%)
1	*Pinus kesiya*	165	86.67	68.75	6.6655	3.05	5.90	24.10	33.05	11.02
2	*Castanopsis acuminatissima*	144	80.00	60.00	3.9070	2.82	5.15	14.12	22.09	7.36
3	*Tristania rufescens*	279	66.67	116.25	1.1333	2.35	9.97	4.097	16.42	5.47
4	*Schima wallichii*	150	80.00	62.50	1.9762	2.82	5.36	7.144	15.32	5.11
5	*Wendlandia tinctoria*	219	93.33	91.25	0.6723	3.29	7.83	2.431	13.54	4.51
6	*Vaccinium sprengelii*	206	66.67	85.83	0.5011	2.35	7.36	1.812	11.52	3.84
7	*Quercus brandisiana*	84	46.67	35.00	1.4602	1.64	3.00	5.279	9.92	3.31
8	*Castanopsis diversifolia*	59	53.33	24.58	1.6151	1.88	2.11	5.839	9.83	3.28
9	*Ternstroemia gymnanthera*	86	60.00	35.83	0.7368	2.11	3.07	2.664	7.85	2.62
10	*Helicia nilagirica*	71	66.67	29.58	0.7661	2.35	2.54	2.770	7.65	2.55
11	*Lithocarpus elegans*	70	60.00	29.17	0.7739	2.11	2.50	2.798	7.41	2.47
12	*Engelhardtia spicata*	62	60.00	25.83	0.7950	2.11	2.22	2.874	7.20	2.40
13	*Castanopsis purpurea*	42	60.00	17.50	0.9565	2.11	1.50	3.458	7.07	2.36
14	*Anneslea fragrans*	66	66.67	27.50	0.5384	2.35	2.36	1.946	6.65	2.22
15	*Quercus vestita*	68	60.00	28.33	0.4388	2.11	2.43	1.586	6.13	2.04
16	*Craibiodendron stellatum*	78	66.67	32.50	0.2233	2.35	2.79	0.807	5.94	1.98
17	*Dalbergia cultrata*	58	60.00	24.17	0.4551	2.11	2.07	1.645	5.83	1.94
18	*Phyllanthus emblica*	63	73.33	26.25	0.1004	2.58	2.25	0.363	5.20	1.73
19	*Glochidion sphaerogynum*	39	86.67	16.25	0.1060	3.05	1.39	0.383	4.83	1.61
20	*Semecarpus albescens*	48	60.00	20.00	0.2431	2.11	1.72	0.879	4.71	1.57
21	*Eurya nitida*	69	46.67	28.75	0.0859	1.64	2.47	0.311	4.42	1.47
22	*Styrax benzoides*	36	60.00	15.00	0.1426	2.11	1.29	0.515	3.91	1.30
23	*Aporosa villosa*	42	53.33	17.50	0.0916	1.88	1.50	0.331	3.71	1.24
24	*Phoebe paniculata*	43	40.00	17.92	0.1560	1.41	1.54	0.564	3.51	1.17
25	*Diospyros glandulosa*	27	46.67	11.25	0.0928	1.64	0.96	0.335	2.94	0.98
26	*Lithocarpus polystachyus*	22	40.00	9.17	0.1924	1.41	0.79	0.696	2.89	0.96
27	*Viburnum sambucinum*	37	40.00	15.42	0.0187	1.41	1.32	0.068	2.80	0.93
28	*Lithocarpus fenestratus*	17	33.33	7.08	0.2526	1.17	0.61	0.913	2.69	0.90
29	*Glochidion acuminatum*	48	26.67	20.00	0.0043	0.94	1.72	0.016	2.67	0.89
30	*Quercus semiserrata*	19	13.33	7.92	0.3406	0.47	0.68	1.231	2.38	0.79
31	*Helicia terminalis*	15	40.00	6.25	0.1130	1.41	0.54	0.408	2.35	0.78
32	*Dillenia aurea*	13	40.00	5.42	0.0599	1.41	0.46	0.216	2.09	0.70
33	*Syzygium gratum*	11	33.33	4.58	0.1210	1.17	0.39	0.437	2.00	0.67
34	*Stereospermum neuranthum*	16	33.33	6.67	0.0413	1.17	0.57	0.149	1.89	0.63
35	*Lithocarpus sootepensis*	17	20.00	7.08	0.0715	0.70	0.61	0.259	1.57	0.52
36	*Albizia odoratissima*	6	33.33	2.50	0.0490	1.17	0.21	0.177	1.57	0.52
37	*Pyrenaria diospyricarpa*	18	20.00	7.50	0.0189	0.70	0.64	0.068	1.42	0.47
38	*Lindera metcalfiana*	16	20.00	6.67	0.0375	0.70	0.57	0.135	1.41	0.47
39	*Phoebe cathia*	8	20.00	3.33	0.1054	0.70	0.29	0.381	1.37	0.46
40	*Albizia chinensis*	6	26.67	2.50	0.0522	0.94	0.21	0.189	1.34	0.45
41	*Elaeocarpus stipularis*	4	13.33	1.67	0.1975	0.47	0.14	0.714	1.33	0.44
42	*Eriolaena candollei*	11	20.00	4.58	0.0616	0.70	0.39	0.223	1.32	0.44
43	*Rhus javanica*	10	26.67	4.17	0.0016	0.94	0.36	0.006	1.30	0.43
44	*Rapanea porteriana*	11	20.00	4.58	0.0528	0.70	0.39	0.191	1.29	0.43
45	*Archidendron clypearia*	7	26.67	2.92	0.0272	0.94	0.25	0.098	1.29	0.43
46	*Beilschmiedia gammieana*	9	26.67	3.75	0.0055	0.94	0.32	0.020	1.28	0.43
47	*Engelhardtia serrata*	6	20.00	2.50	0.0982	0.70	0.21	0.355	1.27	0.42
48	*Syzygium albiflorum*	9	20.00	3.75	0.0563	0.70	0.32	0.204	1.23	0.41
49	*Turpinia cochinchinensis*	12	20.00	5.00	0.0177	0.70	0.43	0.064	1.20	0.40
50	*Litsea glutinosa*	5	26.67	2.08	0.0187	0.94	0.18	0.067	1.19	0.40
51	*Catunaregam tomentosa*	6	26.67	2.50	0.0032	0.94	0.21	0.011	1.16	0.39
52	*Callicarpa arborea*	10	6.67	4.17	0.1484	0.23	0.36	0.537	1.13	0.38

Table 2-3 (Continued)

No	Species	No. of trees	Frequency (%)	Density (trees/ha)	Basal area (m^2/ha)	Relative (%) Frequency	Density	Dominance	IVI (300)	(%)
53	*Castanopsis armata*	1	6.67	0.42	0.2268	0.23	0.04	0.820	1.09	0.36
54	*Symplocos racemosa*	5	20.00	2.08	0.0460	0.70	0.18	0.166	1.05	0.35
55	*Terminalia chebula*	4	20.00	1.67	0.0470	0.70	0.14	0.170	1.02	0.34
56	*Ilex umbellulata*	7	20.00	2.92	0.0163	0.70	0.25	0.059	1.01	0.34
57	*Milletia pachycarpa*	7	20.00	2.92	0.0054	0.70	0.25	0.020	0.97	0.32
58	*Quercus kingiana*	6	20.00	2.50	0.0135	0.70	0.21	0.049	0.97	0.32
59	*Embelia subcoriacea*	4	20.00	1.67	0.0302	0.70	0.14	0.109	0.96	0.32
60	*Buchanania lanzan*	3	13.33	1.25	0.1024	0.47	0.11	0.370	0.95	0.32
61	*Erythrina subumbrans*	4	20.00	1.67	0.0193	0.70	0.14	0.070	0.92	0.31
62	*Ampelocissus martinii*	4	20.00	1.67	0.0124	0.70	0.14	0.045	0.89	0.30
63	*Gardenia sootepensis*	4	20.00	1.67	0.0107	0.70	0.14	0.039	0.89	0.30
64	*Vernonia volkameriifolia*	4	20.00	1.67	0.0079	0.70	0.14	0.028	0.88	0.29
65	*Saurauia roxburghii*	9	13.33	3.75	0.0072	0.47	0.32	0.026	0.82	0.27
66	*Bombax anceps*	2	13.33	0.83	0.0470	0.47	0.07	0.170	0.71	0.24
67	*Glochidion hirsutum*	6	13.33	2.50	0.0064	0.47	0.21	0.023	0.71	0.24
68	*Trichilla connaroides*	5	13.33	2.08	0.0086	0.47	0.18	0.031	0.68	0.23
69	*Mussaenda sanderiana*	5	13.33	2.08	0.0020	0.47	0.18	0.007	0.66	0.22
70	*Magnolia henryi*	3	13.33	1.25	0.0170	0.47	0.11	0.061	0.64	0.21
71	*Dolichandrone serrulata*	3	13.33	1.25	0.0073	0.47	0.11	0.026	0.60	0.20
72	*Gordonia dalglieshiana*	2	13.33	0.83	0.0087	0.47	0.07	0.032	0.57	0.19
73	*Syzygium cumini*	2	13.33	0.83	0.0044	0.47	0.07	0.016	0.56	0.19
74	*Pavetta tomentosa*	2	13.33	0.83	0.0005	0.47	0.07	0.002	0.54	0.18
75	*Cinnamomum porrectum*	7	6.67	2.92	0.0003	0.23	0.25	0.001	0.49	0.16
76	*Pterospermum acerifolium*	6	6.67	2.50	0.0047	0.23	0.21	0.017	0.47	0.16
77	*Gmelina philippensis*	6	6.67	2.50	0.0003	0.23	0.21	0.001	0.45	0.15
78	*Litsea semecarpifolia*	3	6.67	1.25	0.0295	0.23	0.11	0.107	0.45	0.15
79	*Olea salicifolia*	4	6.67	1.67	0.0158	0.23	0.14	0.057	0.43	0.14
80	*Lithocarpus lindleyanus*	2	6.67	0.83	0.0245	0.23	0.07	0.089	0.39	0.13
81	*Sarcosperma arboreum*	3	6.67	1.25	0.0134	0.23	0.11	0.048	0.39	0.13
82	*Gluta usitata*	1	6.67	0.42	0.0274	0.23	0.04	0.099	0.37	0.12
83	*Garuga pinnata*	3	6.67	1.25	0.0061	0.23	0.11	0.022	0.36	0.12
84	*Antidesma ghaesembilla*	3	6.67	1.25	0.0021	0.23	0.11	0.008	0.35	0.12
85	*Betula alnoides*	1	6.67	0.42	0.0207	0.23	0.04	0.075	0.35	0.12
86	*Protium serratum*	3	6.67	1.25	0.0005	0.23	0.11	0.002	0.34	0.11
87	*Colona flagrocarpa*	2	6.67	0.83	0.0096	0.23	0.07	0.035	0.34	0.11
88	*Dalbergia velutina*	2	6.67	0.83	0.0055	0.23	0.07	0.020	0.33	0.11
89	*Shorea roxburghii*	2	6.67	0.83	0.0049	0.23	0.07	0.018	0.32	0.11
90	*Vitex pinnata*	1	6.67	0.42	0.0142	0.23	0.04	0.051	0.32	0.11
91	*Melastoma malabathricum*	2	6.67	0.83	0.0004	0.23	0.07	0.001	0.31	0.10
92	*Kydia calycina*	1	6.67	0.42	0.0086	0.23	0.04	0.031	0.30	0.10
93	*Radermachera ignea*	1	6.67	0.42	0.0064	0.23	0.04	0.023	0.29	0.10
94	*Cinnamomum iners*	1	6.67	0.42	0.0042	0.23	0.04	0.015	0.29	0.10
95	*Combretum punctatum*	1	6.67	0.42	0.0038	0.23	0.04	0.014	0.28	0.09
96	*Artocarpus gomezianus*	1	6.67	0.42	0.0038	0.23	0.04	0.014	0.28	0.09
97	*Schefflera bengalensis*	1	6.67	0.42	0.0032	0.23	0.04	0.012	0.28	0.09
98	*Ficus sp.*	1	6.67	0.42	0.0012	0.23	0.04	0.004	0.27	0.09
99	*Entada rheedii*	1	6.67	0.42	0.0011	0.23	0.04	0.004	0.27	0.09
100	*Canarium subulatum*	1	6.67	0.42	0.0009	0.23	0.04	0.003	0.27	0.09
101	*Horsfieldia tomentosa*	1	6.67	0.42	0.0007	0.23	0.04	0.003	0.27	0.09
102	*Celastrus paniculata*	1	6.67	0.42	0.0006	0.23	0.04	0.002	0.27	0.09
103	*Eurya acuminata*	1	6.67	0.42	0.0002	0.23	0.04	0.001	0.27	0.09
	Total	2,798	2,840	1,165	27.66	100	100	100	300	100

Table 2-4 Quantitative data of plant communities in the adjacent fragmented forests.

Parameters	Fifteen sample plots in adjacent fragmented forests															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
1. Altitude (m)	1,440	1,470	1,395	1,259	1,300	1,253	1,345	1,250	1,222	1,234	1,390	1,436	1,556	1,545	1,586	
2. Number of Species	16	21	42	20	21	16	34	25	29	26	40	35	37	32	32	103
3. Number of Genus	15	18	35	19	18	13	29	20	23	22	35	32	33	28	29	82
4. Number of Families	10	13	21	13	12	10	18	13	14	13	22	22	24	18	19	44
5. Basal area (m^2/ha)	31.65	25.12	32.88	29.61	27.96	26.22	22.59	23.32	25.85	17.46	31.01	32.80	36.58	27.02	24.85	27.66
6. Dominant tree (%)																
1) *Pinus kesiya*	63.57	53.73	25.67	33.88	16.51	38.67	31.33	33.57	25.99	39.39	-	7.33	0.91	7.00	-	24.10
2) *Castanopsis acuminatissima*	-	0.07	1.61	20.98	30.80	19.96	34.07	17.61	35.83	11.96	17.37	22.43	-	7.78	-	14.12
3) *Schima wallichii*	7.20	5.48	9.36	0.19	0.79	-	0.40	-	4.85	-	5.96	10.85	9.77	21.90	25.73	7.14
4) *Quercus brandisiana*	-	-	-	18.33	19.34	1.27	3.21	14.08	14.22	17.47	-	-	-	-	-	5.28
5) *Castanopsis diversifolia*	0.29	1.16	0.09	-	-	-	-	0.11	-	-	10.80	8.93	33.22	-	21.55	5.84
6) *Ternstroemia gymnanthera*	-	-	3.19	1.91	0.51	-	0.92	-	-	-	2.62	6.25	9.55	5.56	4.97	2.66
7) *Helicia excelsa*	3.65	1.11	0.91	-	-	-	0.49	-	1.10	-	1.17	7.62	9.71	10.90	0.01	2.77
7. IVI (%)																
1) *Pinus kesiya*	39.64	34.16	17.61	21.77	9.44	23.27	18.59	19.12	14.89	26.61	-	4.16	1.64	3.69	-	11.02
2) *Castanopsis acuminatissima*	-	0.24	1.31	16.01	22.80	16.72	22.22	13.80	23.32	9.12	9.39	14.45	-	4.47	-	7.36
3) *Schima wallichii*	5.69	5.24	8.95	1.13	0.99	-	0.87	-	3.50	-	4.04	10.90	8.14	17.00	23.94	5.11
4) *Quercus brandisiana*	-	-	-	11.23	13.22	1.20	2.51	10.71	15.49	14.71	-	-	-	-	-	3.31
5) *Castanopsis diversifolia*	0.41	0.79	0.30	-	-	-	-	0.72	-	-	7.34	7.45	20.16	-	17.56	3.28
6) *Ternstroemia gymnanthera*	-	-	4.11	3.02	0.85	-	1.36	-	-	-	2.72	9.09	10.39	5.12	2.84	2.62
7) *Helicia excelsa*	4.97	1.81	0.71	-	-	-	1.60	-	1.36	-	1.29	9.53	7.52	6.62	0.36	2.55
8. Density (trees/ha)	1,194	1,500	1,244	906	1,056	556	1,388	938	1,156	994	1,769	1,256	1,056	1,600	875	1,166
(1) gbh < 50 cm	905	1,249	898	617	694	316	1,177	717	950	825	1,447	870	733	1,319	596	888
(2) gbh 50-100 cm	157	170	254	165	278	163	134	139	134	110	268	295	235	217	221	196
(3) gbh 100-150 cm	113	81	79	81	66	47	45	50	40	40	40	50	31	43	33	56
(4) gbh 150-200 cm	19	-	13	44	13	25	31	31	26	19	15	34	31	22	19	23
(5) gbh 200-250 cm	-	-	-	-	6	6	-	-	6	-	-	6	13	-	6	3
(6) gbh 250-300 cm	-	-	-	-	-	-	-	-	-	-	-	-	13	-	-	1
9. Species diversity (SWI)	3.01	3.37	4.65	3.45	3.65	3.53	4.38	3.69	4.03	3.87	4.15	4.28	4.51	4.23	3.88	5.28

(5) Stem Basal Area

The total stem basal area of all tree species in adjacent fragmented forests varied between 17.46-36.58 m^2ha^{-1}. This parameter was implied to forest production according to stem size and number of trees, and forest condition. Since the adjacent fragmented forests had different forest conditions, from poor to good, the values were therefore greatly different.

(6) Importance Value Index (IVI)

The IVI value combines relative frequency, relative density and relative dominance into a measure that can be use to indicate the ecological influence of each species in the forest. *P. kesiya* had the highest value (11.02% of all species), and followed by *C. acuminatissima*, *T. rufescens*, *S. wallichii*, *W. tinctoria*, *V. sprengelii*, *Q. brandisiana*, *C. diversifolia*, *T. gymnanthera* and *H. nilagirica*. These ten tree species were accounted for 49.06% of the total IVI.

These adjacent fragmented forests were remained at the ridge or upper slopes of the high mountains where the sites were relatively dried during summer. The forest conditions were favorable for the pine (*P. kesiya*) and some broad-leaved tree species. Mycorrhizal fungi usually associate with the roots of these tree species and help for nutrient uptake and moisture absorption.

(7) Species Diversity Index

Species diversity index in the whole adjacent fragmented forests by Shannon-Wiener Index (SWI) was calculated as 5.28 and varied among the adjacent fragmented forests with a range of 3.01 to 4.65 (Table 2-4). The patch sizes of adjacent fragmented forests were varied from small to big ones, and human disturbance through tree cutting was different among the patches. These indicated to some degradation of adjacent fragmented forests, and thus the SWI values were variable. The SWI of the whole adjacent fragmented forests was nearly the same with the lower montane forest at Doi Suthep-Pui national park, 5.0-5.1 (Vanaprasert, 1985), and implied to the high species diversity of original forest of these adjacent fragmented forests.

2.4.1.3 Climax Montane Forest

The plant community characteristics of the climax montane forest were shown in Table 2-5. There were 122 species, 112 genera and 49 families in five sampling plots of the 15 ha permanent plot. Dominant tree species were mainly *M. euonymoides* (11.74%), *Q. eumorpha* (10.61%), *Manglietia garretii* (8.34%), *Calophyllum polyanthum* (6.76%), *Nyssa javanica* (4.95%), *and Lindera metcalfiana* (3.01%). In terms of basal area, Fagaceae and Lauraceae were the dominant families. The highest and dominant family was Lauraceae (19 species) and followed by Fagaceae (8 species) and Cornaceae (3 species). The average tree density was 7,391 trees/ha. The tree species having the high density values were *Mallotus khasianus* (684), *Euodia triphylla* (552), and *C. calathiformis* (392), respectively.

Table 2-5 Quantitative characteristics of tree species in the climax montane forest

No	Species	No. of trees	Frequency (%)	Density (trees/ha)	Basal area (m^2/ha)	Relative (%) Frequency	Density	Dominance	IVI (300)	(%)
1	*Mastixia euonymoides* Prain	74	100.00	59.20	5.3500	1.15	0.80	11.74	13.70	4.57
2	*Quercus eumorpha* Kurz *(Syn. = Q. lenticellata Barnett)*	125	100.00	100.00	4.8333	1.15	1.35	10.61	13.12	4.37
3	*Mallotus khasianus* Hook. f.	856	100.00	**684.80**	1.0591	1.15	9.27	2.33	12.74	4.25
4	*Calophyllum polyanthum* Wall.	434	100.00	**347.20**	3.0811	1.15	4.70	6.76	12.61	4.20
5	*Manglietia garretii* Craib	108	80.00	86.40	3.7984	0.92	1.17	8.34	10.43	3.48
6	*Euodia triphylla* DC.	690	100.00	**552.00**	0.1646	1.15	7.47	0.36	8.98	2.99
7	*Castanopsis calathiformis* Kurz	491	80.00	**392.80**	0.7888	0.92	5.31	1.73	7.97	2.66
8	*Heynea trijuga* Sims	385	100.00	**308.00**	0.6963	1.15	4.17	1.53	6.85	2.28
9	*Lindera metcalfiana* Allen	245	100.00	196.00	1.3712	1.15	2.65	3.01	6.81	2.27
10	*Cryptocarya densiflora Blume*	276	100.00	220.80	1.1926	1.15	2.99	2.62	6.76	2.25
11	*Nyssa javanica* Wangerin	22	100.00	17.60	2.2530	1.15	0.24	4.95	6.34	2.11
12	*Symplocos macrophylla* Wall. ex DC. *ssp. sulcata* (Kurz) Noot. *var. sulcata*	257	100.00	205.60	0.8551	1.15	2.78	1.88	5.81	1.94
13	*Eurya nitida* Korth. *var. nitida*	284	80.00	227.20	0.3532	0.92	3.07	0.78	4.77	1.59
14	*Persea sp.*	70	100.00	56.00	1.2752	1.15	0.76	2.80	4.71	1.57
15	*Psychotria symplocifolia Kurz*	305	80.00	244.00	0.0817	0.92	3.30	0.18	4.40	1.47
16	*Syzygium angkae* (Craib) P. Chantaranothai & J. Parnell *ssp. angkae*	158	100.00	126.40	0.6733	1.15	1.71	1.48	4.34	1.45
17	*Tarenna disperma* (Hook. f.) Pit. *(Syn. = Webra disperma* Hook. f.)	89	100.00	71.20	0.9422	1.15	0.96	2.07	4.18	1.39
18	*Syzygium tetragonum* Wall.	134	100.00	107.20	0.6496	1.15	1.45	1.43	4.03	1.34
19	*Polyosma integrifolia* Blume	130	100.00	104.00	0.6497	1.15	1.41	1.43	3.99	1.33
20	*Camellia oleifera* Abel *var. confusa* (Craib) Sealy	191	100.00	152.80	0.2757	1.15	2.07	0.61	3.82	1.27
21	*Daphniphyllum cf. glaucescens* Blume *ssp. beddomei* (Craib) Huang	87	100.00	69.60	0.7807	1.15	0.94	1.71	3.81	1.27
22	*Chionanthus ramiflorus* Roxb.	94	100.00	75.20	0.7005	1.15	1.02	1.54	3.71	1.24
23	*Elaeocarpus lanceifolius* Roxb.	100	100.00	80.00	0.6085	1.15	1.08	1.34	3.57	1.19
24	*Cryptocarya cf. calcicola* H. W. Li	142	100.00	113.60	0.3920	1.15	1.54	0.86	3.55	1.18
25	*Castanopsis purpurea* Barnett	132	100.00	105.60	0.4310	1.15	1.43	0.95	3.53	1.18
26	*Lithocarpus vestitus* (Hickel & A. Camus) A. Camus	128	100.00	102.40	0.4476	1.15	1.39	0.98	3.52	1.17
27	*Quercus brevicalyx* A. Camus	68	100.00	54.40	0.6945	1.15	0.74	1.52	3.41	1.14
28	*Ostodes paniculata* Blume	153	80.00	122.40	0.3491	0.92	1.66	0.77	3.34	1.11
29	*Cinnamomum bejolghota* (Ham.) Sweet *var. bejolghota*	89	100.00	71.20	0.5522	1.15	0.96	1.21	3.33	1.11
30	*Aidia yunnanensis* (Hutch) T. Yamaz.	77	100.00	61.60	0.6087	1.15	0.83	1.34	3.32	1.11
31	*Psychotria densa* W. C. Chen	183	100.00	146.40	0.0235	1.15	1.98	0.05	3.18	1.06

Table 2-5 (Continued)

No	Species	No. of trees	Frequency (%)	Density (trees/ha)	Basal area (m^2/ha)	Relative (%)			IVI	
						Frequency	Density	Dominance	(300)	(%)
32	*Acer laurinum* Hassk.	52	100.00	41.60	0.5187	1.15	0.56	1.14	2.85	0.95
33	*Rapanea yunnaensis* Mez	93	100.00	74.40	0.2735	1.15	1.01	0.60	2.76	0.92
34	*Lithocarpus echinops* Hjelmq.	63	100.00	50.40	0.4107	1.15	0.68	0.90	2.74	0.91
35	*Litsea subcoriacea* Yen C. Yang & P. H. Huang	70	100.00	56.00	0.3653	1.15	0.76	0.80	2.71	0.90
36	*Litsea beusekomii* Kostermans	146	80.00	116.80	0.0700	0.92	1.58	0.15	2.66	0.89
37	*Lasianthus hookerii* C. B. Clarke ex Hook. F. *var. hookeri*	132	100.00	105.60	0.0311	1.15	1.43	0.07	2.65	0.88
38	*Litsea yunnanensis* Yen C. Yang & P. H. Huang	106	80.00	84.80	0.2605	0.92	1.15	0.57	2.64	0.88
39	*Drypetes sp.*	36	80.00	28.80	0.5885	0.92	0.39	1.29	2.60	0.87
40	*Unknown*	95	100.00	2.40	0.1895	0.46	1.03	0.42	2.60	0.87
41	*Toona ciliata* M. Roem.	71	80.00	56.80	0.3801	0.92	0.77	0.83	2.52	0.84
42	*Ardisia attenuata* Wall. ex A. DC.	114	100.00	91.20	0.0270	1.15	1.23	0.06	2.45	0.82
43	*Lasianthus indorus* Bl. *(Syn. = L. tubiferus* Hook. f.	130	80.00	104.00	0.0220	0.92	1.41	0.05	2.38	0.79
44	*Ardisia corymbifera* Mez *var. corymbifera*	109	100.00	87.20	0.0130	1.15	1.18	0.03	2.36	0.79
45	*Ixora cf. kerrii* Craib.	118	80.00	94.40	0.0266	0.92	1.28	0.06	2.26	0.75
46	*Drypetes indica* (Mull. Arg.) Pax & Hoffm. *var. indica*	58	100.00	46.40	0.1976	1.15	0.63	0.43	2.21	0.74
47	*Sarcosperma arboreum* Buch. -Ham. ex C. B. Clarke	11	100.00	8.80	0.4215	1.15	0.12	0.93	2.20	0.73
48	*Litsea pedunculata* (Diels) Yang & P. H. Huang	59	100.00	47.20	0.1694	1.15	0.64	0.37	2.16	0.72
49	*Podocarpus neriifolius* D.Don	12	80.00	9.60	0.4925	0.92	0.13	1.08	2.13	0.71
50	*Neolitsea zeylanica* (Nees) Merr.	55	100.00	44.00	0.1394	1.15	0.60	0.31	2.05	0.68
51	*Artocarpus cf. lacucha* Ham.	37	100.00	29.60	0.1900	1.15	0.40	0.42	1.97	0.66
52	*Lithocarpus aggregatus* Barnett *ssp. aggregatus*	36	100.00	28.80	0.1747	1.15	0.39	0.38	1.93	0.64
53	*Pyrenaria garrettiana* Craib	40	100.00	32.00	0.1281	1.15	0.43	0.28	1.87	0.62
54	*Ardisia virens* Kurz	57	100.00	45.60	0.0092	1.15	0.62	0.02	1.79	0.60
55	*Cordia cf. cochinchinensis* Gagnep.	10	80.00	8.00	0.3376	0.92	0.11	0.74	1.77	0.59
56	*Capparis cf. assamica* Hook. f. & Thoms.	36	80.00	28.80	0.1815	0.92	0.39	0.40	1.71	0.57
57	*Platea latifolia* Blume	31	80.00	24.80	0.1923	0.92	0.34	0.42	1.68	0.56
58	*Carallia brachiata* (Laur.) Merr.	8	100.00	6.40	0.1995	1.15	0.09	0.44	1.68	0.56
59	*Ilex longecaudata* Comber *var. longecaudata*	45	80.00	36.00	0.1113	0.92	0.49	0.24	1.65	0.55
60	*Actinodaphne sp.*	28	100.00	22.40	0.0816	1.15	0.30	0.18	1.63	0.54
61	*Ficus hirta* Vahl *var. hirta*	32	80.00	25.60	0.1597	0.92	0.35	0.35	1.62	0.54
62	*Prunus wallichii* Steud	28	100.00	22.40	0.0708	1.15	0.30	0.16	1.61	0.54

Table 2-5 (Continued)

No	Species	No. of trees	Frequency (%)	Density (trees/ha)	Basal area (m^2/ha)	Relative (%) Frequency	Density	Dominance	IVI (300)	(%)
63	*Antidesma sootepense* Craib.	40	100.00	32.00	0.0059	1.15	0.43	0.01	1.60	0.53
64	*Lauraceae sp.*	8	20.00	6.40	0.5448	0.23	0.09	1.20	1.51	0.50
65	*Horsfieldia sp.*	48	60.00	38.40	0.1272	0.69	0.52	0.28	1.49	0.50
66	*Camellia taliensis* (W. W. Sm.) Melch.	46	80.00	36.80	0.0306	0.92	0.50	0.07	1.49	0.50
67	*Symplocos henschelii* (Mor.) Benth. ex C. B. Clarke *var. magnifica* (Fletcher)	15	80.00	12.00	0.1689	0.92	0.16	0.37	1.45	0.48
68	*Phoebe macrocarpa* C. Y. Wu	4	60.00	3.20	0.3248	0.69	0.04	0.71	1.45	0.48
69	*Castanopsis acuminatissima* (Blume) A. DC.	28	40.00	22.40	0.2686	0.46	0.30	0.59	1.35	0.45
70	*Gomphostemma arbusculum* C. Y. Wu	15	100.00	12.00	0.0014	1.15	0.16	0.00	1.32	0.44
71	*Symplocos hookeri* C. B. Clarke	27	80.00	21.60	0.0122	0.92	0.29	0.03	1.24	0.41
72	*Macaranga denticulata* (Blume) Muell.-Arg.	25	60.00	20.00	0.1247	0.69	0.27	0.27	1.24	0.41
73	*Prunus phaeosticta* (Hance) Maxim.	39	60.00	31.20	0.0523	0.69	0.42	0.11	1.23	0.41
74	*Psychotria calocarpa* Kurz	27	80.00	21.60	0.0025	0.92	0.29	0.01	1.22	0.41
75	*Cinnamomum cf. soegengii* Kosterm.	26	60.00	20.80	0.0952	0.69	0.28	0.21	1.18	0.39
76	*Euonymus colonoides* Craib	27	60.00	21.60	0.0788	0.69	0.29	0.17	1.16	0.39
77	*Elaeocarpus petiolaris* (Jack.) Wall ex Kurz	13	60.00	10.40	0.1377	0.69	0.14	0.30	1.13	0.38
78	*Capparis sabiaefolia* Hook. f. & Thoms.	38	60.00	30.40	0.0112	0.69	0.41	0.02	1.13	0.38
79	*Ardisia rubro-glandulosa* Fletcher	10	80.00	8.00	0.0407	0.92	0.11	0.09	1.12	0.37
80	*Litsea lancifolia* Hook. f.	47	40.00	37.60	0.0488	0.46	0.51	0.11	1.08	0.36
81	*Gomphandra tetrandra* (Wall. in Roxb.) Sleumer	24	60.00	19.20	0.0551	0.69	0.26	0.12	1.07	0.36
82	*Nothapodytes cf. obscura* C. Y. Wu	23	60.00	18.40	0.0503	0.69	0.25	0.11	1.05	0.35
83	*Dysoxylum sp.1*	24	60.00	19.20	0.0207	0.69	0.26	0.05	1.00	0.33
84	*Diospyros frutescens* Blume	4	80.00	3.20	0.0013	0.92	0.04	0.00	0.97	0.32
85	*Beilschmiedia glauca* Sin. C. Lee et L. F. Lau *var. glaucoides* H. W. Li	19	60.00	15.20	0.0307	0.69	0.21	0.07	0.96	0.32
86	*Elaeocarpus braceanus* Watt ex C. B. Clarke	8	60.00	6.40	0.0681	0.69	0.09	0.15	0.93	0.31
87	*Dysoxylum sp.2*	15	60.00	12.00	0.0075	0.69	0.16	0.02	0.87	0.29
88	*Engelhardia spicata* Lesch. ex Blume *var. spicata*	4	40.00	3.20	0.1650	0.46	0.04	0.36	0.87	0.29
89	*Pterospermum grandiflorum* Craib.	6	60.00	4.80	0.0484	0.69	0.06	0.11	0.86	0.29
90	*Sterculia sp.*	6	60.00	4.80	0.0433	0.69	0.06	0.09	0.85	0.28
91	*Litsea cubeba* Pers.	18	40.00	14.40	0.0741	0.46	0.19	0.16	0.82	0.27
92	*Euonymus sp.1*	4	60.00	3.20	0.0244	0.69	0.04	0.05	0.79	0.26
93	*Litsea cf. membranifolia* Hook. f.	7	60.00	5.60	0.0070	0.69	0.08	0.02	0.78	0.26

Table 2-5 (Continued)

No	Species	No. of trees	Frequency (%)	Density (trees/ha)	Basal area (m^2/ha)	Relative (%) Frequency	Relative (%) Density	Relative (%) Dominance	IVI (300)	IVI (%)
94	*Annonaceae sp.*	6	60.00	4.80	0.0014	0.69	0.06	0.00	0.76	0.25
95	*Betula alnoides* Buch.-Ham.	1	20.00	0.80	0.2259	0.23	0.01	0.50	0.74	0.25
96	*Strobilanthes aff. mucronato-productus* Lindl.	18	40.00	14.40	0.0020	0.46	0.19	0.00	0.66	0.22
97	*Schoepfia fragrans* Wall.	11	40.00	8.80	0.0340	0.46	0.12	0.07	0.65	0.22
98	*Diospyros glandulosa* Lace	2	20.00	1.60	0.1751	0.23	0.02	0.38	0.64	0.21
99	*Turpinia nepalensis* Wall.	5	40.00	4.00	0.0243	0.46	0.05	0.05	0.57	0.19
100	*Daphne composita* (L. f.) Gilg	6	40.00	4.80	0.0010	0.46	0.06	0.00	0.53	0.18
101	*Lasianthus sikkimensis* Hook f.	5	40.00	4.00	0.0007	0.46	0.05	0.00	0.52	0.17
102	*Polygala arillata* Ham.	5	40.00	4.00	0.0006	0.46	0.05	0.00	0.52	0.17
103	*Debregeasia longifolia* (Burm. f) Wedd.	4	40.00	3.20	0.0018	0.46	0.04	0.00	0.51	0.17
104	*Zanthoxylum rhesta* (Roxb.) DC.	3	40.00	76.00	0.0027	1.15	0.03	0.01	0.50	0.17
105	*Viburnum punctatum* Ham ex D. Don	3	40.00	2.40	0.0006	0.46	0.03	0.00	0.49	0.16
106	*Baliospermum micrantum* Mull. Arg.	3	40.00	2.40	0.0004	0.46	0.03	0.00	0.49	0.16
107	*Myrica esculenta* Buch.-Ham.	2	40.00	1.60	0.0023	0.46	0.02	0.01	0.49	0.16
108	*Pittosporum chatterjeeanum* Gowda.	2	40.00	1.60	0.0005	0.46	0.02	0.00	0.48	0.16
109	*Lasianthus saxorum* Craib.	2	40.00	1.60	0.0002	0.46	0.02	0.00	0.48	0.16
110	*Archidendron clypearia* (Jack) L. T. Nielsen *ssp. clypearia var. clypearia*	4	20.00	3.20	0.0066	0.23	0.04	0.01	0.29	0.10
111	*Ficus sp.1*	2	20.00	1.60	0.0120	0.23	0.02	0.03	0.28	0.09
112	*Beilschmiedia purpurascens* H. W. Li	3	20.00	2.40	0.0042	0.23	0.03	0.01	0.27	0.09
113	*Olea cf. salicifolia* Wall.	1	20.00	0.80	0.0131	0.23	0.01	0.03	0.27	0.09
114	*Meliosma sp.*	2	20.00	1.60	0.0019	0.23	0.02	0.00	0.26	0.09
115	*Prunus sp.2*	2	20.00	1.60	0.0006	0.23	0.02	0.00	0.25	0.08
116	*Maytenus sp.*	1	20.00	0.80	0.0008	0.23	0.01	0.00	0.24	0.08
117	*Broussonetia kazinoki* Sieb.	1	20.00	0.80	0.0006	0.23	0.01	0.00	0.24	0.08
118	*Miliusa sp.*	1	20.00	0.80	0.0002	0.23	0.01	0.00	0.24	0.08
119	*Desmodium multiflorum* DC.	1	20.00	0.80	0.0001	0.23	0.01	0.00	0.24	0.08
120	*Lycianthes neesiana* (Wall. ex Nees) D'Arcy & Z. Y. Zhang	1	20.00	0.80	0.0001	0.23	0.01	0.00	0.24	0.08
121	*Mycetia rivicola* Craib.	1	20.00	0.80	0.0001	0.23	0.01	0.00	0.24	0.08
122	*Strobilanthes sp.1*	1	20.00	0.80	0.0001	0.23	0.01	0.00	0.24	0.08
	Total	**9,239**	**8,680**	**7,391.20**	**45.55**	**100**	**100**	**100**	**300**	**100**

M.euonymoides had the highest value (13.70% of all species), and followed by *Q. eumorpha* (10.61%), *M. khasianus* (12.74%), *C. polyanthum* (12.61%) and *M. garretii* (10.43%). Species diversity index was 5.72, based on the Shannon-Wiener index (SWI)

The SWI value was usually high in this forest. Khamyong and Seramethakun (1998) reported that the forest at Mt. Doi Suthep in area of 1,200-1,300 m altitude had the value of 4.5, and it was increased to be 6.1 as the sampling area was expanded (Khamyong, 2009). Laorpansakul (2000) found that SWI of the forest at the Queen Sirikit botanic garden was 5.67, and it was higher as 6.05 for the fragmented forests in Pang Ma Pha district, Mae Hong Son province (Seanchanthong, 2005). However, the SWI value of the upper montane forest at Mt. Doi Inthanon was lower as 4.26 (Khamyong *et al*., 2004).

2.4.2 Tree Volume and Wood Production

2.4.2.1 *Pinus kesiya* Plantations

(1) Growth of *P. kesiya* and Succession Trees

The growths of pine trees in 21 age-class pine plantations of 14 to 34 years old at Boakaew Watershed Management Station were analyzed in mean and increment values of stem diameter at breast height (dbh) and tree height for each age-class stand (Table 2-6). The mean height (H) and dbh of these stands were in ranges of 15.31-23.30 m and 24.24-35.37 cm, respectively. The annual height increment varied between 0.52-1.15 m with the mean of 0.81 m yr^{-1}, whereas the annual dbh increment was 0.94-2.24 cm, and 1.28 cm yr^{-1} of mean value. The height and stem diameter growths were varied among different age plantations. However, they did not increase continuously with stand ages. The height and dbh of pine trees in some older stands were lower than the younger stands.

The annual growth (height and dbh) increments of *P. kesiya* can be compared to other sites of northern Thailand, e.g. Mae Hard watershed station in early aged in 7-12 year-old were 1.54 m.yr^{-1} and 2.63 cm.yr^{-1} (Rojanakul, 1997); Doi Boa Luang Plantation in 12-37 year-old were 0.49 m.yr^{-1} and 0.66 cm.yr^{-1} (Khamyong, 2001); and Huey Bong experimental station in 14 year-old were 0.63 m.yr^{-1} and 1.11 cm.yr^{-1} (Wattanasuksakul *et al*., 1996). FAO (1968) stated that height increment of *P. kesiya* in natural forests was 0.80 m.yr^{-1} in 10-15 year-old, increasing to 1.0 m.yr^{-1} in 15-20 year-old and up to 1.17 m.yr^{-1} between 20-25 year-old; whereas dbh increment in early fifteen years was 0.94 cm.yr^{-1}, increasing to 1.06 cm.yr^{-1} in 15-20 year-old but reducing to 0.82 cm.yr^{-1} in 20-25 year-old.

For the growth of succession trees in a series of plantations showed that the mean height and stem dbh were ranged between 11.56-17.50 m and 14.67-27.33 cm, respectively. Their annual height and dbh increment were in ranges of 0.37-0.88 m.yr^{-1} and 0.66-1.58 cm.yr^{-1} (Table 2-6).

The average growths (height and dbh) of *P. kesiya* and succession trees in 21 age-class plantations were characterized according to real site conditions and real stand structures under natural succession. Site condition is the most important factor for determining productivity and profit. Indeed substantial variation in growth and morphology from trees planted in a wide variety of countries is well documented (Armitage and Burley, 1980). For example, 5 year results from a provenance test at Huay Tong in Chiang Mai, Thailand demonstrated substantial difference in height growth among the 18 provenances (Granhof, 1978). Das and Stephan (1986) reported that 11year results from a trial of 12 provenances from the Philippines, Thailand, Vietnam, Zambia and Assam in India, revealed no significant differences among provenances for either height or diameter growth.

Table 2-6 Growth of *P. kesiya* and succession trees in a series of pine plantations of 21 age-class stands

Ages (yrs)	*P. kesiya*				Succession trees			
	Growths		Annual growth increment		Growths		Annual growth increment	
	H (m.)	DBH (cm.)	H ($m.yr^{-1}$)	DBH ($cm.yr^{-1}$)	H (m.)	DBH (cm.)	H ($m.yr^{-1}$))	DBH ($cm.yr^{-1}$)
14	16.13	31.35	1.15	2.24	12.25	20.57	0.88	1.47
15	15.31	28.69	1.02	1.91	12.54	23.73	0.84	1.58
16	17.59	27.61	1.10	1.73	13.68	21.09	0.86	1.32
17	15.87	26.44	0.93	1.56	12.76	21.14	0.75	1.24
18	17.14	29.33	0.95	1.63	13.10	16.49	0.73	0.92
19	17.32	26.08	0.91	1.37	14.16	17.53	0.75	0.92
20	17.07	27.03	0.85	1.35	17.50	22.63	0.88	1.13
21	19.01	26.98	0.91	1.28	13.61	18.81	0.65	0.90
22	17.11	25.72	0.78	1.17	11.56	14.67	0.53	0.67
23	18.41	25.70	0.80	1.12	13.11	18.94	0.57	0.82
24	18.23	24.24	0.76	1.01	14.14	24.51	0.59	1.02
25	18.47	25.25	0.74	1.01	12.91	18.72	0.52	0.75
26	19.72	29.81	0.76	1.15	14.34	24.31	0.55	0.94
27	20.26	26.46	0.75	0.98	15.78	20.59	0.58	0.76
28	18.68	33.44	0.67	1.19	12.81	22.80	0.46	0.81
29	15.13	28.53	0.52	0.98	11.66	21.68	0.40	0.75
30	19.58	32.79	0.65	1.09	13.82	20.70	0.46	0.69
31	21.49	35.37	0.69	1.14	14.41	21.33	0.46	0.69
32	20.46	32.32	0.64	1.01	15.34	27.33	0.48	0.85
33	23.30	34.52	0.71	1.05	16.63	26.23	0.50	0.79
34	21.47	32.10	0.63	0.94	12.54	22.43	0.37	0.66
Average	18.46	29.04	0.81	1.28	13.74	21.25	0.61	0.94

(2) Stem Volumes of *P. kesiya* and Succession Trees

Stem volume of *P. kesiya* was estimated every age class of plantations following Pornleesangsuwan, (2012). The total volume of *P. kesiya* in a series of pine plantation were range from 32.73-337.10 m^3ha^{-1}, and the timber volume of *P. kesiya* were range from 19.93-200.62 m^3ha^{-1}. The results on growth and yield indicated by the mean of annual total volume increment (MAI) of *P. kesiya* was 6.23 $m^3ha^{-1}yr^{-1}$ (2.04-10.22 $m^3ha^{-1}yr^{-1}$ in range). The mean of annual timber volume increment of *P. kesiya* was 4.24 $m^3ha^{-1}yr^{-1}$ (1.17-7.21 $m^3ha^{-1}yr^{-1}$ in range) (Table 2-7). The highest annual total volume increment of *P. kesiya* was 7.68 $m^3ha^{-1}yr^{-1}$ for 16 to 20 year-old stands which are considered as the injuvenile stage. Stem volume increment of *P. kesiya* at Boakaew Watershed Management Station was higher than Boa Luang Plantation which was reported as 3.44 $m^3ha^{-1}yr^{-1}$ (Khamyong, 2001). Yield increment of general *P. kesiya* plantations were in range of 3-4 $m^3ha^{-1}yr^{-1}$, whereas the intensive management could increase stem volume to 6-9 $m^3ha^{-1}yr^{-1}$ (Pousujja, 1984).

Stem volumes of succession broad-leaved trees were estimated every age-class plantation by using equation of Sungpalee, *et al.* (2009). Their total volumes in a series of pine plantations were in range of 7.52-124.73 m^3ha^{-1}, and the timber log volume were 4.16-67.30 m^3ha^{-1}. The annual total volume increment of succession trees were varied between 0.23-4.43 $m^3ha^{-1}yr^{-1}$, whereas the timber log volume increments were 0.13-2.23 $m^3ha^{-1}yr^{-1}$ (Table 2-7).

Table 2-7 Stem Volume of *P. kesiya* and succession trees in a series of pine plantations of 21 age-class stands.

Age (year)	*P. kesiya*				Succession trees			
	Volume (m^3ha^{-1})		Annual volume increment ($m^3ha^{-1}yr^{-1}$)		Volume (m^3ha^{-1})		Annual volume increment ($m^3ha^{-1}yr^{-1}$)	
	V_{Total}	V_{Timber}	V_{Total}	V_{Timber}	V_{Total}	V_{Timber}	V_{Total}	V_{Timber}
14	78.45	50.23	5.60	3.59	57.71	25.56	4.12	1.83
15	32.73	21.12	2.18	1.41	56.35	25.91	3.76	1.73
16	160.13	108.87	10.01	6.80	12.11	5.84	0.76	0.37
17	34.63	19.93	2.04	1.17	75.38	37.97	4.43	2.23
18	135.59	89.49	7.53	4.97	61.61	30.95	3.42	1.72
19	172.77	116.44	9.09	6.13	44.19	24.95	2.33	1.31
20	194.83	127.15	9.74	6.36	10.34	5.17	0.52	0.26
21	198.04	151.42	9.43	7.21	81.76	40.38	3.89	1.92
22	126.54	94.91	5.75	4.31	55.87	26.40	2.54	1.20
23	89.83	61.35	3.91	2.67	57.58	28.66	2.50	1.25
24	121.92	87.13	5.08	3.63	91.74	49.18	3.82	2.05
25	158.79	110.37	6.35	4.41	51.46	28.70	2.06	1.15
26	252.18	173.67	9.70	6.68	91.59	54.81	3.52	2.11
27	156.70	106.16	5.80	3.93	85.08	43.60	3.15	1.61
28	143.73	103.08	5.13	3.68	30.53	16.57	1.09	0.59
29	100.07	67.30	3.45	2.32	26.47	14.29	0.91	0.49
30	163.83	117.11	5.46	3.90	71.57	39.22	2.39	1.31
31	99.51	68.37	3.21	2.21	124.73	67.30	4.02	2.17
32	223.82	154.47	6.99	4.83	86.86	44.82	2.71	1.40
33	337.10	200.62	10.22	6.08	7.52	4.16	0.23	0.13
34	140.37	91.26	4.13	2.68	101.21	55.79	2.98	1.64
Average	148.64	100.97	6.23	4.24	61.03	31.92	2.63	1.36

(3) Wood Productions of *P. kesiya* and Succession Trees

Timber volumes of *P. kesiya* and succession trees in a series of pine plantations were classified with different stem-girth classes presented in Table 2-8 and 2-9. Most of *P. kesiya* were large trees which had stem gbh in range of 50-150 cm. Timber A grade was higher, it were varied in 5.87-109.76 m^3ha^{-1}. The succession trees were large trees which had stem gbh in range of 50-100 cm. Timber B grade was higher, it were 0.89-14.34 m^3ha^{-1}.

Table 2-8 Timber volumes of *P. kesiya* with different timber quality and stem-girth classes in 21 age-class plantations

Age (year)	Volume of timber grade classification with different stem-girth classes (m^3ha^{-1})												Total
	30-50 cm			50-100 cm			100-150 cm			150-200 cm			
	A	B	C	A	B	C	A	B	C	A	B	C	
14	0.00	0.00	0.00	10.10	7.26	2.03	18.24	11.80	0.80	0.00	0.00	0.00	50.23
15	0.00	0.00	0.00	8.50	1.24	0.46	5.87	3.41	1.65	0.00	0.00	0.00	21.12
16	0.00	0.09	0.00	53.28	16.02	2.06	27.63	9.79	0.00	0.00	0.00	0.00	108.87
17	0.00	0.00	0.00	15.37	0.56	0.32	3.15	0.54	0.00	0.00	0.00	0.00	19.93
18	0.13	0.08	0.00	30.16	12.67	3.95	30.29	10.44	1.77	0.00	0.00	0.00	89.49
19	0.00	0.44	0.21	63.05	21.59	4.64	18.76	7.33	0.42	0.00	0.00	0.00	116.44
20	0.41	0.19	0.38	61.30	23.54	7.49	14.99	14.64	4.21	0.00	0.00	0.00	127.15
21	0.52	0.13	0.00	70.68	15.80	2.15	54.15	6.47	1.52	0.00	0.00	0.00	151.42
22	0.47	0.33	0.15	56.70	7.43	1.88	22.94	5.00	0.00	0.00	0.00	0.00	94.91
23	0.00	0.00	0.00	34.94	5.24	0.49	17.15	3.53	0.00	0.00	0.00	0.00	61.35
24	0.00	0.00	0.00	52.30	21.02	3.47	8.78	1.56	0.00	0.00	0.00	0.00	87.13
25	0.00	0.00	0.00	84.63	6.59	1.53	16.51	1.10	0.00	0.00	0.00	0.00	110.37
26	0.00	0.11	0.00	63.62	13.34	0.31	86.24	10.04	0.00	0.00	0.00	0.00	173.67
27	0.42	0.31	0.00	53.98	14.79	1.86	25.68	9.13	0.00	0.00	0.00	0.00	106.16
28	0.00	0.00	0.00	16.94	3.62	1.62	57.08	17.34	6.49	0.00	0.00	0.00	103.08
29	0.00	0.00	0.00	14.56	10.78	2.17	26.02	13.76	0.00	0.00	0.00	0.00	67.30
30	0.00	0.00	0.00	27.16	9.43	1.22	59.79	17.05	2.46	0.00	0.00	0.00	117.11
31	0.00	0.00	0.00	9.99	3.92	0.33	43.10	11.02	0.00	0.00	0.00	0.00	68.37
32	0.00	0.00	0.00	28.17	15.11	4.25	74.03	24.33	8.58	0.00	0.00	0.00	154.47
33	0.00	0.00	0.00	24.00	7.84	1.09	109.76	49.20	0.00	8.72	0.00	0.00	200.62
34	0.00	0.00	0.00	22.82	3.72	0.57	56.70	1.55	0.00	2.40	3.51	0.00	91.26

Table 2-9 Timber volumes of succession trees with different timber quality and stem-girth classes in 21 age-class plantations

Age (year)	Volume of timber grade classification with different stem-girth classes (m^3ha^{-1})												Total
	30-50 cm			50-100 cm			100-150 cm			150-200 cm			
	A	B	C	A	B	C	A	B	C	A	B	C	
14	1.35	2.20	1.18	1.49	5.78	4.07	1.40	2.04	4.72	0.00	1.25	0.00	25.56
15	1.31	1.37	0.56	1.52	6.10	1.96	2.16	3.31	3.17	0.70	0.92	2.82	25.91
16	0.16	0.57	0.22	2.64	1.45	0.81	0.00	0.00	0.00	0.00	0.00	0.00	5.84
17	2.06	3.43	1.44	4.25	6.58	3.08	1.61	3.99	0.83	0.44	5.41	4.86	37.97
18	1.14	5.21	2.20	4.48	8.46	3.62	1.79	2.86	1.17	0.00	0.00	0.00	30.95
19	0.60	3.03	2.11	3.86	3.91	4.84	1.24	0.89	0.38	0.00	2.84	1.21	24.95
20	0.13	0.65	0.45	0.53	0.91	2.06	0.00	0.00	0.45	0.00	0.00	0.00	5.17
21	2.15	3.26	1.37	7.82	7.78	2.41	2.10	3.08	1.39	5.84	0.00	3.15	40.38
22	2.99	7.55	1.59	2.89	4.52	2.77	0.00	1.32	2.78	0.00	0.00	0.00	26.40
23	1.14	3.62	1.98	3.88	5.35	3.52	0.00	3.61	3.75	0.00	1.79	0.00	28.66
24	0.20	1.24	1.38	2.80	6.52	5.08	0.00	2.30	2.02	19.44	6.39	1.77	49.18
25	2.01	2.09	0.72	5.08	4.23	1.10	2.48	1.04	0.00	7.23	0.00	2.72	28.70
26	0.87	1.83	0.55	6.40	3.64	1.43	2.58	3.90	1.38	8.16	11.08	12.99	54.81
27	1.40	3.77	1.42	10.88	14.34	4.39	3.15	3.70	0.56	0.00	0.00	0.00	43.60
28	0.33	0.48	0.26	5.79	2.54	1.73	3.62	1.36	0.47	0.00	0.00	0.00	16.57
29	0.32	0.85	0.58	1.59	1.75	2.55	1.42	3.01	0.00	0.00	0.00	2.20	14.29
30	0.38	2.21	1.79	6.73	8.54	4.57	0.77	0.35	1.70	0.00	12.18	0.00	39.22
31	1.75	3.76	3.14	12.10	8.95	2.09	6.39	5.00	4.48	7.16	10.05	2.39	67.30
32	0.12	0.41	0.55	3.18	5.25	4.82	3.53	11.40	1.19	9.50	2.35	2.51	44.82
33	0.07	0.04	0.00	0.70	0.83	0.00	2.05	0.00	0.47	0.00	0.00	0.00	4.16
34	0.79	1.61	2.21	1.72	8.81	7.40	7.49	3.83	5.18	10.70	3.02	3.03	55.79

2.4.2.2 Adjacent Fragmented Forests

Stem volumes of the broad-leaved trees were estimated of fifteen adjacent fragmented forest by using equation of Sungpalee, *et al.* (2009). Their total volumes in a fifteen natural forest were in range of 36.19-78.42 m^3ha^{-1}, and the timber log volumes were 22.31-49.01 m^3ha^{-1} (Table 2-10). Most of broad-leaved trees were large trees which had stem gbh in range of >150 cm and timber A grade was higher, following in range of 100-150 cm.

2.4.2.3 Climax Montane Forest

Stem volumes of the broad-leaved trees were estimated of the climax montane forest by using equation of Sungpalee, *et al.* (2009). The average total volumes in a climax montane forest was 94.81 m^3ha^{-1}, and the timber log volume was 48.69 m^3ha^{-1} (Table 2-11). Most of broad-leaved trees were large trees which had stem gbh in range of >150 cm and timber A grade was higher.

Table 2-10 Stem and timber volumes of the fifteen adjacent fragmented forests with different timber quality and stem-girth classes

Plot	Total Volume (m^3ha^{-1})	Volume of timber grade classification with different stem-girth classes (m^3ha^{-1})												
		30-50 cm			50-100 cm			100-150 cm			>150 cm			Total
		A	B	C	A	B	C	A	B	C	A	B	C	
1	**78.42**	0.16	0.78	1.03	1.65	5.37	1.98	14.52	14.87	1.61	5.38	1.66	0.00	**49.01**
2	**52.38**	0.21	1.93	1.60	3.44	5.44	2.28	12.75	2.50	0.51	0.00	0.00	0.00	**30.66**
3	**73.78**	0.84	2.71	0.77	4.59	9.52	2.04	9.09	6.11	0.64	3.57	2.39	0.00	**42.25**
4	**70.84**	0.00	0.39	0.29	2.67	4.42	1.50	4.70	3.35	3.80	19.72	1.69	1.56	**44.08**
5	**63.27**	0.12	2.28	0.62	1.25	9.45	2.31	2.04	5.79	0.48	4.30	4.96	0.00	**33.59**
6	**61.31**	0.00	0.78	0.40	1.21	5.68	0.93	3.94	4.27	0.00	15.40	2.32	0.00	**34.93**
7	**50.69**	0.48	1.16	0.58	0.36	3.87	1.79	3.91	3.00	0.67	5.92	5.30	0.00	**27.05**
8	**55.15**	0.06	1.10	0.46	0.25	4.44	0.47	4.24	6.01	0.00	10.62	1.12	0.00	**28.77**
9	**59.46**	0.24	1.51	0.47	1.52	4.83	0.41	3.20	2.86	0.32	6.04	7.81	1.32	**30.53**
10	**36.19**	0.13	1.41	0.20	1.37	2.84	0.85	2.92	2.97	0.00	6.80	0.82	0.00	**20.31**
11	**63.59**	0.22	2.73	0.92	1.25	7.81	4.11	0.00	5.03	1.10	1.36	0.00	1.56	**26.09**
12	**74.81**	0.40	1.97	0.83	3.78	3.85	3.23	0.94	2.95	2.32	1.08	13.14	0.00	**34.50**
13	**73.30**	0.45	1.13	0.40	1.23	4.04	2.55	0.00	2.58	1.03	0.00	12.52	11.22	**37.14**
14	**60.97**	0.47	2.26	0.21	3.69	3.74	1.02	0.00	4.79	3.57	0.00	4.93	2.38	**27.08**
15	**58.02**	0.51	0.62	0.23	3.84	4.43	2.97	0.55	3.71	0.92	0.00	2.07	3.11	**22.95**
Average	**62.15**	0.29	1.52	0.60	2.14	5.34	1.90	4.19	4.72	1.13	5.35	4.05	1.41	**32.596**

Table 2-11 Stem and timber volumes of climax montane forest with different timber quality and stem-girth classes

Plot	Total Volume (m^3ha^{-1})	Volume of timber grade classification with different stem-girth classes (m^3ha^{-1})												
		30-50 cm			50-100 cm			100-150 cm			>150 cm			Total
		A	B	C	A	B	C	A	B	C	A	B	C	
1	**124.74**	1.46	0.27	0.02	5.98	1.06	0.07	12.51	0.00	0.00	44.38	0.00	1.02	**66.75**
2	**96.82**	0.66	0.50	0.14	3.83	1.34	0.04	5.27	1.90	0.00	35.19	0.00	0.00	**48.88**
3	**94.68**	1.78	0.60	0.07	7.83	4.93	0.24	7.68	2.39	0.00	19.10	3.03	0.00	**47.66**
4	**68.98**	1.83	1.29	0.09	9.19	2.28	0.14	6.40	1.99	0.00	12.79	0.00	0.00	**36.00**
5	**88.83**	1.89	0.67	0.03	7.70	0.80	0.10	9.32	1.94	0.00	20.27	1.45	0.00	**44.17**
Average	**94.81**	1.53	0.67	0.07	6.91	2.08	0.12	8.24	1.64	0.00	26.35	0.90	0.20	**48.69**

2.4.3 Tree Biomass

2.4.3.1 *Pinus kesiya* Plantations

The biomass amounts of pine trees were calculated using the allometric equations of Nongnuang, (2010). The root biomass of pine trees was based on allometric equations of Tsutsumi *et al.* (1983). The results shown that the pine biomass in different age plantations did not increase continueously with stand ages. The values were 23.6 to 212.7 $Mg.ha^{-1}$. The lowest amount was found in the 15-year-old stand, whereas the largest amount was occurred in the 33-year-old stand. The majority of pine biomass was allocated in the stem component, followed by root, branch and leaf (Table 2-12). The high fluctuation of pine biomass was observed among the pine plantations caused by many factors such as spacing of planting, tree densities, competition with succession trees, site conditions, etc.

The number of succession tree species in different age pine plantations was different, varying 16-69 species. The biomass amounts of these trees were calculated using the allometric equations of Tsutsumi *et al.* (1983). The results shown that the biomass in these pine plantations were different from 8.1 to 94.1 Mg.ha^{-1}. Their biomass did not increase with plantation ages. It was the lowest in 20-year-old stand, 8.1 Mg.ha^{-1}, and the highest amount was occurred in 31-year-old stand, 94.1 Mg.ha^{-1}. The larger biomass of succession trees was dued to existing bigger trees with high density. These succession tree species played the important role on plantation biomass stocks. The majority of their biomass was allocated in stem component, followed by root, branch and leaf (Table 2-12).

The total forest biomass in a series of 21 age-class pine plantations involved biomass of pine and succession broad-leaved trees. The amounts were varied between 70.5-248.2 Mg.ha^{-1} (Table 2-12 and Figure 2-5). They did not increase with stand ages. It was the lowest in 15-year-old stand, and the highest amount was observed in 26-year-old stand. The low amounts were found in plantaions with altitude above 500 m msl., and those in areas between 1,314-1,453 m msl. had the high total biomass.

Table 2-12 Biomass of pine trees and succession trees in a series of pine plantations

Age (year)	*P. kesiya* (Mg.ha^{-1})					Succession trees (Mg.ha^{-1})					Total
	Stem	Branch	Leaf	Root	Total	Stem	Branch	Leaf	Root	Total	(Mg.ha^{-1})
14	37.9	8.1	1.6	11.9	59.5	28.8	5.0	1.2	9.8	44.8	104.3
15	15.1	3.1	0.6	4.8	23.6	29.9	5.9	1.2	9.9	46.9	70.5
16	79.2	16.8	3.3	25.0	124.2	7.1	1.1	0.3	2.5	11.1	135.3
17	15.5	3.0	0.6	5.0	24.2	39.1	7.2	1.6	13.4	61.3	85.5
18	59.0	12.2	2.4	18.7	92.4	34.6	5.4	1.4	12.3	53.8	146.2
19	74.5	14.7	3.1	24.0	116.3	24.1	4.1	1.0	8.3	37.6	153.9
20	83.5	16.6	3.5	26.9	130.5	5.2	0.8	0.2	1.8	8.1	138.6
21	86.3	17.6	3.6	27.6	135.1	41.0	7.8	1.7	13.7	64.3	199.4
22	56.9	11.1	2.4	18.5	88.8	37.8	5.0	1.6	14.1	58.6	147.4
23	44.7	8.9	1.9	14.5	70.0	31.9	5.2	1.3	11.3	49.7	119.7
24	55.1	10.6	2.3	18.0	86.0	41.5	10.8	1.7	12.5	66.6	152.6
25	71.8	14.0	3.0	23.3	112.2	26.1	5.1	1.1	8.7	41.0	153.2
26	115.5	25.5	4.8	36.0	181.8	41.6	10.3	1.7	12.7	66.4	248.2
27	70.8	15.0	2.9	22.3	111.0	43.4	7.6	1.8	14.7	67.5	178.5
28	80.7	18.7	3.3	24.7	127.4	15.1	2.8	0.6	5.0	23.5	150.9
29	45.1	9.1	1.9	14.5	70.5	19.3	3.6	0.8	6.4	30.1	100.6
30	79.9	18.2	3.3	24.6	126.0	33.5	7.4	1.4	10.8	53.1	179.1
31	46.2	10.8	1.9	14.1	73.0	59.8	12.5	2.5	19.3	94.1	167.1
32	90.7	20.2	3.7	28.1	142.7	39.4	9.7	1.6	12.0	62.7	205.4
33	134.4	31.8	5.5	40.9	212.7	5.9	0.9	0.2	2.2	9.2	221.9
34	61.7	14.0	2.5	19.1	97.3	50.8	10.5	2.1	16.4	79.9	177.2

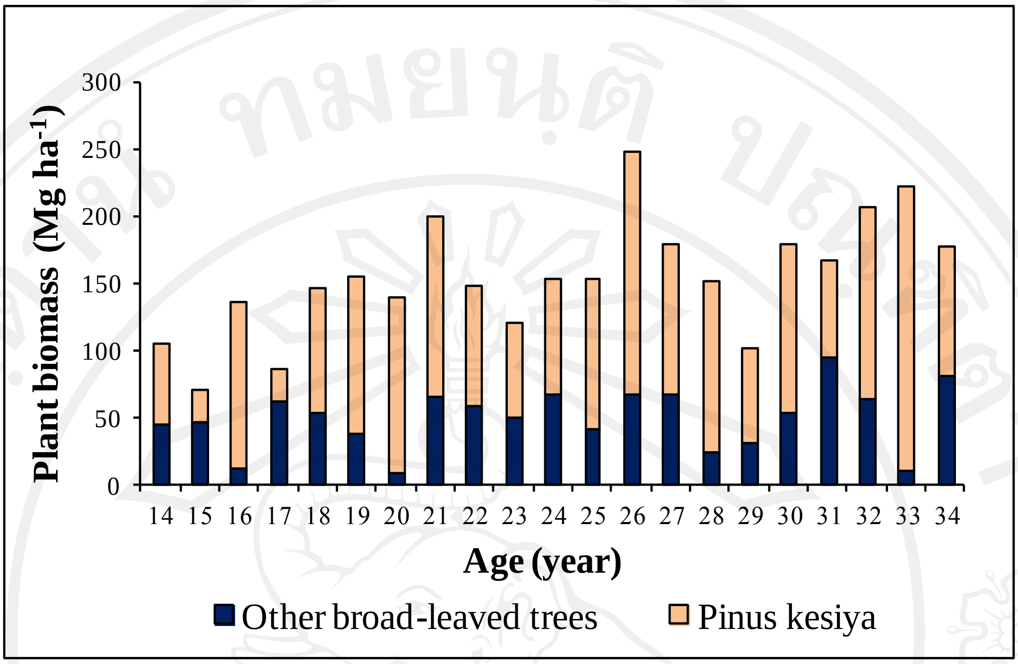


Figure 2-5 Total forest biomass in a series of pine plantations

2.4.3.2 Adjacent Fragmented Forests

The biomass amounts of these trees were calculated using the allometric equations of Tsutsumi *et al.* (1983). Biomass of tree species in fifteen adjacent fragmented forests were different, 117.3 to 253.3 Mg.ha^{-1}, the average total was 201.1 Mg.ha^{-1}. It was the highest in FF1 and the lowest in FF10. The average amounts allocated in stem, branch, leaf and root components were 130.0 Mg.ha^{-1} (64.65%), 40.5 Mg.ha^{-1} (20.14%), 3.3 Mg.ha^{-1} (1.64%) and 27.3 Mg.ha^{-1}(13.57%), respectively (Table 2-13 and Figure 2-6). The majority of biomass was stored in tree species of Fagaceae (34.23%), Pinaceae (32.90%) and Theaceae families (11.48%).

Among 103 species in fifteen adjacent fragmented forests, *P. kesiya* had the highest amount of biomass was 66.16 Mg.ha^{-1} (32.90%), followed by *C. acuminatissima* (12.76%), *S. wallichii* (7.17%), *C. diversifolia* (5.93%), *Q. brandisiana* (4.62%), *T. rufescens* (3.25%), *C.purpurea* (3.12%), *L.elegans* (2.76%), *E.spicata* (2.75%), *T.gymnanthera* (2.38%) etc. (Table 2-14).

Table 2-13 Tree biomass in adjacent fragmented forests

Site	Tree biomass (Mg.ha^{-1})				
	Stem	Branch	Leaf	Root	Total
FF1	164.2	51.7	3.9	33.5	253.3
FF2	109.2	32.5	3.4	25.0	170.0
FF3	154.1	46.9	4.3	33.7	239.0
FF4	148.5	47.4	3.3	29.5	228.7
FF5	132.3	40.9	3.5	28.2	204.8
FF6	128.6	41.3	2.8	25.3	198.0
FF7	106.0	32.9	2.8	22.4	164.1
FF8	115.5	36.4	2.8	23.7	178.4
FF9	124.6	39.6	3.0	25.3	192.4
FF10	75.6	23.3	2.1	16.3	117.3
FF11	132.6	39.7	3.9	30.0	206.3
FF12	156.4	48.3	4.1	33.3	242.1
FF13	153.7	49.3	3.5	30.5	236.9
FF14	127.4	39.0	3.4	27.5	197.4
FF15	121.4	37.7	3.0	25.4	187.5
Average	130.0	40.5	3.3	27.3	201.1
Percentage	64.65	20.14	1.64	13.57	100.00

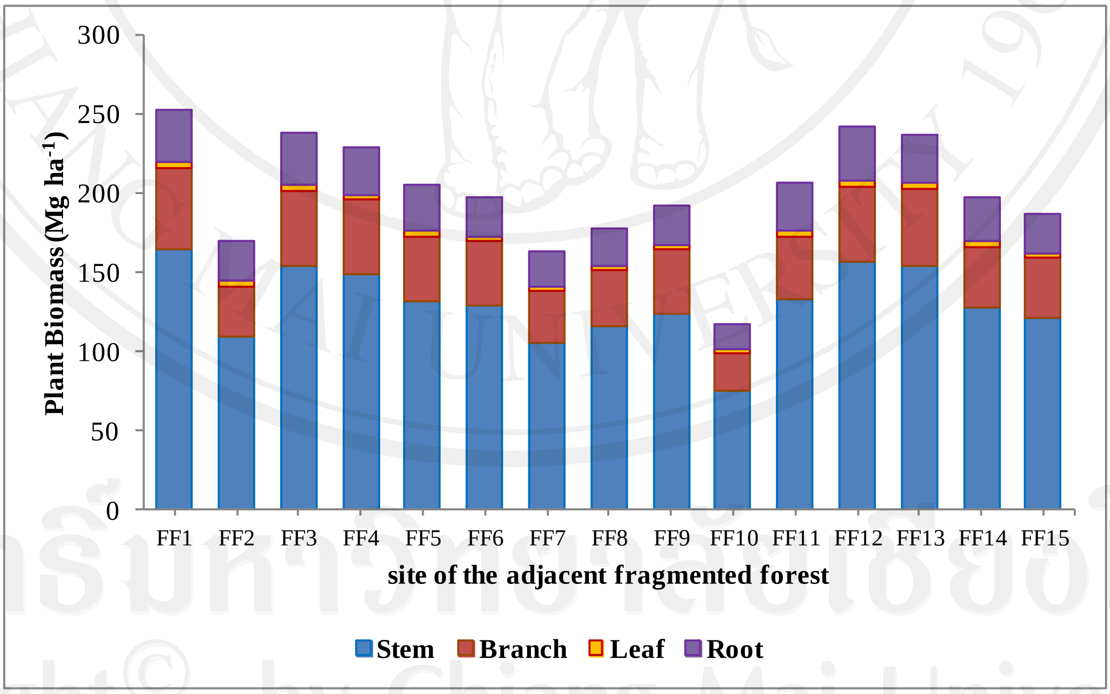


Figure 2-6 Total forest biomass in fifteen adjacent fragmented forests

2.4.3.3 Climax Montane Forest

The biomass of living tree was estimated by using allometric equation proposed by Sungpalee *et.al.* (2009). The root biomass was base on allometric equations of Tsutsumi *et al.* (1983) Table 2-15 shows the summarized data of total biomass. Total biomass of Doi Inthanon forest was calculated as 376.33 $Mg.ha^{-1}$ separated to stem, branch, leaf and root as 261.21 $Mg.ha^{-1}$ (69.41%), 49.76 $Mg.ha^{-1}$ (13.22%), 5.18 $Mg.ha^{-1}$ (1.38%) and 60.19 $Mg.ha^{-1}$ (15.99%), respectively. At the family level, nearly 21% of the total biomass were belonged to Fagaceae (77.68 $Mg.ha^{-1}$) followed by Lauraceae (14.89%), Cornaceae (12.44%), Guttiferae (8.07%), Magnoliaceae (7.74%), Nyssaceae (5.64%), Rubiaceae (8%).

They were 122 species in Doi Inthanon forest. The top five species of total aboveground biomass were *Q. eumorpha* (50.47 $Mg.ha^{-1}$), *M. euonymoides* (46.98 $Mg.ha^{-1}$), *C. polyanthum* (30.48 $Mg.ha^{-1}$), *M. garretii* (29.24 $Mg.ha^{-1}$), *N. javanica* (21.29 $Mg.ha^{-1}$), *Persea* sp. (12.59 $Mg.ha^{-1}$), *L. metcalfiana* (9.97 $Mg.ha^{-1}$), *C. densiflora* (8.69 $Mg.ha^{-1}$), *T. disperma* (7.86 $Mg.ha^{-1}$) *and Q. brevicalyx* (7.82 $Mg.ha^{-1}$), respectively.

The total biomass of Doi Inthanon forest (376.33 $Mg.ha^{-1}$) was considerable nearly the same to those of some lowland rain forests, such as Yasuni in Ecuador (282.4 $Mg.ha^{-1}$) and Palanan in Philippiness (290.1 $Mg.ha^{-1}$) and smaller than lowland rain forest in Lambir in Sarawak Malasia (497.2 $Mg.ha^{-1}$). The Doi Inthanon forest had the larger total biomass than a tropical dry evergreen forest, Huai Kha Khang in Thailand (211.2 $Mg.ha^{-1}$) (Chave *et al*., 2008).

Table 2-14 Biomass of tree species in the adjacent fragmented forests

No	Species	Biomass ($Mg.ha^{-1}$)					
		Stem	Branch	Leaf	Root	Total	%
1	*Pinus kesiya*	43.1441	14.2060	0.8112	8.0011	66.1624	32.9031
2	*Castanopsis acuminatissima*	16.6169	5.1611	0.4057	3.4651	25.6488	12.7554
3	*Schima wallichii*	9.3059	2.8451	0.2476	2.0107	14.4092	7.1658
4	*Castanopsis diversifolia*	7.7512	2.4929	0.1660	1.5166	11.9268	5.9313
5	*Quercus brandisiana*	6.0231	1.8660	0.1492	1.2626	9.3008	4.6254
6	*Tristania rufescens*	4.1532	1.1775	0.1562	1.0451	6.5320	3.2484
7	*Castanopsis purpurea*	4.0658	1.2553	0.1024	0.8589	6.2824	3.1243
8	*Lithocarpus elegans*	3.5680	1.0686	0.1043	0.8040	5.5449	2.7575
9	*Engelhardtia spicata*	3.5670	1.0838	0.0964	0.7776	5.5248	2.7475
10	*Ternstroemia gymnanthera*	3.0688	0.8965	0.0987	0.7240	4.7880	2.3811
11	*Helicia terminalis*	2.6324	0.7854	0.0793	0.5996	4.0968	2.0374
12	*Anneslea fragrans*	2.0797	0.6030	0.0683	0.4962	3.2472	1.6148
13	*Dalbergia cultrata*	1.9973	0.5970	0.0587	0.4509	3.1038	1.5436
14	*Wendlandia tinctoria*	1.9267	0.5072	0.0954	0.5554	3.0847	1.5340
15	*Quercus vestita*	1.6615	0.4842	0.0551	0.3957	2.5965	1.2912
16	*Quercus semiserrata*	1.5808	0.4978	0.0367	0.3213	2.4365	1.2117
17	*Castanopsis armata*	1.1264	0.3927	0.0161	0.1854	1.7205	0.8556
18	*Vaccinium sprengelii*	1.1091	0.2865	0.0611	0.3339	1.7906	0.8905
19	*Elaeocarpus stipularis*	1.0406	0.3455	0.0187	0.1893	1.5941	0.7928
20	*Lithocarpus fenestratus*	1.0113	0.2940	0.0326	0.2398	1.5777	0.7846
21	*Glochidion acuminatum*	0.9230	0.2779	0.0269	0.2063	1.4340	0.7131
22	*Lithocarpus polystachyus*	0.7257	0.2101	0.0241	0.1739	1.1338	0.5639
23	*Phoebe paniculata*	0.6865	0.1963	0.0242	0.1687	1.0757	0.5349
24	*Styrax benzoides*	0.6190	0.1801	0.0216	0.1496	0.9703	0.4826
25	*Phoebe cathia*	0.5986	0.1954	0.0122	0.1138	0.9200	0.4575
26	*Callicarpa arborea*	0.5925	0.1688	0.0206	0.1457	0.9276	0.4613
27	*Craibiodendron stellatum*	0.5595	0.1487	0.0272	0.1590	0.8944	0.4448
28	*Syzygium gratum*	0.5538	0.1622	0.0172	0.1292	0.8624	0.4289
29	*Helicia nilagirica*	0.4729	0.1377	0.0153	0.1120	0.7378	0.3669
30	*Buchanania lanzan*	0.4680	0.1503	0.0100	0.0914	0.7196	0.3579
31	*Engelhardtia serrata*	0.4489	0.1387	0.0111	0.0942	0.6929	0.3446
32	*Glochidion sphaerogynum*	0.3534	0.0970	0.0153	0.0949	0.5607	0.2788
33	*Eurya nitida*	0.3529	0.0965	0.0155	0.0953	0.5601	0.2786
34	*Diospyros glandulosa*	0.3501	0.0996	0.0127	0.0871	0.5494	0.2732
35	*Phyllanthus emblica*	0.3042	0.0795	0.0165	0.0904	0.4906	0.2440
36	*Eriolaena candollei*	0.2816	0.0815	0.0093	0.0674	0.4398	0.2187
37	*Lithocarpus sootepensis*	0.2583	0.0684	0.0124	0.0734	0.4125	0.2051
38	*Dillenia aurea*	0.2491	0.0697	0.0096	0.0638	0.3922	0.1950
39	*Syzygium albiflorum*	0.2307	0.0677	0.0072	0.0538	0.3594	0.1787
40	*Aporosa villosa*	0.2149	0.0562	0.0113	0.0631	0.3455	0.1718
41	*Albizia odoratissima*	0.2136	0.0613	0.0072	0.0518	0.3339	0.1660
42	*Albizia chinensis*	0.2111	0.0613	0.0068	0.0500	0.3292	0.1637
43	*Terminalia chebula*	0.2088	0.0611	0.0066	0.0489	0.3254	0.1618
44	*Bombax anceps*	0.2067	0.0611	0.0061	0.0472	0.3211	0.1597
45	*Rapanea porteriana*	0.1860	0.0510	0.0076	0.0493	0.2939	0.1461
46	*Lindera metcalfiana*	0.1700	0.0482	0.0063	0.0426	0.2670	0.1328
47	*Litsea semecarpifolia*	0.1533	0.0444	0.0049	0.0365	0.2390	0.1189
48	*Symplocos racemosa*	0.1348	0.0367	0.0057	0.0363	0.2135	0.1062
49	*Embelia subcoriacea*	0.1325	0.0400	0.0037	0.0292	0.2053	0.1021
50	*Lithocarpus lindleyanus*	0.1184	0.0358	0.0031	0.0258	0.1831	0.0910
51	*Stereospermum neuranthum*	0.1130	0.0292	0.0061	0.0338	0.1822	0.0906
52	*Gluta usitata*	0.1089	0.0328	0.0029	0.0239	0.1685	0.0838
53	*Archidendron clypearia*	0.1071	0.0305	0.0039	0.0266	0.1681	0.0836

Table 2-14 (Continued)

No	Species	Biomass (Mg.ha^{-1})					
		Stem	Branch	Leaf	Root	Total	%
54	*Litsea glutinosa*	0.1065	0.0315	0.0032	0.0244	0.1656	0.0823
55	*Betula alnoides*	0.0885	0.0252	0.0030	0.0216	0.1384	0.0688
56	*Olea salicifolia*	0.0708	0.0200	0.0026	0.0178	0.1112	0.0553
57	*Erythrina subumbrans*	0.0697	0.0197	0.0025	0.0175	0.1094	0.0544
58	*Ampelocissus martinii*	0.0688	0.0185	0.0030	0.0188	0.1091	0.0543
59	*Sarcosperma arboreum*	0.0626	0.0181	0.0021	0.0150	0.0978	0.0486
60	*Vitex pinnata*	0.0595	0.0172	0.0019	0.0141	0.0927	0.0461
61	*Magnolia henryi*	0.0546	0.0150	0.0022	0.0143	0.0861	0.0428
62	*Ilex umbellulata*	0.0485	0.0126	0.0025	0.0143	0.0779	0.0387
63	*Gardenia sootepensis*	0.0465	0.0124	0.0021	0.0129	0.0739	0.0368
64	*Kydia calycina*	0.0455	0.0129	0.0016	0.0111	0.0711	0.0353
65	*Turpinia cochinchinenssis*	0.0445	0.0114	0.0026	0.0137	0.0720	0.0358
66	*Viburnum sambucinum*	0.0427	0.0100	0.0036	0.0156	0.0719	0.0358
67	*Pyrenaria diospyricarpa*	0.0427	0.0102	0.0032	0.0149	0.0709	0.0353
68	*Quercus kingiana*	0.0356	0.0091	0.0020	0.0108	0.0575	0.0286
69	*Colona flagrocarpa*	0.0312	0.0083	0.0014	0.0087	0.0497	0.0247
70	*Milletia pachycarpa*	0.0291	0.0077	0.0014	0.0082	0.0463	0.0230
71	*Dalbergia velutina*	0.0244	0.0066	0.0010	0.0065	0.0385	0.0192
72	*Trichilla connaroides*	0.0233	0.0060	0.0013	0.0070	0.0375	0.0186
73	*Dolichandrone serrulata*	0.0227	0.0058	0.0013	0.0069	0.0367	0.0182
74	*Radermachera ignea*	0.0225	0.0061	0.0009	0.0060	0.0356	0.0177
75	*Gordonia dalglieshiana*	0.0185	0.0046	0.0012	0.0060	0.0302	0.0150
76	*Combretum punctatum*	0.0166	0.0044	0.0007	0.0046	0.0263	0.0131
77	*Syzygium cumini*	0.0158	0.0040	0.0009	0.0048	0.0255	0.0127
78	*Garuga pinnata*	0.0158	0.0039	0.0010	0.0050	0.0257	0.0128
79	*Shorea roxburghii*	0.0157	0.0042	0.0007	0.0044	0.0250	0.0125
80	*Cinnamomum iners*	0.0151	0.0040	0.0007	0.0042	0.0240	0.0119
81	*Vernonia volkameriifolia*	0.0146	0.0036	0.0009	0.0047	0.0238	0.0119
82	*Beilschmiedia gammieana*	0.0136	0.0033	0.0010	0.0046	0.0224	0.0111
83	*Saurauia roxburghii*	0.0134	0.0032	0.0010	0.0047	0.0223	0.0111
84	*Glochidion hirsutum*	0.0132	0.0031	0.0010	0.0047	0.0220	0.0109
85	*Artocarpus gomezianus*	0.0108	0.0028	0.0005	0.0032	0.0172	0.0086
86	*Pterospermum acerifolium*	0.0088	0.0021	0.0007	0.0031	0.0147	0.0073
87	*Semecarpus albescens*	0.0080	0.0017	0.0011	0.0036	0.0143	0.0071
88	*Entada rheedii*	0.0063	0.0016	0.0004	0.0020	0.0103	0.0051
89	*Schefflera bengalensis*	0.0063	0.0016	0.0004	0.0020	0.0102	0.0050
90	*Catunaregam tomentosa*	0.0042	0.0009	0.0005	0.0018	0.0074	0.0037
91	*Antidesma ghaesembilla*	0.0040	0.0009	0.0004	0.0015	0.0068	0.0034
92	*Mussaenda sanderiana*	0.0035	0.0008	0.0004	0.0014	0.0061	0.0030
93	*Rhus javanica*	0.0026	0.0005	0.0003	0.0012	0.0046	0.0023
94	*Ficus sp.*	0.0023	0.0005	0.0002	0.0008	0.0039	0.0019
95	*Canarium subulatum*	0.0016	0.0004	0.0001	0.0006	0.0027	0.0013
96	*Horsfieldia tomentosa*	0.0016	0.0004	0.0001	0.0006	0.0026	0.0013
97	*Protium serratum*	0.0010	0.0002	0.0001	0.0004	0.0017	0.0008
98	*Pavetta tomentosa*	0.0009	0.0002	0.0001	0.0004	0.0015	0.0008
99	*Celastrus paniculata*	0.0008	0.0002	0.0001	0.0003	0.0014	0.0007
100	*Melastoma malabathricum*	0.0007	0.0002	0.0001	0.0003	0.0013	0.0006
101	*Gmelina philippensis*	0.0005	0.0001	0.0001	0.0003	0.0009	0.0005
102	*Cinnamomum porrectum*	0.0004	0.0001	0.0001	0.0002	0.0008	0.0004
103	*Eurya acuminata*	0.0003	0.0001	0.0000	0.0001	0.0005	0.0003
Total		**129.99**	**40.46**	**3.31**	**27.32**	**201.08**	**100.00**

Table 2-15 Biomass of tree species in the climax montane forest

No.	Species	Biomass (Mg.ha^{-1})					
		Stem	Branch	Leaf	Root	Total	%
1	*Quercus eumorpha*	36.2987	7.0563	0.5459	6.5655	50.4664	13.4101
2	*Mastixia euonymoides*	32.8762	6.5933	0.4049	7.1077	46.9822	12.4843
3	*Calophyllum polyanthum*	21.7078	4.2603	0.3212	4.1936	30.4829	8.1000
4	*Manglietia garretii*	19.8107	3.8402	0.3103	5.2834	29.2446	7.7710
5	*Nyssa javanica*	15.0200	2.9572	0.2087	3.1134	21.2993	5.6597
6	*Persea* sp.	8.9701	1.7106	0.1651	1.7504	12.5962	3.3471
7	*Lindera metcalfiana*	6.7144	1.2330	0.1633	1.8657	9.9765	2.6510
8	*Cryptocarya densiflora*	5.8889	1.0654	0.1615	1.5761	8.6918	2.3096
9	*Tarenna disperma*	5.4655	0.9983	0.1333	1.2584	7.8555	2.0874
10	*Quercus brevicalyx*	5.6594	1.0946	0.0919	0.9704	7.8163	2.0770
11	*Chionanthus ramiflorus*	4.9538	0.9478	0.0880	0.9740	6.9635	1.8504
12	*Syzygium tetragonu*	4.1900	0.7908	0.0902	0.8617	5.9328	1.5765
13	*Drypetes* sp.	3.9851	0.7676	0.0654	0.8278	5.6459	1.5002
14	*Mallotus khasianus*	3.6545	0.6246	0.1636	1.0801	5.5227	1.4675
15	*Daphniphyllum*	3.5502	0.6471	0.0900	1.0728	5.3602	1.4243
16	*Lauraceae* sp.	3.7542	0.7506	0.0464	0.7385	5.2897	1.4056
17	*Syzygium angkae*	3.4441	0.6079	0.1122	0.8614	5.0256	1.3354
18	*Heynea trijuga*	3.3426	0.6053	0.1016	0.8466	4.8961	1.3010
19	*Symplocos macrophylla*	3.0991	0.5381	0.1156	1.0663	4.8191	1.2806
20	*Elaeocarpus lanceifolius*	3.1016	0.5801	0.0652	0.8467	4.5935	1.2206
21	*Aidia yunnanensis*	3.1140	0.5569	0.0908	0.7362	4.4979	1.1952
22	*Polyosma integrifolia*	2.8527	0.5137	0.0829	0.8520	4.3013	1.1430
23	*Acer laurinum*	2.9370	0.5469	0.0629	0.7242	4.2711	1.1349
24	*Cinnamomum bejolghota*	2.7750	0.5100	0.0681	0.7528	4.1059	1.0910
25	*Lithocarpus vestitus*	2.8626	0.5314	0.0682	0.5945	4.0567	1.0780
26	*Podocarpus neriifolius*	2.7561	0.5330	0.0429	0.6947	4.0267	1.0700
27	*Castanopsis calathiformis*	2.4112	0.4189	0.0966	0.9211	3.8478	1.0225
28	*Lithocarpus echinops*	2.6792	0.5022	0.0554	0.5696	3.8065	1.0115
29	*Cryptocarya* cf. *calcicola*	2.6248	0.4999	0.0538	0.5193	3.6977	0.9826
30	*Castanopsis purpurea*	2.5817	0.4912	0.0532	0.5704	3.6965	0.9822
31	*Litsea subcoriacea*	2.1104	0.3959	0.0454	0.4984	3.0500	0.8105
32	*Toona ciliata*	2.0715	0.3942	0.0383	0.5301	3.0342	0.8063
33	*Sarcosperma arboreum*	2.0156	0.3771	0.0405	0.5979	3.0311	0.8054
34	*Phoebe macrocarpa*	2.1132	0.4035	0.0358	0.4637	3.0162	0.8015
35	*Cordia* cf. *cochinchinensis*	2.0061	0.3932	0.0285	0.4693	2.8972	0.7698
36	*Castanopsis acuminatissima*	1.7835	0.3392	0.0322	0.3790	2.5338	0.6733
37	*Betula alnoides*	1.6874	0.3298	0.0237	0.3210	2.3619	0.6276
38	*Rapanea yunnaensis*	1.4821	0.2639	0.0471	0.3450	2.1380	0.5681
39	*Carallia brachiata*	1.4212	0.2696	0.0258	0.2830	1.9995	0.5313
40	*Camellia oleifera*	1.1884	0.2064	0.0472	0.3233	1.7653	0.4691
41	*Ostodes paniculata*	1.0652	0.1856	0.0399	0.4439	1.7346	0.4609
42	*Eurya nitida*	1.0827	0.1796	0.0583	0.3623	1.6829	0.4472
43	*Capparis* cf. *assamica*	1.1720	0.2214	0.0233	0.2512	1.6679	0.4432
44	*Diospyros glandulosa*	1.1309	0.2179	0.0177	0.2502	1.6167	0.4296
45	*Litsea yunnanensis*	0.9477	0.1680	0.0310	0.3393	1.4860	0.3949
46	*Lithocarpus aggregatus*	1.0051	0.1835	0.0255	0.2373	1.4514	0.3857
47	*Unknown*	0.9804	0.1813	0.0242	0.2525	1.4384	0.3822
48	*Drypetes indica*	0.9014	0.1577	0.0317	0.2508	1.3415	0.3565
49	*Symplocos henschelii*	0.9127	0.1729	0.0170	0.2377	1.3403	0.3562
50	*Artocarpus* cf. *lacucha*	0.8294	0.1532	0.0199	0.2603	1.2629	0.3356
51	*Neolitsea zeylanica*	0.8124	0.1512	0.0193	0.1852	1.1681	0.3104
52	*Engelhardia spicata*	0.7688	0.1456	0.0140	0.2344	1.1628	0.3090
53	*Platea latifolia*	0.7422	0.1337	0.0216	0.2573	1.1547	0.3068
54	*Elaeocarpus petiolaris*	0.7968	0.1475	0.0179	0.1911	1.1532	0.3064
55	*Litsea pedunculata*	0.6673	0.1181	0.0224	0.2174	1.0252	0.2724
56	*Ficus hirta*	0.6567	0.1206	0.0157	0.2228	1.0158	0.2699
57	*Pyrenaria garrettiana*	0.6118	0.1119	0.0153	0.1763	0.9152	0.2432
58	*Horsfieldia* sp.	0.5452	0.0978	0.0160	0.1693	0.8283	0.2201
59	*Actinodaphne* sp.	0.4030	0.0712	0.0137	0.1026	0.5905	0.1569
60	*Ilex longecaudata*	0.3551	0.0606	0.0154	0.1369	0.5680	0.1509
61	*Macaranga denticulata*	0.3123	0.0536	0.0126	0.1610	0.5394	0.1433
62	*Cinnamomum* cf. *soegengii*	0.3334	0.0584	0.0120	0.1227	0.5265	0.1399

Table 2-15 (Continued)

No.	Species	Biomass (Mg.ha^{-1})					
		Stem	Branch	Leaf	Root	Total	%
63	*Elaeocarpus braceanus*	0.3275	0.0599	0.0079	0.0948	0.4901	0.1302
64	*Euodia triphylla*	0.3127	0.0475	0.0336	0.0766	0.4704	0.1250
65	*Prunus wallichii*	0.2985	0.0510	0.0123	0.0871	0.4490	0.1193
66	*Litsea cubeba*	0.2734	0.0467	0.0113	0.0921	0.4235	0.1125
67	*Euonymus colonoides*	0.2686	0.0452	0.0121	0.0956	0.4216	0.1120
68	*Pterospermum grandiflorum*	0.2563	0.0468	0.0061	0.0680	0.3772	0.1002
69	*Prunus phaeosticta*	0.2505	0.0434	0.0100	0.0633	0.3671	0.0975
70	*Sterculia* sp.	0.2144	0.0387	0.0057	0.0594	0.3182	0.0846
71	*Gomphandra tetrandra*	0.1996	0.0341	0.0085	0.0663	0.3086	0.0820
72	*Nothapodytes* cf. *obscura*	0.1935	0.0333	0.0078	0.0624	0.2970	0.0789
73	*Psychotria symplocifolia*	0.1504	0.0226	0.0165	0.0497	0.2392	0.0636
74	*Ardisia rubro-glandulosa*	0.1521	0.0260	0.0062	0.0507	0.2350	0.0625
75	*Litsea beusekomii*	0.1352	0.0208	0.0122	0.0578	0.2260	0.0601
76	*Schoepfia fragrans*	0.1210	0.0208	0.0047	0.0430	0.1896	0.0504
77	*Litsea lancifolia*	0.0986	0.0156	0.0072	0.0504	0.1718	0.0456
78	*Beilschmiedia glauca*	0.0956	0.0160	0.0048	0.0362	0.1526	0.0406
79	*Camellia taliensis*	0.0933	0.0155	0.0051	0.0339	0.1479	0.0393
80	*Turpinia nepalensis*	0.0925	0.0158	0.0036	0.0307	0.1427	0.0379
81	*Euonymus* sp.1	0.0863	0.0145	0.0038	0.0300	0.1346	0.0358
82	*Dysoxylum* sp.1	0.0602	0.0099	0.0035	0.0232	0.0969	0.0257
83	*Lasianthus hookerii*	0.0518	0.0076	0.0065	0.0188	0.0847	0.0225
84	*Olea* cf. *salicifolia*	0.0535	0.0093	0.0019	0.0171	0.0818	0.0217
85	*Ixora* cf. *kerrii*	0.0479	0.0072	0.0055	0.0185	0.0791	0.0210
86	*Ardisia attenuata*	0.0459	0.0068	0.0056	0.0173	0.0756	0.0201
87	*Ficus* sp.1	0.0442	0.0075	0.0018	0.0150	0.0685	0.0182
88	*Lasianthus indorus*	0.0366	0.0054	0.0048	0.0131	0.0599	0.0159
89	*Psychotria densa*	0.0344	0.0049	0.0054	0.0112	0.0559	0.0149
90	*Symplocos hookeri*	0.0271	0.0042	0.0023	0.0124	0.0460	0.0122
91	*Capparis sabiaefolia*	0.0229	0.0035	0.0022	0.0103	0.0390	0.0104
92	*Litsea* cf. *membranifolia*	0.0212	0.0035	0.0012	0.0081	0.0339	0.0090
93	*Archidendron clypearia*	0.0187	0.0030	0.0011	0.0075	0.0304	0.0081
94	*Ardisia corymbifera*	0.0186	0.0026	0.0030	0.0059	0.0301	0.0080
95	*Ardisia virens*	0.0143	0.0021	0.0020	0.0065	0.0249	0.0066
96	*Dysoxylum* sp.2	0.0138	0.0021	0.0013	0.0076	0.0248	0.0066
97	*Beilschmiedia purpurascens*	0.0115	0.0019	0.0007	0.0047	0.0187	0.0050
98	*Antidesma sootepense*	0.0088	0.0013	0.0013	0.0044	0.0157	0.0042
99	*Zanthoxylum rhesta*	0.0064	0.0010	0.0005	0.0029	0.0108	0.0029
100	*Myrica esculenta*	0.0053	0.0008	0.0004	0.0024	0.0089	0.0024
101	*Meliosma* sp.	0.0040	0.0006	0.0003	0.0019	0.0069	0.0018
102	*Psychotria calocarpa*	0.0034	0.0005	0.0006	0.0015	0.0060	0.0016
103	*Debregeasia longifolia*	0.0034	0.0005	0.0003	0.0017	0.0059	0.0016
104	*Strobilanthes* aff. *mucronato-*	0.0028	0.0004	0.0005	0.0013	0.0051	0.0013
105	*Diospyros frutescens*	0.0024	0.0004	0.0002	0.0012	0.0042	0.0011
106	*Annonaceae* sp.	0.0022	0.0003	0.0003	0.0011	0.0039	0.0010
107	*Gomphostemma arbusculum*	0.0019	0.0003	0.0003	0.0009	0.0034	0.0009
108	*Daphne composita*	0.0015	0.0002	0.0002	0.0009	0.0029	0.0008
109	*Maytenus* sp.	0.0016	0.0002	0.0001	0.0008	0.0027	0.0007
110	*Lasianthus sikkimensis*	0.0010	0.0001	0.0002	0.0006	0.0020	0.0005
111	*Broussonetia kazinoki*	0.0011	0.0002	0.0001	0.0005	0.0019	0.0005
112	*Polygala arillata*	0.0009	0.0001	0.0001	0.0006	0.0018	0.0005
113	*Viburnum punctatum*	0.0009	0.0001	0.0001	0.0005	0.0017	0.0005
114	*Prunus* sp.2	0.0009	0.0001	0.0001	0.0005	0.0017	0.0004
115	*Pittosporum chatterjeeanum*	0.0008	0.0001	0.0001	0.0005	0.0015	0.0004
116	*Baliospermum micrantum*	0.0006	0.0001	0.0001	0.0004	0.0012	0.0003
117	*Miliusa* sp.	0.0002	0.0000	0.0000	0.0001	0.0004	0.0001
118	*Desmodium multiflorum*	0.0002	0.0000	0.0000	0.0001	0.0004	0.0001
119	*Lasianthus saxorum*	0.0002	0.0000	0.0000	0.0001	0.0004	0.0001
120	*Lycianthes neesiana*	0.0001	0.0000	0.0000	0.0001	0.0002	0.0001
121	*Mycetia rivicola*	0.0001	0.0000	0.0000	0.0001	0.0002	0.0000
122	*Strobilanthes* sp.1	0.0001	0.0000	0.0000	0.0001	0.0002	0.0000
Total		**261.21**	**49.75**	**5.17**	**60.18**	**376.33**	**100.00**

2.4.4 Carbon and Nutrients

2.4.4.1 Carbon and Nutrients in Pine Plantations

Total amounts of carbon and other nutrients as well as their allocation in different tree organs in 21 age-class pine plantations, at the Boakaew Watershed Management Station were shown in Table 2-16 to 2-18 and Appendix Table 2-1.

Carbon:

Carbon storages in biomass of *P. kesiya* did not increase with plantation age (Table 2-16). The amounts were highly fluctuated among 21 plantations, 12-106 $MgC.ha^{-1}$. It was the lowest in 17-year-old stand, and the highest amount was occurred in 33-year-old stand. As same as biomass many factors such as spacing of planting, tree densities, competition with succession trees and site conditions are considered as the main effects. The carbon amounts accumulated in biomass of other succession broad-leaved tree species in pine plantations were different among 21 plantations. The amounts varied from 6 to 69 $MgC.ha^{-1}$. It was the lowest in 20-year-old stand and the highest amount was observed in 31-year-old stand. The number of succession tree species in these pine plantations varied between 16-69 species. In 20-year-old stand, the number of succession tree species was low as 16 species. For 31-year old stand, the number of succession tree species was 38 species. However, the biomass carbon of succession trees was depended on their growths. The succession trees in 20-year-old stand were still small, and thus had the low biomass. In contrast, those succession trees in the 31-year-old stand were abundant and consisted of many big trees. (Table 2-17).

Same as biomass carbon in a series of 21 age-class pine plantations included stored carbon in pine trees and succession broad-leaved trees. The amounts did not increase with stand ages, and varied from 46 to 140 $MgC.ha^{-1}$. It was the lowest in 15-year-old stand, and the highest amount was observed in 26-year-old stand. The low amounts were found in plantations with altitude above 500 m msl., and those in areas between 1,314-1,453 m msl. had the high total biomass carbon. The large proportion was allocated in stem component, followed by root, branch and leaf.

Nitrogen:

The amounts of nitrogen accumulation in biomass of pine plantations varied between 370-965 $kg.ha^{-1}$. It was the highest in 26-year-old stand, and the lowest in 20-year-old stand. The fluctuations were similar for nutrients accumulated in the pine biomass and other succession broad-leaved trees were 55-490 $kg.ha^{-1}$ and 65-765 $kg.ha^{-1}$, respectively.

Phosphorus:

The amounts of phosphorus accumulation in biomass of pine plantations varied between 44-127 $kg.ha^{-1}$. It was the highest in 31-year-old stand, and the lowest in 20-year-old stand. The fluctuations were similar for nutrients accumulated in the pine biomass and other succession broad-leaved trees were 6-58 $kg.ha^{-1}$and 9-107 $kg.ha^{-1}$, respectively.

Potassium:

The amounts of potassium in accumulation in the forest biomass varied between 263-680 kg.ha^{-1}. It was the highest in 26-year-old stand, and the lowest in 20-year-old stand. The fluctuations were similar for nutrients accumulated in the pine biomass and other succession broad-leaved trees were 40-362 kg.ha^{-1}and 44-523 kg.ha^{-1}, respectively.

Calcium:

The amounts of stored calcium accumulation in the forest biomass varied between 480-1,329 kg.ha^{-1}. It was the highest in 26-year-old stand, and the lowest in 20-year-old stand. The fluctuations were similar for nutrients accumulated in the pine biomass and other succession broad-leaved trees were 70-627 kg.ha^{-1}and 94-1,113 kg.ha^{-1}, respectively.

Magnesium:

The amounts of magnesium accumulation in the forest biomass varied between 75-279 kg.ha^{-1}. It was the highest in 31-year-old stand, and the lowest in 20-year-old stand. The fluctuations were similar for nutrients accumulated in the pine biomass and other succession broad-leaved trees were 10-86 kg.ha^{-1}and 21-249 kg.ha^{-1}, respectively. The most nutrients were accumulated in the stem followed by the root, branch then leaf.

The accumulated nutrients were also varied in the same trend as carbon, nitrogen, phosphorus, potassium, calcium, and magnesium. The nutrient allocations in various organs of tree species were accumulated in the stem followed by the root, branch then leaf. Among 12-72 species of succession broad-leaved in 21 age-class pine plantation were varied. At the family level, nutrients accumulated in biomass outstandingly appeared in the families of Fagaceae, Theaceae, Myrtaceae, Leguminosae, Euphorbiaceae, Rubiaceae and Lauraceae. The major species of nutrients accumulation were observed in *C. acuminatissima*, *S. wallichii*, *C. diversifolia*, *Q. brandisiana*, *C. purpurea*, *L. elegans* and *E. spicata, G. sphaerogynum*, *W. tinctoria*, *S. albiflorum*, ect.

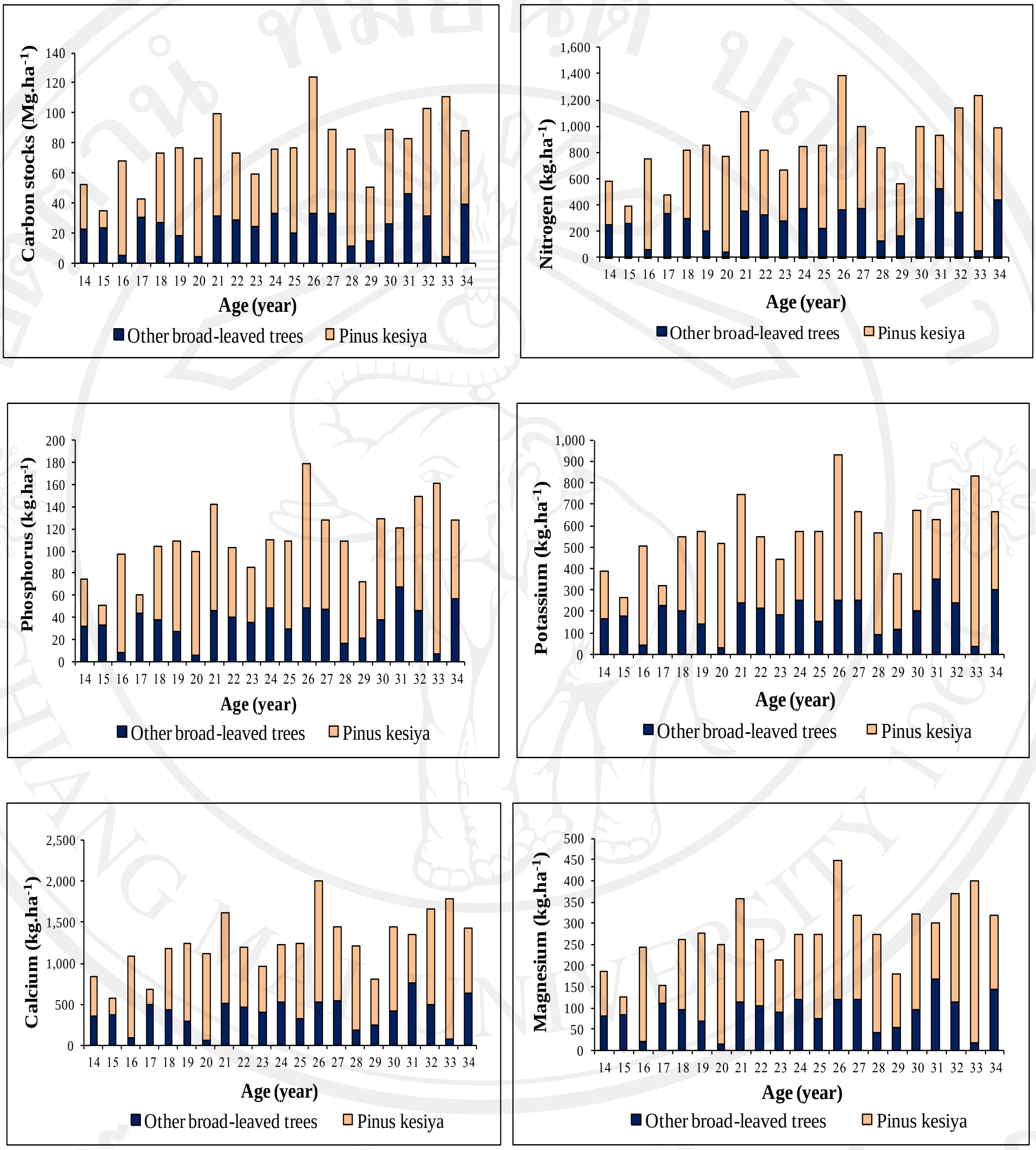


Figure 2-7 Stored biomass nutrients in a series of pine plantations

Table 2-16 Stored biomass nutrients of pine trees in a series of pine plantations

	Nutrient	Age (year)																				
		14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
1	Carbon ($Mg.ha^{-1}$)	30	12	62	12	46	58	66	68	45	35	43	56	91	56	64	35	63	37	72	106	49
	C_S	20	8	42	8	31	39	44	45	30	24	29	38	61	37	42	24	42	24	48	71	32
	C_B	3	1	7	1	5	6	7	8	5	4	5	6	11	6	8	4	8	5	9	14	6
	C_L	1	0	1	0	1	1	2	2	1	1	1	1	2	1	1	1	1	1	2	2	1
	C_R	6	2	12	2	9	12	13	13	9	7	9	11	17	11	12	7	12	7	14	20	9
2	Nitrogen ($kg.ha^{-1}$)	138	55	289	57	215	272	305	315	208	164	202	263	421	258	294	165	291	168	331	490	225
	N_S	38	15	79	15	59	74	84	86	57	45	55	72	116	71	81	45	80	46	91	134	62
	N_B	19	7	40	7	29	35	40	42	27	21	25	34	61	36	45	22	44	26	48	76	34
	N_L	18	7	37	7	28	35	39	40	27	21	26	34	54	33	38	21	37	21	42	63	29
	N_R	63	26	133	27	99	127	142	146	98	77	95	124	191	118	131	77	131	75	149	217	101
3	Phosphorus ($kg.ha^{-1}$)	16	6	33	6	25	31	35	36	24	19	23	30	49	30	35	19	34	20	39	58	26
	P_S	8	3	16	3	12	15	17	17	11	9	11	14	23	14	16	9	16	9	18	27	12
	P_B	4	2	8	1	6	7	8	9	6	4	5	7	13	8	9	5	9	5	10	16	7
	P_L	2	1	4	1	3	4	4	5	3	2	3	4	6	4	4	2	4	2	5	7	3
	P_R	2	1	5	1	4	5	5	6	4	3	4	5	7	4	5	3	5	3	6	8	4
4	Potassium ($kg.ha^{-1}$)	100	40	209	40	156	195	219	227	149	117	144	188	307	187	216	118	214	124	242	362	165
	K_S	34	14	71	14	53	67	75	78	51	40	50	65	104	64	73	41	72	42	82	121	56
	K_B	25	9	52	9	38	46	52	55	34	28	33	43	79	47	58	28	56	33	63	99	43
	K_L	9	4	19	4	14	18	20	20	13	11	13	17	27	17	19	11	19	11	21	32	15
	K_R	32	13	68	14	51	65	73	74	50	39	49	63	97	60	67	39	66	38	76	110	52
5	Calcium ($kg.ha^{-1}$)	176	70	367	72	273	344	386	399	263	207	255	332	536	328	376	208	372	215	421	627	287
	Ca_S	23	9	47	9	35	45	50	52	34	27	33	43	69	42	48	27	48	28	54	81	37
	Ca_B	44	16	90	16	66	80	90	95	60	48	57	76	138	81	101	49	98	58	109	172	76
	Ca_L	4	2	9	2	7	8	9	10	6	5	6	8	13	8	9	5	9	5	10	15	7
	Ca_R	105	43	220	44	165	211	237	243	163	127	158	205	317	197	217	127	217	124	248	360	168
6	Magnesium ($kg.ha^{-1}$)	24	10	51	10	38	48	54	55	37	29	36	46	74	45	52	29	51	30	58	86	40
	Mg_S	8	3	16	3	12	15	17	17	11	9	11	14	23	14	16	9	16	9	18	27	12
	Mg_B	3	1	7	1	5	6	7	7	4	4	4	6	10	6	7	4	7	4	8	13	6
	Mg_L	2	1	3	1	2	3	3	4	2	2	2	3	5	3	3	2	3	2	4	6	3
	Mg_R	12	5	25	5	19	24	27	28	18	14	18	23	36	22	25	14	25	14	28	41	19

Note: S = Stem, B = Branch, L = Leaf , R = Root

Table 2-17 Stored biomass nutrients of succession trees in a series of pine plantations

Nutrient		Age (year)																				
		14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
1	Carbon ($Mg.ha^{-1}$)	32	34	8	44	38	27	6	47	41	36	50	30	49	49	17	22	39	69	47	7	59
	C_S	21	22	5	29	25	17	4	30	26	23	32	19	32	32	11	14	25	45	31	4	38
	C_B	6	7	1	8	7	5	1	9	7	6	10	6	10	9	3	4	8	14	10	1	11
	C_L	1	1	0	1	1	1	0	1	1	1	1	1	1	1	0	0	1	1	1	0	1
	C_R	5	5	1	6	6	4	1	7	7	5	6	4	6	7	2	3	5	9	6	1	8
2	Nitrogen ($kg.ha^{-1}$)	361	380	89	494	430	302	65	520	465	399	546	332	544	544	191	244	431	765	513	74	649
	N_S	223	236	54	304	262	186	40	321	277	243	345	205	343	336	118	151	269	477	324	44	405
	N_B	65	71	15	90	75	54	11	96	76	70	112	62	110	99	36	45	84	147	104	13	125
	N_L	21	20	6	30	29	18	4	29	37	26	22	18	23	32	10	13	21	38	21	6	32
	N_R	52	52	13	71	65	44	10	73	75	60	66	46	68	78	26	34	57	102	64	11	87
3	Phosphorus ($kg.ha^{-1}$)	50	53	12	68	58	41	9	72	62	54	78	46	77	75	26	34	60	107	73	10	91
	P_S	34	36	8	46	40	28	6	49	42	37	52	31	52	51	18	23	41	72	49	7	61
	P_B	12	13	3	17	14	10	2	18	14	13	21	12	21	19	7	9	16	28	20	2	23
	P_L	2	2	0	2	2	1	0	2	3	2	2	2	2	3	1	1	2	3	2	0	3
	P_R	2	2	1	3	2	2	0	3	3	2	3	2	3	3	1	1	2	4	2	0	3
4	Potassium ($kg.ha^{-1}$)	246	260	60	337	292	206	44	354	314	271	375	226	373	371	130	166	295	523	352	50	444
	K_S	155	165	38	212	183	130	28	224	194	170	241	143	240	234	83	105	188	333	226	31	283
	K_B	49	54	12	68	56	41	9	73	57	53	85	47	83	75	27	34	63	111	79	10	94
	K_L	15	14	4	21	20	13	3	20	25	18	15	13	16	22	7	9	15	26	15	4	22
	K_R	27	27	7	36	33	22	5	37	38	30	34	24	34	40	13	17	29	52	32	6	44
5	Calcium ($kg.ha^{-1}$)	525	553	129	717	624	439	94	755	671	578	795	482	792	790	277	354	627	1,113	748	107	944
	Ca_S	319	338	77	436	375	266	57	461	398	348	495	294	492	481	170	216	386	685	465	64	581
	Ca_B	99	108	23	136	113	82	17	146	115	106	170	94	167	149	54	68	127	222	157	19	188
	Ca_L	20	19	6	28	27	17	4	27	35	25	21	17	21	30	10	13	20	36	20	5	30
	Ca_R	87	87	22	118	108	73	16	121	125	99	110	77	112	130	44	57	95	170	106	19	145
6	Magnesium ($kg.ha^{-1}$)	118	124	29	162	141	99	21	170	152	130	178	108	177	178	62	79	141	249	167	24	212
	Mg_S	71	76	17	97	84	60	13	103	89	78	111	66	110	108	38	48	86	153	104	14	130
	Mg_B	25	27	6	34	28	20	4	36	29	26	42	23	42	37	13	17	32	56	39	5	47
	Mg_L	12	12	3	17	16	10	2	16	21	15	12	10	13	18	6	8	12	22	12	3	18
	Mg_R	10	10	3	13	12	8	2	14	14	11	13	9	13	15	5	6	11	19	12	2	16

Note: S = Stem, B = Branch, L = Leaf , R = Root

Table 2-18 Total biomass nutrients of pine and succession trees in a series of pine plantations

Nutrient	Age (year)																				
	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
1 Carbon ($Mg.ha^{-1}$)	62	46	70	56	85	85	71	114	86	71	93	86	140	104	81	57	102	105	118	113	107
C_S	41	30	47	37	56	57	48	76	56	46	61	57	93	69	54	38	67	69	78	75	71
C_B	9	8	9	10	12	11	8	16	12	10	15	12	21	15	11	8	15	18	18	15	17
C_L	1	1	2	1	2	2	2	2	2	2	2	2	3	2	2	1	2	2	2	3	2
C_R	10	7	13	9	15	16	14	20	16	12	15	15	23	18	14	10	17	16	19	21	17
2 Nitrogen ($kg.ha^{-1}$)	500	435	378	551	646	574	370	835	673	562	747	595	965	803	485	408	722	933	844	564	875
N_S	261	251	133	319	321	260	123	408	334	288	400	277	459	407	199	196	349	524	415	179	467
N_B	85	79	56	97	104	90	51	139	102	91	138	96	172	135	80	67	128	173	153	89	158
N_L	39	28	43	37	56	53	43	69	63	47	48	52	76	65	48	35	58	59	63	68	61
N_R	115	78	146	98	165	171	152	219	173	136	162	170	258	197	157	111	188	177	213	228	188
3 Phosphorus ($kg.ha^{-1}$)	66	59	46	74	83	72	44	108	86	73	100	76	126	105	61	53	95	127	111	68	117
P_S	41	39	24	49	51	43	23	66	53	46	63	45	75	65	34	32	57	81	67	34	74
P_B	16	15	11	19	20	18	10	27	20	18	26	19	34	26	16	13	25	33	30	18	30
P_L	4	2	5	3	6	6	5	7	6	5	5	5	8	6	5	4	6	6	7	8	6
P_R	4	3	6	4	6	6	6	8	7	5	6	6	10	7	6	4	7	7	8	9	7
4 Potassium ($kg.ha^{-1}$)	346	299	270	377	448	401	263	582	463	388	519	414	680	558	346	285	508	647	594	412	609
K_S	190	178	109	226	236	197	103	302	245	210	290	208	344	298	155	146	260	375	308	152	339
K_B	74	63	64	77	94	87	60	127	92	80	118	90	162	121	85	62	120	144	141	108	137
K_L	24	18	23	24	34	30	22	40	39	29	28	30	43	39	26	20	33	37	36	35	37
K_R	59	40	74	50	84	87	77	112	88	69	82	87	131	100	80	56	96	90	108	116	96
5 Calcium ($kg.ha^{-1}$)	700	622	496	789	897	783	480	1154	934	785	1050	814	1329	1118	653	562	999	1328	1169	734	1232
Ca_S	342	347	125	445	411	311	107	513	432	375	528	337	562	524	218	243	434	712	519	144	618
Ca_B	142	124	114	152	179	161	107	241	174	154	227	169	304	230	155	117	225	280	266	191	264
Ca_L	24	21	14	30	34	26	13	37	41	30	27	25	34	38	19	18	29	41	30	20	37
Ca_R	192	130	242	162	273	285	252	364	287	226	269	282	429	326	261	184	311	294	353	379	313
6 Magnesium ($kg.ha^{-1}$)	142	134	80	172	179	147	75	225	189	159	214	155	251	223	114	108	192	279	225	110	251
Mg_S	79	79	33	101	96	74	29	120	100	87	122	80	133	122	54	57	102	162	122	41	142
Mg_B	28	28	13	35	33	26	11	43	33	30	47	29	52	43	21	21	39	60	47	18	53
Mg_L	14	12	7	17	19	13	6	20	23	17	15	13	18	21	9	9	15	23	16	9	21
Mg_R	22	15	28	18	31	32	29	41	33	26	31	32	49	37	30	21	35	33	40	43	36

Note: S = Stem, B = Branch, L = Leaf , R = Root

2.4.4.2 Stored Carbon and Nutrients in Adjacent Fragmented Forests

Total amounts of carbon and other nutrients as well as their allocation in different tree organs in fifteen adjacent fragmented forests at the Boakaew Watershed Management Station were shown in Table 2-19 and Appendix Table 2-2.

Carbon:

Total carbon storages in biomass of tree species in fifteen adjacent fragmented forests varied between 58-125 $Mg.ha^{-1}$. Same as biomass, the lowest amount was found in FF10, and it was the highest in FF1. The average amount of adjacent fragmented forests was 99.34 $Mg.ha^{-1}$. The carbon stored in pine trees was 32.69 $Mg.ha^{-1}$, and the remaining 66.65 $Mg.ha^{-1}$ stored in broad-leaved trees species. Among 102 species of broad-leaved species, *C. acuminatissima* had the highest storage, 12.67 $Mg.ha^{-1}$, and followed by *S. wallichii*, *C. diversifolia*, *Q. brandisiana*, *T. rufencens*, *C. purpurea*, *L. elegans* and *E. spicata*. The amounts in these seven tree species were 2.73-7.12 $Mg.ha^{-1}$. About 1-2 $Mg.ha^{-1}$ was allocated in leaf component, and this will be recycling to forest floor through leaf litterfall. The stored carbon in forest biomass depended on the forest condition. The good forest could accumulate the higher biomass carbon than the deteriorated forest.

Nitrogen:

The amounts of nitrogen accumulation in biomass of tree species in the fifteen adjacent fragmented forests varied between 643-1,384 $kg.ha^{-1}$. The average amount of adjacent fragmented forests was 1,100.83 $kg.ha^{-1}$. The nitrogen accumulated in pine trees was 359.26 $kg.ha^{-1}$, and the remaining 741.57 $kg.ha^{-1}$ stored in broad-leaved trees species. Among broad-leaved species, *C. acuminatissima* had the highest storage, 140.24 $kg.ha^{-1}$, and followed by *S. wallichii*, *C. diversifolia*, *Q. brandisiana*, *T. rufencens*, *C. purpurea*, *L. elegans* and *E. spicata*. The amounts in these seven tree species were 30.3-78.99 $kg.ha^{-1}$. The nitrogen amounts in leaf compartment, 33-68 $kg.ha^{-1}$ will be recycling to forest floor.

Phosphorus:

The phosphorus amounts in biomass of tree species in the fifteen adjacent fragmented forests varied between 90-195 $kg.ha^{-1}$. The average amount of adjacent fragmented forests was 154.22 $kg.ha^{-1}$. The phosphorus storage in pine trees was the highest, 51.38 $kg.ha^{-1}$, and the remaining 102.84 $kg.ha^{-1}$ were accumulated in broad-leaved species. Among the broad-leaved species, *C. acuminatissima* had the highest amount of 19.68 $kg.ha^{-1}$. The lower amounts of biomass phosphorus (4.22-19.68 $kg.ha^{-1}$) were observed for *S. wallichii*, *C. diversifolia*, *Q. brandisiana, T. rufencens*, *C. purpurea*, *L. elegans* and *E. spicata*. The recycling amounts of phosphorus through leaf litterfall were 3-6 $kg.ha^{-1}$.

Potassium:

The biomass potassium of tree species in the fifteen adjacent fragmented forests varied between 440-948 $kg.ha^{-1}$. The average amount of adjacent fragmented forests was 752.99 kg.ha^{-1}. The potassium stored in pine trees was the highest, 246.98 kg.ha^{-1}. The remaining amount of 506.01 kg.ha^{-1} was accumulated in broad-leaved species. Among these broad-leaved species, *C. acuminatissima* could store the highest amount, 95.95 kg.ha^{-1}. The trees having the lower amounts (20.69-53.96 kg.ha^{-1}) were *S. wallichii*, *C. diversifolia*, *Q. brandisiana*, *T. rufencens*, *C. purpurea*, *L. elegans* and *E. spicata*. The potassium amounts in leaf compartment (30-47 kg.ha^{-1}) will be recycling to forest floor

Calcium:

The biomass calcium amounts of tree species in the fifteen adjacent fragmented forests varied between 935-2,015 kg.ha^{-1}. The average amount of adjacent fragmented forests was 1,601.69 kg.ha^{-1}. The calcium accumulated in pine trees was the highest, 524.12 kg.ha^{-1}. The remaining amount of 1,077.57 kg.ha^{-1} was accumulated in broad-leaved species, and *C. acuminatissima* could accumulate the highest amount, 402.16 kg.ha^{-1}. The trees having the lower amounts (44.07-114.89 kg.ha^{-1}) were *S. wallichii*, *C. diversifolia*, *Q. brandisiana*, *T. rufencens*, *C. purpurea*, *L. elegans* and *E. spicata*. The calcium amounts of 31-64 kg.ha^{-1} in leaf compartment will be recycling to the forest floor

Magnesium:

The magnesium amounts in biomass of tree species in the fifteen adjacent fragmented forests varied between 210-451 kg.ha^{-1}. The average amount of adjacent fragmented forests was 359.02 kg.ha^{-1}. The magnesium storage in pine trees was the highest, 117.06 kg.ha^{-1}. The remaining 241.96 kg.ha^{-1} was stored in broad-leaved species, and *C. acuminatissima* had the highest amount, 45.69 kg.ha^{-1}. The trees having the lower amounts (9.88-25.75 kg.ha^{-1}) were *S. wallichii*, *C. diversifolia*, *Q. brandisiana*, *T. rufencens*, *C. purpurea*, *L. elegans* and *E. spicata*. The magnesium amounts of 18-38 kg.ha^{-1} in leaf component will be recycling to the soil.

Some amounts of carbon and other nutrients in stem and branch compartments of tree species might be recycling to the forest floor and soil as above-ground litterfall. Some amounts of dead root of tree species were contributed to their recycling into soil as below-ground litterfall.

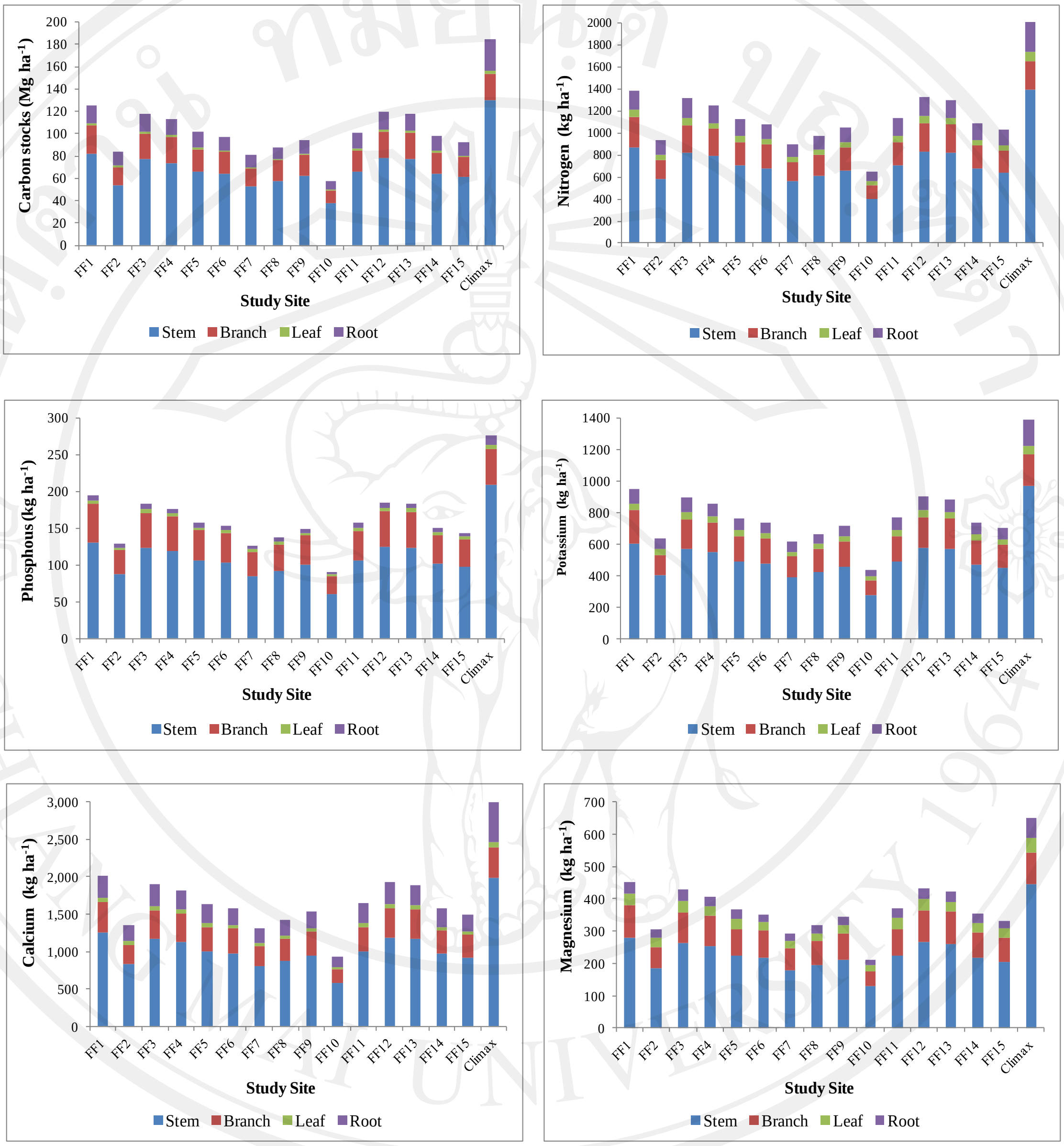


Figure 2-8 Stored biomass nutrients in fifteen adjacent fragmented forest and the climax montane forest

Table 2-19 Variations of stored carbon and nutrients in biomass of tree species in fifteen adjacent fragmented forests and the climax montane forest

	Nutrient	Adjacent fragmented forests																Climax montane forest
		FF1	FF2	FF3	FF4	FF5	FF6	FF7	FF8	FF9	FF10	FF11	FF12	FF13	FF14	FF15	Average	
1	Carbon (Mg.ha^{-1})	**125**	**84**	**118**	**113**	**101**	**98**	**81**	**88**	**95**	**58**	**102**	**120**	**117**	**98**	**93**	**99.34**	**186.80**
	C_S	82	54	77	74	66	64	53	58	62	38	66	78	77	64	61	64.87	130.83
	C_B	25	16	23	23	20	20	16	18	19	11	19	24	24	19	18	19.70	24.32
	C_L	2	2	2	2	2	1	1	1	1	1	2	2	2	2	1	1.60	2.51
	C_R	16	12	16	14	14	12	11	11	12	8	14	16	15	13	12	13.17	29.13
2	Nitrogen (kg.ha^{-1})	**1,384**	**937**	**1,312**	**1,247**	**1,122**	**1,079**	**899**	**975**	**1,051**	**643**	**1,135**	**1,326**	**1,293**	**1,083**	**1,026**	**1,100.83**	**2,057.32**
	N_S	870	579	817	787	701	681	562	612	660	401	703	829	815	675	643	688.97	1,389.59
	N_B	274	172	248	251	217	219	174	193	210	124	210	256	261	207	200	214.44	264.68
	N_L	62	53	68	53	55	45	44	45	47	33	63	65	55	55	48	52.63	82.72
	N_R	178	133	179	157	149	134	119	126	134	86	159	177	162	146	135	144.79	320.33
3	Phosphorus (kg.ha^{-1})	**195**	**129**	**182**	**176**	**157**	**153**	**126**	**137**	**148**	**90**	**157**	**185**	**183**	**151**	**144**	**154.22**	**278.54**
	P_S	131	87	123	119	106	103	85	92	100	61	106	125	123	102	97	103.99	209.75
	P_B	52	33	47	47	41	41	33	36	40	23	40	48	49	39	38	40.46	49.94
	P_L	5	4	6	4	4	4	4	4	4	3	5	5	5	4	4	4.30	6.76
	P_R	7	5	7	6	6	5	4	5	5	3	6	7	6	6	5	5.46	12.09
4	Potassium (kg.ha^{-1})	**948**	**638**	**896**	**855**	**767**	**740**	**615**	**668**	**720**	**440**	**774**	**907**	**886**	**740**	**702**	**752.99**	**1,390.26**
	K_S	608	404	570	549	489	476	392	427	461	280	491	579	569	471	449	480.98	970.09
	K_B	207	130	188	190	164	165	132	145	158	93	159	193	197	156	151	161.84	199.76
	K_L	43	37	47	37	38	31	30	31	33	23	43	45	38	38	33	36.41	57.23
	K_R	91	68	91	80	76	68	61	64	68	44	81	90	82	74	69	73.76	163.18
5	Calcium (kg.ha^{-1})	**2,015**	**1,360**	**1,907**	**1,817**	**1,632**	**1,573**	**1,308**	**1,419**	**1,531**	**935**	**1,649**	**1,930**	**1,883**	**1,574**	**1,493**	**1,601.69**	**3,002.04**
	Ca_S	1,248	830	1,171	1,128	1,005	977	806	878	947	575	1,008	1,189	1,168	968	922	987.95	1,992.62
	Ca_B	414	260	375	379	327	331	263	291	317	187	318	387	394	312	301	323.68	399.52
	Ca_L	58	50	64	50	52	42	41	42	45	31	59	61	52	52	45	49.65	78.04
	Ca_R	295	220	297	260	248	223	197	209	223	143	264	293	269	242	224	240.41	531.86
6	Magnesium (kg.ha^{-1})	**451**	**306**	**428**	**407**	**366**	**352**	**293**	**318**	**343**	**210**	**370**	**433**	**422**	**353**	**334**	**359.02**	**652.86**
	Mg_S	279	186	262	252	225	219	180	196	212	129	225	266	261	217	206	220.99	445.72
	Mg_B	103	65	94	95	82	83	66	73	79	47	79	97	99	78	75	80.92	99.88
	Mg_L	35	30	38	30	31	25	25	25	27	18	36	37	31	31	27	29.79	46.82
	Mg_R	34	25	34	30	28	25	22	24	25	16	30	33	31	28	25	27.32	60.44

Note: S = Stem, B = Branch, L = Leaf , R = Root

2.4.4.3 Stored Carbon and Nutrients in Climax Montane Forest

Total amounts of carbon and other nutrients in the forest at Doi Inthanon natural park were shown in Table 2-19 and Appendix Table 2-3.

Carbon:

Carbon stock in biomass of tree species in the forest was 186.80 Mg.ha^{-1}. apportion to stem, branch, leaf and root as 130.83, 24.32, 2.51 and 29.13 Mg.ha^{-1}, respectively.At the family level, carbon stock in biomass outstandingly appeared in the family of Fagaceae followed by Lauraceae, Cornaceae, Guttiferae, Magnoliaceae, Nyssaceae, and Rubiaceae 38.43, 27.81, 23.24, 15.08, 14.45, 10.54 and 7.80 Mg.ha^{-1}, respectively. They were of 122 species in Doi Inthanon forest The top five species in carbon stock in biomass were *Q. eumorpha* (24.98 Mg.ha^{-1}), *M. euonymoides* (23.24 Mg.ha^{-1}), *C. polyanthum* (15.08 Mg.ha^{-1}), *M. garretii* (14.45 Mg.ha^{-1}), *N. javanica* (10.54 Mg.ha^{-1}), respectively.

The different forest types have variable potentials of carbon storages in biomass. (Ogawa *et al.*, 1965; Negi *et.al*., 2003). Aboveground biomass carbon stocks at Kaeng Krachan National Park, Pectchaburi province in evergreen, mixed deciduous and dry evergreen forests were in the order of 129, 93.2 and 37.1 Mg.ha^{-1}. The carbon storages in aboveground biomass of lower montane forest (125.2 Mg.ha^{-1}) (Nongnuang *et al*., 2010), and the same forest at Mt. Doi Inthanon, Chiang Mai (246.0 Mg.ha^{-1}) (Khamyong *et al*., 2008).

Nitrogen:

The amounts of nitrogen accumulation in biomass of tree species in the forest was 2,057.32 kg.ha^{-1}. *Q. eumorpha* had the highest storage, 273.26 kg.ha^{-1}, followed by *M. euonymoides* (253.30 kg.ha^{-1}), *C. polyanthum* (164.96 kg.ha^{-1}), *M. garretii* (158.29 kg.ha^{-1}), and *N. javanica* (115.10 kg.ha^{-1}).

Phosphorus:

The phosphorus amounts in biomass of tree species in the forest was 278.54 kg.ha^{-1}. *Q. eumorpha* had the highest storage, 38.12 kg.ha^{-1}, followed by *M. euonymoides* (34.84 kg.ha^{-1}), *C. polyanthum* (22.88 kg.ha^{-1}), *M. garretii* (21.15 kg.ha^{-1}), and *N. javanica* (15.87 kg.ha^{-1})

Potassium:

The biomass potassium of tree species in the forest was 1,390.26 kg.ha^{-1}. *Q. eumorpha* had the highest storage, 186.26 kg.ha^{-1}, followed by *M. euonymoides* (171.66 kg.ha^{-1}), *C. polyanthum* (112.22 kg.ha^{-1}), *M. garretii* (106.34 kg.ha^{-1}), and *N. javanica* (78.10 kg.ha^{-1})

Calcium:

The biomass calcium amounts of tree species in the forest was 3,002.04 kg.ha^{-1}. *Q. eumorpha* had the highest storage, 398.29 kg.ha^{-1}, followed by

M. euonymoides (371.23 kg.ha^{-1}), *C. polyanthum* (240.78 kg.ha^{-1}), *M. garretii* (232.43 kg.ha^{-1}), and *N. javanica* (168.34 kg.ha^{-1})

Magnesium:

The magnesium amounts in biomass of tree species in the forest was 652.86 kg.ha^{-1}. *Q. eumorpha* had the highest storage, 87.30 kg.ha^{-1}, followed by *M. euonymoides* (79.83 kg.ha^{-1}), *C. polyanthum* (52.51 kg.ha^{-1}), *M. garretii* (49.43 kg.ha^{-1}), and *N. javanica* (36.44 kg.ha^{-1})

The different forest types had variable potentials of nutrient storages in aboveground biomass. In the moist evergreen forest at Khao Khitchakut national park, amount of N, P, K, Ca and Mg were 1,618.09, 85.39, 679.80, 2,064.13, and 318.83 kg.ha^{-1}, respectively. Where as those in the dry evergreen forest at Khao Soi Dao Wildlife Sanctuary, Chanthaburi province were in the order of 1,500.40, 124.92, 690.29, 3,611.40, and 480.85 kg.ha^{-1}. (Glumphabutr *et al*., 2007)

2.5 Discussion

The pine growths in a series of *P. kesiya* plantations were did not increase with stand age because of great variations of site factors and other causes. The plantation areas covered area of 2,285 ha with different altitude, 1,202-1,655 m msl. The growths were fast in 14-15 year-old stands and slow for 21 to 25 year-old. The 14-15 year-old plantations were located on mesic sites in lower areas whereas those stands of 21 to 25 year-old were xeric sites on the higher altitude. The site factor particularly soil fertility affected on tree growths in the plantation forest (Bowen and Nambiar, 1989). Soil moisture condition was one important limiting factor on pine growth. Dry season soil moisture supply was a relevant soil parameter for *P. kesiya* performance, as it sustains dry season diameter and height growth (Armitage and Burley, 1980) and forest fire was also important (Fisher and Binkley, 2000). These factors affected their growths and biomass allocation.

Annual volume increment of *P. kesiya* at Boakaew Watershed Management Station was 5.48 m^{3}ha^{-1}yr^{-1}. It was higher than plantations in the area of pine-dry dipterocarp forest at Boa Luang Plantation (3.44 m^{3}ha^{-1}yr^{-1})(Khamyong, 2001). The pine plantations in this area was located in area of pine-montane forest which has more cool weather and site moisture which were favorable for pine growth. Pine plantation in highland watershed areas of pine-dry dipterocarp and pine-montane forests might result in different pine growths. The pine-dry dipterocarp forest normally has very poor soil, lower moisture condition and annual forest fire whereas more fertile soil, higher moisture condition and occasionally fire is characteristics of pine-montane forest. Yield increment of general *P. kesiya* plantations were in range of 3-4 m^{3}ha^{-1}yr^{-1}, whereas the intensive management could increase stem volume to 6-9 m^{3}ha^{-1}yr^{-1} (Pousujja, 1984).

The natural regeneration was occured in every age-class of plantations. The pioneer species show their highest levels of germination in large gaps and seedlings may grow very rapidly in full light (Raich and Gong, 1990; Kennedy and Swaine, 1992) whereas the climax species did not germinate or establish well in the large gaps (Howe *et al.*, 1985; Turner, 1990), and were poorly dispersed (Burgess, 1970). As the succession begins, the pioneer colonization of annual plant species which had short life spans (one growing season) occurred in the gaps. The plants which had the high densities included *Curcuma sessilis*, *Ageratina adenophora* and *Amorphophallus sp.*, whereas those of woody species were *Vaccinium sprengelii*, *Q. brandisiana* and *Glochidion hirsutum*. The tree species which had light seed and produced a lot of seeds could establish well in full sunlight such as *V. sprengelii*, *Tristania rufescens*, *Craibiodendron stellatum*, *Leea guineensis*, *Wendlandia tinctoria*, *Rhus javanica*, *P. kesiya*, etc. The oak species, *Q. brandisiana* had the good succession in some the adjacent fragmented forests of dry site whereas the other oaks (Fagaceae) had the poor succession. The succession tree species were mainly in the families of Fagaceae, Euphorbiaceae, Juglandaceae, Lauraceae, and Myrtaceae which are almost the climax species in pine-montane forest. Therefore, the recovery process of forest plantations to be the climax montane forest may needs a long period of times, many decades or hundred years. The fact that plantations of fast-growing species could help to jump start the regeneration of natural species had been exploited in the tropics in programs to restore natural forests (Fisher, 1995).

The biomass of pine in 14- to 34-year-old plantations did not increase with stand age. The data were different from Miller (1989) who reports that biomass in stem, branch and foliages of *Pinus nigra* was increased with stand ages during 20 years after planting. However, the succession tree species had the important role on biomass stocks in pine plantations. These tree species were in the families of Fagaceae, Theaceae, Myrtaceae, Leguminosae, Euphorbiaceae, Rubiaceae and Lauraceae.

The storages of carbon and nutrients in tree biomass in a series of pine plantations depended on biomass allocation in pine trees and succession tree species. The stored carbon and nutrients in pine biomass of 14- to 34-year-old plantations did not increase with stand ages. As same to the biomass, many factors including densities of pine and succession trees, site factors and forest fire were influenced on pine growths in this study. These factors affected tree growths, and allocation of carbon and nutrients. The rate of nutrient accumulations by the plantation is a function of the rate of growth, development stage and the availability of soil nutrients and water. The nutrient cycling involving recycling through litterfall, storage and litter decomposition in forest floor, nutrient availability and storage in soil, plant uptake and accumulation in tree biomass will be altered during stand development (Miller, 1989). The succession tree species in different age pine plantations had the variable contribution to plantation carbon and nutrient storages. The carbon amount was in range of 6-69 Mg.ha^{-1}, whereas those of nitrogen, phosphorus, potassium, calcium and magnesium were in the order of 65-765, 9-107, 44-523, 94-1,113 and 21-249 kg.ha^{-1}. Therefore, the natural succession in *Pinus kesiya* plantations is very important for increasing biomass carbon and nutrient stocks.

Comparisons of nutrient availability in the adjacent fragmented forest and the climax montain forests that carbon and nutrients storages in biomass of tree species at Doi Inthanon was most abundant compared to the adjacent fragmented forest. The tropical montane forests were often sufficiently supplied with N and P relative to lowland forests (Vitousek and Sanford 1986 and Tanner *et al.*, 1998).