CHAPTER 5

Conclusions and Recommendations

The main objectives of this study were to evaluated pine growth and wood production in a series of *Pinus kesiya* plantations in highland watershed at Boakaew Watershed Management Station, Chiang Mai province; then, assessed plant succession in a series of *Pinus kesiya* plantations and roles of adjacent fragmented forests on succession; finally, classified the changing of soil properties under a series of *Pinus kesiya* plantations in order to restore highland watershed areas. The summarized of these results were below.

5.1 Pine Growths and Wood Productions in a Series of Plantations

(1) Pine Growths and Wood Production in a Series of Plantations

Growth of *P. kesiya* in 14-34 year-old of 21 age classes pine plantations at Boakaew Watershed Management Station 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 which varied from 0.52-1.15 m/yr; and the mean annual diameter at breast height increment was 1.28 cm/yr which varied from 0.94-2.24 cm/yr.

The total volume of *P. kesiya* calculated from volume equation which constructed from the exact volume of five felling trees from five aged classes of plantations were range from 32.73-337.10 m^3/ha, and the timber volume of *P. kesiya* were range from 19.93-200.62 m^3/ha. MAI of *P. kesiya* was 6.23 m^3/ha/yr which varied from 2.04-10.22 m^3/ha/yr. The highest MAI of *P. kesiya* was in juvenile stage (7.68 m^3/ha/yr).

(2) Plant Succession in a Series of Plantations

Tree species succession in pine plantations were mainly Fagaceae, e.g. *Castanopsis diversifolia, C. acuminatissima, C. purpurea, Quercus 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 which were separated to be 75-429 trees/ha of *P. kesiya* and 131-2,331 trees/ha 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 and 0.66-1.58 cm/yr, whereas MAI varied from 0.23-4.43 m^3/ha/yr.

Natural regeneration and under-ground species in a series of plantation were varied between 21-59 species. The common ground-covered species were *Ageratina adenophora, Chromolaena odoratum, Rubus rugosus, Hypolepis punctata, Adiantum*

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capillus-veneris and *Asparagus filicinus*; whereas the common seedlings of woody species were *P. kesiya, Melastoma sanguineum, Leea guineensis, Glochidion acuminatum, Aporosa villosa, Wendlandia tinctoria, Schima wallichii, Engelhardtia spicata, Quercus vestita* and *Castanopsis purpurea*, etc. The density of *P. kesiya* was varied among 0-4,867 individuals/ha and other seedlings varied 3,200-17,800 individuals/ha, whereas ground-covered varied 3,200-65,033 individuals/ha. The major limiting factors of forest succession were fire disturbance, light intensity and the presence of mature seed producing trees.

5.2 Plant Diversity in Fragmented Forests and Roles of Adjacent Fragmented Forests on Succession

(1) Plant Diversity in Fragmented Forests

The species richness in fifteen 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 fragmented forests. The index of forest conditions in fragmented forests was 50.16, range from 31.39-69.42. Tree species in fragmented forests indicated a good rejuvenation potential.

Five tree species had the frequency over than 80% of all trees in fifteen fragmented forests. There were *W. tinctoria, P. kesiya, G. sphaerogynum, C. acuminatissima* and *S. wallichii*. The average density for tree species in the whole 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). 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. *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. The similarity of plant communities among fragmented forests were varied in a wide range, 2-78%. The nearest of distance between two fragmented forests with the same altitude showed the high similarity.

The total number of seedling and ground-covered species existed in the whole fragment forests were 96 species which were separated to be 74 species of tree, 13 species of herb, 8 species of climber and 1 species of fern. The average number of seedlings and ground-covered species was 780 individuals/ha, and varied in a wide range among fragmented forests, 231-1,856 individuals/ha. The common seedlings of woody species were *Micromelum minutum, Phoebe cathia, P. paniculata, Dillenia aurea, Terminalia chebula* and *Euodia roxburghiana* whereas the herb species were *Orthosiphon aristatus, Asparagus filicinus, Chromolaena odoratum* and *Ageratina*

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adenophora. The regeneration of *Q. brandisiana* was better than other oaks, but usually on dry site.

(2) Roles of Fragmented Forests on Succession in Pine Plantations

The seed/fruit characteristics and their possible seed dispersal agents of tree species played the key roles of plant succession in adjacent *P. kesiya* plantation forests of Boakaew Watershed Management Station. Thirty-five tree species in the fragmented forests had seed dispersal by wind such as *P. kesiya, S. wallichii, B. alnoides, D. serrulata, S. neuranthum, C. stellatum, E. serrata, E. spicata, A. chinensis, T. rufescens, R. javanica,* etc. The seeds of 49 tree species were identified as animal dispersal such as those in the families of Fagaceae, Lauraceae, Euphorbiaceae, Burseraceae, Proteaceae, etc. The explosions dispersal were found for 12 species such as *M. malabathricum, W. tinctoria, C. arborea, V. pinnata, M. henryi* and those in the family of Leguminosae. Some heavy-seed tree species dispersed the seeds surrounding the mother trees including *P. diospyricarpa, A. fragrans, T. cochinchinenssis, S. arboretum, E. subcoriacea, B. gammieana* and *S. albescens*.

The roles of plant resources especially fragmented forests were still very important for naturally succession in pine plantations on highland watershed areas. There were 87 tree species common to both fragmented forests and pine plantations. The common tree species in both sites were *S. wallichii, W. tinctoria, G. acuminatum, P. emblica, G. sphaerogunum, C. diversifolia, P. kesiya, C. purpurea, T. rufescens,* etc. The numbers of tree species (16 species) only found in fragmented forests which were quite rare species in these areas such as *Artocarpus gomezianus, C. armata, Combretum punctatum, Radermachera ignea, Schefflera bengalensis*. 111 species only found in pine plantations includings, *Melastoma sanguineum, Dalbergia assamica, Mallotus paniculatus, Memecylon celastrinum, Litsea cubeba, Blumea balsamifera, Elaeocarpus sphaericus, Neolitsea zeylanica, Gluta obovata*, etc.

5.3 Soil Properties in a Series of *Pinus kesiya* Plantations, Fragmented Forests and Opened Area

(1) Soil Properties in a Series of Pinus kesiya Plantations

Total age classes of *Pinus kesiya* plantations had low/very low bulk densities in the top soils and increased with soil depth. Bulk densities of the surface soils up to 10 cm depth 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 top 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

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in this age classed more than other so it was shown the highest of bulk density because bulk density increased with clay content and is considered a measure of the compactness of the soil.

Soil chemical properties were investigated including, reaction (pH), contents of organic matter, carbon, nitrogen, extractable minerals as soil, cation exchange capacity (CEC) and base saturation.

Soil pH of total age classes samplings of pine plantations were strongly acid to very strongly acid. pH values tend to be increased over stand age. 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 $cmol.kg^{-1}$. These chemical properties tend to be higher over stand age except at 17 year-old and 33 year-old. The extractable potassium had very high (201.7-498.5 $mg.kg^{-1}$), whereas the extractable sodium had low to very low (15.0-67.2 $mg.kg^{-1}$) in soil profiles of total age classed. The percent base saturations in the top soil depth (0-10 cm) of total age classed samplings tend to be higher over stand age. Fertile assessments in the top 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.

Soil properties in 17 and 29 year-old pine plantation were quite well so the average growth increment in 17 year-old had the highest (0.93 m/yr height and 1.56 cm/yr diameter), contrast with 29 year-old had the lowest (0.52 m/yr height and 0.98 cm/yr diameter). This may caused of too high elevation (1,606 m msl) at 29 year-old in cool condition would delay the mechanism growth process.

(2) Soil Properties in Fragmented Forests and Opened Area

The soils in 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-AB-Bt with high clay mineral in subsoils.

Total fragmented forests had low to very low bulk densities in the top soils and increased with soil depth. The top soils (A horizon) of total fragmented forests had very low densities of 0.70-0.97 $Mg.m^{-3}$. The 2nd fragmented forest had the highest amounts of gravel on the top soils because of lower soil horizon development process than other 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 3rd and 4th fragmented forest had the highest sand particles, whereas the 2nd fragmented forest had the highest clay particles. The top soils of almost fragmented forests were sandy loam whereas subsoils were sandy clay loam, loam and clay loam. The 2nd fragmented forest had sandy clay loam in top soil and clay to clay loam in subsoil.

Soil pH of most fragmented forests were strongly acid (5.25-5.55) except the 1st fragmented forest was slightly acid (6.13) in top soil and moderately acid to very strongly acid in subsoil. The contents of organic matter, carbon and nitrogen in the

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top soil depth of total 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 fragmented forests varied range from 12.69-84.45%. Fertile assessments in the top soil depth of total fragmented forests tend to be medium to high and they were decreased with soil depth. The 5th fragmented forest had the highest of the base saturation percentage. The 2nd fragmented forest had poorer soil properties than other fragmented forests so species diversity (SWI) was quite low (3.65). They were found the dominated tree species in fragmented forests by *P. kesiya*, *C. acuminatissima*, *S. wallichii*, *C. diversifolia*, *C. purpurea*, *Helicia nilagirica* and *T. gymnanthera*. However, *Q. brandisiana* only distributed in the 2nd fragmented forest.

Bulk density in opened area was very low in the top soils and increased with soil depth as 0.80-1.38 $Mg.m^{-3}$. The amounts of gravel were range from 10.52-23.08%. The percentages of sand in soil profiles varied from 57.0-72.2%. Silt particles in soil profiles varied from 18.5-30.0%, whereas the clay varied from 7.2-20.7%. The top soils of opened area was sandy loam and sandy loam to sandy clay loam in subsoil

Soil pH of opened area was mainly strongly acid. The contents of organic matter, carbon and nitrogen in the top soil depth had quite high as 105.6-118.7, 61.3-68.9 and 5.2-5.3 $g.kg^{-1}$; phosphorus available, extractable potassium, calcium, magnesium and sodium as 8.8-12.8, 352.6-468.3, 1,019.2-1,690.7, 97.2-228.5 and 18.2-19.4 $mg.kg^{-1}$, cation exchange capacity as 30.4-33.5 $cmol.kg^{-1}$.

It was found the highest density of herb species in opened areas including, *Hypolepis punctata* and *Ageratina adenophora*. Other herb species were *Imperata cylindrical, Catimbium speciosum*. There were some seedlings of *Eurya nitida*, and few of *Melastoma sanguineum, Camellia pleurocarpa, Litsea cubeba, Blumea balsamifera* and *Tephrosia purpurea* in opened areas.

Recommendations

The recommendations for successions of reforestation on highland watershed should be following below.

When the forest areas on highland watershed are clear felling, plantations play the firstly key role to reforestations. Pioneer local species including *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. Furthermore, damage from forest fires is efficiently prevented. Growth rate and microclimate at establishment are influenced by soil properties and ground vegetation. The forest microclimate can change as the plantations develop.

After establishment *P kesiya* plantations were succeed, increasing size and biomass, a distinctive microclimate and soil environment develop which in turn strongly influence the growth process itself. Other local broad-leaved tree species need ever be planted in mixed stand with *P kesiya* plantations. Certain tree species in

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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. Changes in plant diversities will become more apparent and rapid restoration of a forest community as well as forest succession progress.

Trees retain large reserve of nutrients within them, especially in the foliage and stem, and have a remarkable ability to mobilize and re-use the nutrients to support sustained growth in the long term.

Adjacent fragmented forests are urgently to facilitate their conservation and management especially prevent clear felling and forest fires in order to play a key role as the mother trees which are a source of seed dispersal into plantations and opened areas to increase plant diversities. The roles of plant resources are still very important for naturally succession.

Finally, the local communities could also have a role in forest management.

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