CHAPTER 5

Conclusions and Recommendations

5.1 Conclusions

The research objectives of this study were to evaluate the biological production, in terms of wood production as direct benefit, and carbon and nutrient storages as indirect benefits of forest plantation ecosystems in a series of *Pinus kesiya* plantations in highland watershed and adjacent fragmented forests at Boakaew Watershed Management Station, Chiang Mai province; and evaluated economic value of forest ecosystem in three part, such as value of wood production, value of carbon and nutrient storages (in plant, forest floor and soil). Finally, to make comparison of economic values between forest plantation ecosystems and adjacent fragmented forests as well as climax montane forest on highland. The summarized of these results were below.

5.1.1 Plant Communities, Wood Production, Biomass Carbon and Nutrient Storages

(1) *Pinus kesiya* Plantations

Tree species succession in pine plantations were mainly Fagaceae, e.g. *C. diversifolia, C. acuminatissima, C. purpurea, Q. brandisiana, Q. vestita,* etc.; additionally, including *S. wallichii*, *Ternstroemia gymnanthera, Anneslea fragrans and Elaeocarpus sphaericus*, etc. The number of tree succession species was different among 21 age class pine plantations, 17-72 species. Tree density of total pine plantations were varied, 540-2,688 trees ha^{-1} which were separated to be 75-429 trees ha^{-1} of *P. kesiya* and 131-2,331 trees ha^{-1} of other broad-leaved trees. The importance value index (IVI) of *P. kesiya* in plantations varied range from 10.65-60.09%. Shannon-Wiener Index (SWI) varied range from 1.57-4.65. The growth of succession trees were range from 11.56-17.50 m, height and 14.67-27.33 cm, dbh. The annual height and dbh increment of succession trees were range from 0.37-0.88 m.yr^{-1} and 0.66-1.58 cm.yr^{-1}.

Growth of *P. kesiya* in 14-34 year-old of 21 age classes pine plantations varied from 15.31-23.30 m, height and 24.24-35.37 cm, dbh. The mean annual height increment was 0.82 m.yr^{-1} and the mean annual diameter at breast height increment was 1.28 cm.yr^{-1}. The total volume of *P. kesiya* plantations were range from 32.73-337.10 m^3 ha^{-1}, and the timber volume of *P. kesiya* were range from 19.93-200.62 m^3 ha^{-1}.

Pine biomass in different age-class plantations did not increase continuously with stand ages. The values were 23.6 to 212.7 Mg.ha^{-1}. The majority of pine biomass was allocated in the stem component, followed by root, branch and leaf. Succession tree biomass in pine plantations were varied from 8.1 to 94.1 Mg.ha^{-1}.

Their biomass contributed to 4.2 to 71.7% of total plantation biomass. The total tree biomass in a series of 21 age-class pine plantations were varied between 70.5 to 248.2 Mg.ha^{-1}, and did not increase continuously with stand ages. Carbon storages in biomass of *Pinus kesiya* were 12 to106 MgC ha^{-1} and other succession broad-leaved tree species in pine plantations were varied from 6 to 69 MgC.ha^{-1}. The total biomass carbon in a series of 21 age-class pine plantations varied from 46 to 140 MgC ha^{-1}.

In the stored nutrients were found nitrogen; 370-965 kg.ha^{-1} (pine; 55-490 kg.ha^{-1}, succession trees; 65-765 kg.ha^{-1}), phosphorus; 44-127 kg.ha^{-1} (pine; 6-58 kg.ha^{-1}, other trees; 263-680 kg.ha^{-1}), potassium; 9-107 kg.ha^{-1} (pine; 40-362 kg.ha^{-1}, other trees; 44-523 kg.ha^{-1}), calcium; 480-1,329 kg.ha^{-1} (pine; 70-627 kg.ha^{-1}, other trees; 94-1,113 kg.ha^{-1}), and magnesium; 75-279 kg.ha^{-1} (pine; 10-86 kg.ha^{-1}, other trees; 21-249 kg.ha^{-1}).

(2) Adjacent Fragmented Forests

The species richness in fifteen adjacent fragmented forests was 103 species, 82 genus and 44 families which varied from 16-42 species (13-35 genus and 10-24 families). The dominant families were Fagaceae (13 species), Leguminosae (8), Lauraceae (8), Euphorbiaceae (7), Rubiaceae (6), and Theaceae (6). The major dominant tree species were *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.; and the small trees were *T. rufescens*, *W. tinctoria*, and *V. sprengelii*. The indexes of species diversity in these forests calculated by the Shannon-Wiener Index (SWI) were 3.01-4.65, and 5.28 for the whole adjacent fragmented forests. Five tree species had the frequency over than 80% of all trees in fifteen adjacent fragmented forests. There were *W. tinctoria*, *P. kesiya*, *G. sphaerogynum*, *C. acuminatissima* and *S. wallichii*. The average density for tree species in the whole adjacent fragmented forests was 1,166 trees ha^{-1}. 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). They were low in the area of 1,230-1,260 m, and high between 1,300-1,560 m. The total stem basal area of all tree species in the forests varied between 17.46-36.58 m^{2} ha^{-1}. *P. kesiya* had the highest IVI 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. Their total volumes were in range of 36.19-78.42 m^{3} ha^{-1}, and the timber log volume were 22.23.-51.04 m^{3} ha^{-1}.

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}. The average amounts derived from 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. The majority of biomass was stored in tree species of Fagaceae (34.23%), Pinaceae (32.90%) and Theaceae families (11.48%). Total carbon storages in biomass of tree species were varied between 58-125 MgC.ha^{-1}. The average amount of adjacent fragmented forests was 99.34 Mg.ha^{-1}. The carbon stored in pine trees was 32.69 MgC.ha^{-1}, and the remaining 66.64 MgC.ha^{-1} stored in broad-leaved trees species.

The storages of other nutrients were different: nitrogen; 643-1,384 kg.ha^{-1}, phosphorus; 90-195 kg.ha^{-1}, potassium; 440-948 kg.ha^{-1}, calcium; 935-1,883 kg.ha^{-1}, and magnesium; 210-451 kg.ha^{-1}.

(3) Climax Montane Forest

Tree species in climax montane forest at Doi Inthanon National Park was 122 species, 112 genera and 49 families in a 5-ha permanent plot. Dominant tree species were mainly *Mastixia euonymoides* (11.74%), *Quercus 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^{-1}. Species diversity index was 5.72, based on the Shannon-Wiener index (SWI). The average total volumes in a climax montane forest was 94.81 m^{3}ha^{-1}, and the timber log volume was 48.69 m^{3}ha^{-1}

Total biomass of Doi Inthanon forest was 376.33 Mg ha^{-1} allocated 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 belong to Fagaceae (77.68 Mg ha^{-1}) followed by Lauraceae (14.89%), Cornaceae (12.44%), Guttiferae (8.07%), Magnoliaceae (7.74%), Nyssaceae (5.64%), Rubiaceae8%), respectively. Total carbon storages in biomass of tree species at Doi Inthanon was 186 MgC ha^{-1}. 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 MgC. ha^{-1}, respectively.

The storages of nutrients such as nitrogen, phosphorus, potassium, calcium , and magnesium were 2,057.32; 278.54; 1390.26; 3,002.04 and 652.86 kg.ha^{-1}, respectively.

5.1.2 Soil Properties and Carbon-Nutrient Storages in Plant, Forest Floor and Soils

(1) *Pinus kesiya* Plantations

Bulk density was decreased with plantation ages classes. It had low/very low bulk densities in the top soils and increased with soil depth. Bulk densities of the surface soils (0-10 cm) were 0.74-1.11 Mg.m^{-3}. The amounts of gravel quite tend to be decreased except 17 year-old pine plantation had the lowest amounts of gravel.

The percentages of sand in soil profiles varied from 33.6-79.6%. They were rather high in top soils and decreased in subsoils. Silt particles in soil profiles varied from 10.6-31.8%, whereas the clay varied from 5.8-46.4%. The highest sand particles were found on the top soil at 33 year-old of pine plantations but silt and clay were found the lowest. Furthermore, silt and clay particles were found the highest along soil profiles at 21 year-old.

The surface soils of almost pine plantations age-classed samplings were sandy loam except at 21 year-old was sandy clay loam. The clay particles were rather high in this age-classed more than other so it was shown the higher bulk density because of clay content and lower organic content.

Soil pH of total age-classes samplings of pine plantations varied between moderately acid to very strongly acid. pH values tend to be increased over stand age. This tendency was the same for total nitrogen, available phosphorus, calcium and magnesium. In the surface soil layer, the contents of organic matter, carbon and total nitrogen of total age classed had rather moderately high to very high as 27.8-115.1, 16.1-73.5 and 2.0-8.3 g.kg^{-1}; and phosphorus available, extractable calcium and magnesium tend to be high as 3.5-25.6, 73.4-1,714.6 and 62.0-259.5 mg.kg^{-1}. Cation exchange capacity had 17.4-36.6 cmol.kg^{-1}. The percent base saturations in the top soil depth (0-10 cm) of total age classed samplings tend to be higher over stand age. Fertility assessments in the surface soil depth (0-10 cm) of total age-classed samplings of *Pinus kesiya* plantations tend to be medium and higher over stand age except at 17 year-old was high, and they were decreased with soil depth.

Stored carbon amounts in biomass of tree species in total age classed samplings pine plantations were different, 46-140 Mg.ha^{-1}, separated to 12-106 Mg.ha^{-1} in pine trees and 6-69 Mg.ha^{-1} in succession trees. The amounts did not increase continuously with stand ages. Similar to other nutrients, differences in the stored nutrients were found: nitrogen; 370-965 kg.ha^{-1} (pine: 55-490 kg.ha^{-1} for pine, succession trees: 65-765 kg.ha^{-1}), phosphorus; 44-127 kg.ha^{-1} (pine: 6-58 kg.ha^{-1}, other trees: 263-680 kg.ha^{-1}), potassium; 9-107 kg.ha^{-1} (pine: 40-362 kg.ha^{-1}, other trees: 44-523 kg.ha^{-1}), calcium; 480-1,329 kg.ha^{-1} (pine: 70-627 kg.ha^{-1}, other trees: 94-1,113 kg.ha^{-1}), and magnesium; 75-279 kg.ha^{-1} (pine: 10-86 kg.ha^{-1}, other trees: 21-249 kg.ha^{-1}). The carbon and nutrients were stored mainly in tree species in the families of Fagaceae, Theaceae, Myrtaceae, Leguminosae, Euphorbiaceae, Rubiaceae and Lauraceae.

The dry matters of forest floor varied between 4,122-8,379 kg.ha^{-1}. Stored carbon in organic layers varied between 16.68-31.51 MgC.ha^{-1}, and mainly in pine needles. The amounts of nutrients were different: nitrogen; 28,955-69,893 kg.ha^{-1}, phosphorus; 224-461 kg.ha^{-1}, potassium; 2,123-7,733 kg.ha^{-1}, calcium; 2,321-5,695 kg.ha^{-1}, and magnesium; 425-947 kg.ha^{-1}.

Amounts of organic matter and carbon in 0-160 cm depth soils under plantations varied between 138.65-306.30 Mg.ha^{-1}and 80.43-276.46 MgC.ha^{-1}, respectively. The different amounts were found for nitrogen (10,145-18,935 kg.ha^{-1}), phosphorus (27.78-84.98 kg.ha^{-1}), potassium (4,828-6,021 kg.ha^{-1}), calcium (423-8,198 kg.ha^{-1}), magnesium (353-1,211 kg.ha^{-1}), and sodium (619-694 kg.ha^{-1}).

(2) Adjacent Fragmented Forests

The soils in adjacent fragmented forests were classified in Order Ultisols, Suborder Humults. Soil depths were more than 200 cm with 10-15 cm thickness of organic layers. The soil profiles were developed as A-Bt-BC with high clay content in subsoils. Bulk density had low to very low in the surface soils and increased with soil depth. The surface soils (A horizon) of total adjacent fragmented forests had very low densities of 0.70-0.97 Mg.m^{-3}. The 11th adjacent fragmented forest had the highest amounts of gravel on the upper horizon suggesting less lower soil horizon development process than other adjacent fragmented forests.

The percentages of sand in soil profiles varied from 26.5-75.0%. Silt particles in soil profiles varied from 7.7-37.7%, whereas the clay varied from 9.7-56.1%. The 13th and 14th adjacent fragmented forest had the highest sand particles, whereas the 11th adjacent fragmented forest had the highest clay particles. The surface soils of almost adjacent fragmented forests were sandy loam whereas subsoils were sandy clay loam, loam and clay loam. The 11th adjacent fragmented forest had sandy clay loam in top soil and clay to clay loam in subsoil.

Soil pH of most adjacent fragmented forests were strongly acid except the 3rd adjacent fragmented forest was slightly acid in top soil and moderately acid to very strongly acid in subsoil. The contents of organic matter, carbon and nitrogen in the surface soil depth of total adjacent fragmented forests had rather high as 60.9-129.6, 35.3-75.2 and 2.5-6.9 $g.kg^{-1}$. There were decreased with soil depth. The phosphorus available contents, the extractable potassium, calcium, magnesium and sodium were 12.2-22.0; 298.4-745.5; 425.9-1,572.7; 89.9-357.5 and 19.9-26.0 $mg.kg^{-1}$. Cation exchange capacity (CEC) had range from 7.7-29.6 $cmol.kg^{-1}$. The percents base saturation in the top soil depth of total adjacent fragmented forests varied range from 12.69-84.45%. Fertility assessments in the surface soil depth tend to be medium to high and they were decreased with soil depth. The 14th adjacent fragmented forest had the highest of the base saturation percentage.

Carbon storages in biomass of tree species varied between 58-125 $MgC.ha^{-1}$. The storages of other nutrients were different: nitrogen; 643-1,384 $kg.ha^{-1}$, phosphorus; 90-195 $kg.ha^{-1}$, potassium; 440-948 $kg.ha^{-1}$, calcium; 935-1,883 $kg.ha^{-1}$, and magnesium; 210-451 $kg.ha^{-1}$. The large amounts of nutrients were accumulated in stem component, followed by roots, branch and leaf. The majority amounts were stored in *P. kesiya*, *C. acuminatissima*, *S. wallichii*, *C. diversifolia* and *Q.brandisiana.*

The dry matters of forest floor in adjacent fragmented forests varied between 5,855-7,644 $kg.ha^{-1}$. The amounts were different for other nutrients: carbon; 21.51-27.26 $MgC.ha^{-1}$, nitrogen; 42,571-69,386 $kg.ha^{-1}$, phosphorus; 298-408 $kg.ha^{-1}$, potassium; 3,676-9,055 $kg.ha^{-1}$, calcium; 3,642-5,837 $kg.ha^{-1}$ and magnesium; 635-915 $kg.ha^{-1}$.

Amounts of organic matter and carbon in 160 cm depth soils under adjacent fragmented forests varied between 145.4-454.9 $Mg.ha^{-1}$ and 84.3-263.9 $MgC.ha^{-1}$, respectively. The amounts were different for nitrogen; 9,364-18,583 $kg.ha^{-1}$, phosphorus; 40-62 $kg.ha^{-1}$, potassium; 3,473-7,912 $kg.ha^{-1}$, calcium; 1,331-6,972 $kg.ha^{-1}$, magnesium; 596-2,131 $kg.ha^{-1}$ and sodium; 392-404 $kg.ha^{-1}$.

(3) Climax Montane Forest

The soils in climax montane forest was classified in Order Ultisols, Suborder Humults. Soil depths were more than 200 cm with 10-20 cm thickness of organic layers. The soil profiles were developed as A-AB-Bt with high clay mineral in subsoils. The bulk density in the top soil was low to very low, especially in 0-10 cm depth had varying 0.43-0.65 $mg\ m^{-3}$ and increased with soil depth.

The percentages of sand in soil profiles varied from 50.55-74.70%. Silt particles in soil profiles varied from 11.20-31.71%, whereas the clay varied from 12.35-24.77%. The soil texture was varying from sandy loam on surface soils and sandy clay loam to loam in subsoils.

Soil pH forests in the surface soil were very strongly acid to strongly acid in subsoil. The contents of organic matter in the surface soils under climax montane forest were very high as 49.20 to 130.20 g. kg^{-1}. There were decreased with soil depth. Also the carbon contents in the surface soils were very high, varying 28.54-75.52 $g.kg^{-1}$. Total nitrogen was 0.10-6.40 $g.kg^{-1}$. The phosphorus available contents, the extractable potassium, calcium, magnesium and sodium were 0.81-13.08; 138.02-454.89; 9.09-937.61; 3.15-139.99 and 15.89-35.48 $mg.kg^{-1}$. Cation exchange capacity (CEC) had range from 7.09-31.60 $cmol.kg^{-1}$. The percents base saturation in the top soil depth varied ranging from 4.32-24.81%. Fertility assessments in the surface soil depth tend to be medium to low with soil depth.

Carbon stock in biomass of tree species at Doi Inthanon was 186 MgC ha^{-1}. apportion to stem, branch, leaf and root 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.

The dry matters in litterfall varied between 1,308.33-2,264.64 $kg.ha^{-1}$, these were lower than in forest floor litter (2,673.66-4,294.64 $kg.ha^{-1}$). In litterfall, carbon amounts in organic layers varied between 472.270-745.390 $kg.ha^{-1}$. The amounts of nutrients were different: nitrogen; 16.286-30.210 $kg.ha^{-1}$, phosphorus; 0.038-0.134 $kg.ha^{-1}$, potassium; 0.413-0.951 $kg.ha^{-1}$, calcium; 1.644-2.653 $kg.ha^{-1}$, and magnesium; 0.258-0.524 $kg.ha^{-1}$. In forest floor litter, carbon amounts in organic layers varied between 953.143-1,460.72 $kg.ha^{-1}$. Nitrogen contents 38.002-66.209 were $kg.ha^{-1}$, phosphorus; 0.088-0.185 $kg.ha^{-1}$, potassium; 0.300-0.564$kg.ha^{-1}$, calcium; 3.723-6.672 $kg.ha^{-1}$, and magnesium; 0.473-0.893 $kg.ha^{-1}$.

The average of amount organic matter and carbon in 160 cm depth soils was 215.27 $Mg.ha^{-1}$ and 124.9 $MgC.ha^{-1}$. The average amounts for nitrogen was 17,641.85 $kg.ha^{-1}$, phosphorus; 31.90 $kg.ha^{-1}$, potassium; 4,345.33 $kg.ha^{-1}$, calcium; 4,345.33 $kg.ha^{-1}$, magnesium; 112.76 $kg.ha^{-1}$ and sodium; 459.11 $kg.ha^{-1}$.

5.2.3 Economic valuation of wood Production, carbon and nutrient storages

(1) *Pinus kesiya* Plantations

The value of pine wood in a series of 21 age-class pine plantations were varied between 9,926-94,290 baht ha^{-1}. The values of fuelwood and timber products were varied 19,135-289,862 baht ha^{-1}. The total value of wood production in *Pinus kesiya* plantations varied from 70,544 to 341,800 baht ha^{-1} (11,287-54,688 baht rai^{-1}).

The value of 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 140-428 baht ha^{-1} based on voluntary market. The value of nitrogen storages in biomass of pine plantation varied 9,852-25,176 baht ha^{-1}, phosphorus; 1,140-3,294 baht ha^{-1}, potassium; 3,506-9,071 baht ha^{-1}, calcium; 2,767-7,666 baht ha^{-1}, and magnesium: 431-1,609 baht ha^{-1}.

The value of carbon and nutrient storages in forest floor were varied between 810-1,986 baht ha^{-1}. The value of carbon storages within 160 cm depth soils were varied from 243-652 baht ha^{-1} based on voluntary market. The value of nitrogen, phosphorus, potassium, calcium, magnesium and sodium accumulation in soil varied between 264,652-643,800; 730-2,643; 58,973-80,280; 2,440-47,296; 2,036-6,986 and 795-1,067 baht ha^{-1}, respectively. The total value of nutrients within 160 cm depth soils under five age-class pine plantations varied between 350,142-726,790 baht ha^{-1} (56,022-116,286 baht rai^{-1}).

In the five age-class *Pinus kesiya* plantations, the value of carbon storages in pine plantation ecosystems including in plant, forest floor and soil compartments varied between 601-847 bath ha^{-1} based on voluntary market. The value of nutrients were different: nitrogen; 287,500-660,000 baht ha^{-1} (21,158-29,076 baht ha^{-1} based on available forms), phosphorus; 2,580-4,588 baht ha^{-1}, potassium; 64,106-87,015 baht ha^{-1}, calcium; 9,119-51,553 baht ha^{-1}, magnesium; 3,339-7,627 baht ha^{-1}, and sodium; 796-1,068 baht ha^{-1}. Total values of nutrient storages in pine plantation ecosystems varied in ranged of 391,595-755,837 baht ha^{-1} (62,655-120,933 baht rai^{-1}).

The total economic value of ecosystems in five age-class pine plantations was calculated as 626,512-921,985 bath ha^{-1} (100,241-147,517 bath rai^{-1}), separated to those of wood production, carbon on voluntary market and nutrients as 91,474-234,568 bath ha^{-1}; 601-847 bath ha^{-1}; and 391,343-755,031 bath ha^{-1}, respectively. If the carbon was calculated on carbon market, the value was increased to 59,962-84,738 bath ha^{-1}. The total ecosystem value was changed to 685,873-1,001,718 bath ha^{-1} (109,739-160,274 bath rai^{-1}).

(2) Adjacent Fragmented Forests

The value of fuelwood and timber production in fifteen adjacent fragmented forests were different, 9,529-24,185 baht ha^{-1} and 84,480-219,141 baht ha^{-1}. The average total was 17,729 baht ha^{-1} and 134,667 baht ha^{-1}, respectively. The total values of wood production in adjacent fragmented forests were varied 94,009-236,791 baht ha^{-1}. The average total was 152,396 baht ha^{-1} (24,383 baht rai^{-1}).

The values of biomass carbon were varied from 176-381 baht ha^{-1} based on voluntary market. The value of nitrogen storages in biomass were 16,784-36,105 baht ha^{-1}, phosphorus; 2,341-5,082 baht ha^{-1}, potassium; 5,862-12,637 baht ha^{-1}, calcium; 5,396-11,626 baht ha^{-1}, and magnesium 1,211-2,602 baht ha^{-1}. Total values of nutrient storages in plant biomass were varied between 31,773-68,435 baht ha^{-1}.

The total value of carbon and nutrient storages in forest floor were varied 1,199.24-1,988.80 baht ha^{-1}. The value of carbon storages within 160 cm depth soils were varied from 257-804 baht ha^{-1}. The value of nitrogen, phosphorus, potassium, calcium, magnesium and sodium accumulation in soil of five sites of adjacent fragmented forests varied between 220,207-484,766; 1,051-1,492; 46,350-105,500; 7,680-40,220; 3,439-12,294 and 929-1,096 baht ha^{-1}, respectively. The total value of nutrient within 160 cm depth soils under sites of adjacent fragmented forests were varied between 312,126-645,961 baht ha^{-1} (49,940-103,353 baht rai^{-1}).

In five adjacent fragmented forests, the value of carbon storages in plant, forest floor and soil compartments varied between 599-1,110 bath ha^{-1} based on voluntary market. The values of nutrients were different: nitrogen; 250,589-516,187 baht ha^{-1} (34,785-44,344 baht ha^{-1} based on available forms), phosphorus; 5,151-6,181 baht ha^{-1}, potassium; 58,329-115,940 baht ha^{-1}, calcium; 18,567-49,766 baht ha^{-1}, magnesium;5,875-14,436 baht ha^{-1}, and sodium 929-1,096 baht ha^{-1}. Total value of nutrient storages in adjacent fragmented forests ecosystems were varied, 368,751-703,933 baht ha^{-1} (59,000-112,629 baht rai^{-1}).

The total economic value of ecosystems in five adjacent fragmented forests were calculated as 516,429-815,074 bath ha^{-1} (82,628-130,411 bath rai^{-1}), separated to those of wood production, carbon on voluntary market and nutrients as 111,142-180,621 bath ha^{-1}; 599-1,110 bath ha^{-1}; and 368,152-703,154 bath ha^{-1}, respectively. If the carbon was calculated on carbon market, the value was increased to 59,864-111,130 bath ha^{-1}. The total ecosystem value was changed to 575,694-892,268 bath ha^{-1} (92,111-142,762 bath rai^{-1}).

(3) The climax montane forest

The average value of fuelwood was 27,669 baht ha^{-1}. The average value of timber production was 216,214 baht ha^{-1}. The total value of wood production in the climax montane forest was 243,883 baht ha^{-1} (39,021 baht rai^{-1}).

The value of biomass carbon in climax montane forests was 569.54 baht ha^{-1} based on voluntary market. For the value of nitrogen, phosphorus, potassium, calcium, and magnesium storages in plant biomass were 53,699.20; 7,266.28; 18,536.87; 17,319.47 and 3,766.50 baht ha^{-1}, respectively. The total value of carbon and nutrient storages in biomass was calculated as 101,127.87 baht ha^{-1}

The total value of carbon and nutrient storages in forest floor was 5,543.24 baht ha^{-1}. The value of carbon storages within 160 cm depth soils were varied from 342.68-437.93 baht ha^{-1} based on voluntary market. The average was 380.73 baht ha^{-1}. The average value of nitrogen, phosphorus, potassium, calcium, magnesium and sodium storages in soil was 460,222.26; 832.09; 57,937.78; 3,119.79; 650.58 and 1,087.09 baht ha^{-1}, respectively. The average total value of nutrient within 160 cm depth soils under climax montane forests was 524,230.31 baht ha^{-1} (83,876.84 baht rai^{-1}).

In the climax montane forest at Doi Inthanon national park, the carbon stock in ecosystems including in plant, forest floor and soil compartments was 965 baht ha^{-1} based on voluntary market. The value for different nutrient was nitrogen; 519,252 baht ha^{-1} (68,234 baht ha^{-1} based on available forms), phosphorus; 8,112 baht ha^{-1}, potassium; 76,500 baht ha^{-1}, calcium; 20,554 baht ha^{-1}, magnesium; 4,431 baht ha^{-1}, and sodium; 1,087 baht ha^{-1}. Total value of nutrient storage in climax montane forest ecosystems was 630,901 baht ha^{-1}(100,944 baht rai^{-1}).

The total economic value of ecosystems in climax montane forest was 874,784 bath ha^{-1} (139,965 bath rai^{-1}), separated to those of wood production, carbon on voluntary market and nutrients as 243,883 bath ha^{-1}; 965 bath ha^{-1}; and 629,937 bath ha^{-1}, respectively. If the carbon was calculated on carbon market, the value was increased to 96,473 bath ha^{-1}. The total ecosystem value was changed to 970,293 bath ha^{-1} (155,246 bath rai^{-1}).

5.2 Recommendations

5.2.1 Reforestation of Highland Watershed in Northern Thailand

The study found that a pine forest plantation which allow for the replacement of the succession broad-leaved species significantly improving the forest ecosystems. Changes in plant diversities will become more apparent and rapid restoration of a forest community as well as forest succession progress. This forest ecosystem is closing to the adjacent fragmented forest and climax monetane forest in term of value of wood production, carbon and nutrients storages. Therefore, to recover the degraded land should contribute as follow:

1. Plantation forestry offers a tool to rehabilitate these degraded lands. *P kesiya* should be select for plantation on highland watershed because it can establish and grow well on dry site conditions and poor soils. Fertilization and particularly weeding to ensure rapid early tree growth are frequently fundamental to the success of the plantations.
2. Released a succession of natural broad-leaved trees. 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 forests have the potential role as sources of seeds/fruits in pine plantations. The natural succession in these plantations increases biodiversity enrichment, and thus the plantations can develop to be the climax montane forest.
3. Enrichment planting broad-leaved species into pine plantation. Other local broad-leaved tree species need ever be planted in mixed stand with *P. kesiya* plantations. Certain tree species in suitable site including altitude should be recommend such as *C. acuminatissima* as 1,200-1,500 m msl; *Q. brandisiana* and *A. fragrans* as 1,200-1,300 m; *L. elegans*, *T. gymnanthera* and *C. purpurea*, 1,300-1,400 m; and *C. diversifolia*, *T. gymnanthera*, *H. nilagirica*, *S. wallichii*, *Q. vestita* and *E. nitida*; 1,400-1,500 m.

5.2.2 Evaluation of Economic Value in Forest Ecosystem

To evaluation of economic value in forest ecosystems, not only the value of wood production, value of carbon and nutrient storages but also the value of non-timber forest product (NTFP), primarily of wildlife conservation, environmental protection such as biodiversity and water storage should be also included.

In this study, soil nutrients such as nitrogen, phosphorus, potassium, calcium, magnesium and sodium were analyzed in term of extractable form. So, study in the form of total nutrients was recommended in order to compare with the natural released. Also this study should be applied to studies in other ecosystems, such as conservation agriculture, agro-forestry systems, planting trees on the highland etc.