CHAPTER 1

Introduction and Literature Review

1.1 Present Situation of Forests in Thailand

The world forest had been cleared 9.4 x 10^7 ha/yr from 1990 to 2002, and remained forest area of 3,869 x 10^7 ha. The rate of deforestation was increased in Africa but slightly declined in Asia (Office of Natural Resources and Environmental Policy and Planning, 2002). For Thailand, Royal Forest Department reported that the forest area in 1910 was very large, 224.375 x 10^7 rai (6.25 rai = 1 ha) (70% of country area), decreased to 171.017 x 10^7 rai (53.33%) in 1961; 94.29 x 10^7 rai (29.40%) in 1985, and remained as 81 x 10^7 rai (25.30%) in 1998. Though forest concession over the country was terminated in 1989, illegal cutting is still occurred. The annual rate of forest decline was high during 1961-1989, 2.91 x 10^7 rai, and decreased to 0.95 x 10^7 rai during 1989-1998 (Charuphat, 1998). During 2003-2009, the degraded areas were being restored about 392,355 rai by the Royal Forest Department so by 2009 the forest area was increased to 107.24 x 10^7 rai (33.44%). The main forest areas covered in the north of Thailand, 59.42 x 10^7 rai or 56.04% of the total forest areas (Office of the Forest Land Management, 2009).

The main causes of deforestation in Thailand are: (1) forest clearing for agriculture and settlement, (2) shifting cultivation, and (3) development projects such as construction of dam or reservoir, road, electric transmission, etc. Illegal cutting is the main cause of forest degrades over the country whereas forest fragmentation has critical effects on forest biodiversity, flooding, drought, forest fire, air pollution and so on.

The significant ways of solving the problem are protection of remained forest and reforestation. Reforestation gives direct and indirect benefits to human. The direct benefits include wood for construction and non-wood products such as food, medicine, fiber, resin, oil, fuel, etc. The indirect benefits involve ecological and environmental influence of the forest. These influences include carbon sequestration, releasing O_2, soil loss prevention, restoring soil nutrients, water flow regulation, improving microclimatic, recreation value, etc.

1.2 Three Needle Pine (*Pinus kesiya* Royle ex Gordon)

P. kesiya grows mainly in sub-tropical or temperate lower montane and montane forest. It often occurs in pure stands with grass understorey, but may be associated with *P. merkusii*, *Quercus* spp., *Castanopsis* spp., dry dipterocarps and ericaceous genera. It readily colonises sites degraded by fire of shifting cultivation and on such sites forms a mosaic of groups or stands of trees. Trees within each stand are approximately the same age, while adjacent stands may differ widely in age.

In natural stands, this pine generally grows into a large tree, attaining heights between 25 and 45 meters when mature. Height growth is rapid for the first 20 years, and then slows down (Kha, 1966). Growth data summarized by Armitage and Burley (1980) indicate considerable variation according to site conditions and past history. For example, the best stands in the Philippines, at over 1,800 meters elevation in the Boboc area of Benguet Province, reached 30-40 meters, whereas the isolated Zambales stands at lower elevation in western Luzon rarely reach more than 23 meters (Jacalne and Lizardo, 1958; Turnbull, 1972). In the better stands of Burma trees may reach 30-45 meters in height, while in the Khasi Hills of Assam trees over 20 meter are rare (Hundley, 1961; Bor, 1942). Diameters are commonly 40-60 centimeters, but good unlogged stands may average 80-95 centimeters and occasional individuals have been recorded up to 160 centimeters. On good sites in Vietnam this pine may live more than 152 years (Kha, 1966).

1.2.1 Natural Distribution

P. kesiya has a wide but discontinuous distribution in south-east Asia, between latitude 12^0 and 30^0 N and between longitudes 90^0 and 122^0 E. It occurs in India, Burma, China, (Yunnan, Szechwan and Tibet), Thailand, Loas, Vietnam and Philippines (Critchfield and Little, 1966; Mirov, 1967; Armitage and Burley, 1980). The extreme altitudinal range is from 300 to 3,000 meters, but optimum development is usually between 1,000 and 1,800 meters (Turnbull *et.al.*, 1980).

Rainfall is usually between 1,000 and 2,000 mm, with a distinct dry season of 2-4 months, but in certain parts of India and Burma the rainfall is much more. Mean annual temperature varies from about 15^0 C at the higher elevations to about 25^0 C at the lowest.

Tropical soils are free-draining acid podzols, sandy soils, and red or yellow clays or clay loams. In Vietnam, *P. kesiya* tolerates soils which are more acidic and less base rich than those on which *P. merkusii* will grow (Kha, 1966). The precise pattern of *P. kesiya* distribution is greatly influenced by the incidence of fire. In general, fire favors pine at the expense of broad-leaved species, but excessively severe fires may destroy pine generation and lead to the formation of grass savanna (Pousujja *et al*., 1986).

1.2.2 Flowering and Fruit/Seed Development

P. kesiya is monoecious. Male strobili are produced in place of needle fascicles and occur in clusters several centimeters back from the ends of the shoots. Each strobili is cylindrical to oblong, bright yellow or light brown, about 5 mm in diameter by 15 mm long. Female strobili are produced in place of lateral shoots and appear single or in pairs or three near the ends of branches, usually in the upper half or third of the tree. They are 5-10 mm long and up to 8 mm in diameter when receptive, greenish purple, borne on a long peduncle which later attaches the mature cone firmly to the branch (Armitage and Wood, 1980).

In natural stands, flowering and cone production take place annually from age 10-20 onwards. In exotic plantations in Africa, in contrast, flowering starts from age 3-7 years. There is often a period of 3-5 years between first flowering and first production of substantial quantities of viable seeds. In the humid lowland tropics without a dry season, e.g. Malaya and Java, *P. kesiya* is incapable of flowering and setting seed normally.

In the natural stands in South East Asia, male and female flowers appear in the cool, dry season from December to March (Armitage and Wood, 1980). Studies in northern Thailand showed that young male flowers become visible in early November and that pollen was shed from the end of November to the end of February (Kingmuangkow, 1974; Pousujja and Kingmuangkau, 1983). The period of pollen shed for individual trees varied from 2-3 weeks up to 2 months.

In Thailand, cone development takes 23-25 months from pollination to maturity. The conelet remains small (less than 2 cm in length) for the first year, until fertilization takes place. Thereafter, cone elongation is rapid over the next six months and maximum length of 6-7 cm is reached about 18 months after pollination. Further maturation of seeds takes place after the cones have reached their full size and cone harvesting can be carried out from December to February. Observations indicated that over 50% of female flowers fail to develop conelets which survive the first year. On the other hand, cones which reach the stage of rapid elongation from 12-18 months usually survive to set viable seeds (Pousujja and Kingmuangkau, 1983).

1.2.3 Seed Dispersal and Germination

Seed dispersal is by wind. In Thailand, cones open and seed is shed during the dry season, December-February. The cones are persistent and may remain on the branches for several years after seed shed. In the mountains of the Philippines frequent up-draughts during the dry season can transport the winged seeds upwards and across the valley slopes for considerable distances (Colling, 1967).

Germination is epigeal. Seedlings survival is favored by open conditions and bare, weed-free soil, which result from landslides, abandoned cultivation or previous fires. Absence of fire for at least five years is necessary if seedlings are to become established (Armitage and Wood, 1980).

1.2.4 Natural Regeneration

Natural regeneration of this pine is common in the natural range of the species and has been reported in exotic plantations under suitable conditions e.g. in Zimbabwe (Barrett and Mullin, 1968) and South Africa (Poynton, 1977). The species readily colonises land disturbed by logging or burning, especially if the mineral soil is exposed as a result of fire (Turakka *et al.*, 1982).

Seed dispersal in the natural montane habitat of *P. kesiya* is very effective, especially if seed trees are situated on, or near the ridge tops (Colling, 1967). Agencies observed to be destructive of seeds or natural regeneration includes rodents, insects, domestic stock, shifting cultivation and suppression by wood regrowth, grass and weeds (Armitage and Wood, 1980). Fire is an important factor and may cause death or severe damage and dieback to seedlings and saplings up to four years old or more. Bhumibhamon *et al.* (1980) found that germination of *P. kesiya* seeds was inhibited, and germinative energy reduced, by aqueous extracts from dried and powdered parts of *Imperata* grass, so phytotoxicity may be a problem on *Imperata* sites in addition to completion for light, water and nutrients.

1.3 Watershed Restoration through Forest Plantation

Deforestation has led to increased flooding, faster siltation of reservoirs, accelerated soil erosion, more rapid desertification, and climate change. The decrease of forest cover in the watershed results in greater ecological instability. Deforestation and forest fragmentation in highland watershed of northern Thailand still be serious problem and may lead to the extinction of locally adapted populations as well as a reduction in the size of remnant populations. Forest plantations play the key role in harmonizing long-term forest ecosystem restoration goals. To recover the degraded land, fast growing native tree species like three needle pine (*P. kesiya*) had been widely planted on highland watershed areas of the northern part of Thailand.

P. kesiya has been an important plantation species for many countries. The biggest plantation areas of *P. kesiya* are in Madagascar and Zambia, Mikkola (1982) reported 26,000 ha planted in the copper belt of Zambia by October of that year, while Barnes and Gibson (1984) reported over 75,000 ha of plantations of this species in the Madagascar highlands. Vietnam has over 5,000 ha planted in Lam Dong Province, as well as smaller areas elsewhere (Granhof, 1984).

This pine has a rapid height growth after the first year of establishment, 1-2 m annually, with a canopy closure in three to four years (Armitage and Wood, 1980). Although the pine does not fit to all of these optimum descriptions, Oberhauser (1997) has stated that *P. kesiya* plantations might indeed speed up the succession process. The composition of the plantation plays also a key role. When assessing the plantation rehabilitation effectiveness, mixed-in species and multi-storied plantations have been found to be especially successful (Wunderle, 1997; Carnevale and Montagnini, 2002).

It is well adapted to fire according to a thick bark and deep roots (Stott *et al.*, 1990). It even promotes fires and thus excludes other species, by its abundant flammable litter which is nitrogen poor when decomposed (Singh and Singh, 1984). Little and Moore (1953) noted that a severe deeply burned fire can promote pine regeneration by exposing the mineral soil and by eliminating competition with sprouting species. In fact, in total absence of fire, pines could only be found on the very poorest soils (Turakka *et al.*, 1982). On the other hand, broad-leaved species coppice after fire (Koskela, 1993), and if fires are almost annual these species can slowly colonize the understory of a forest stand (Savage, 1994). Previous studies have suggested that *P. kesiya* plantations posses a capability as a foster environment for native broad-leaved tree species, but little is known about the extent of regeneration in these plantations.

In Thailand, two types of reforestation are recognized, plantations for commercial and conservation purposes. Commercial plantations are conducted by both government and private sectors. For conservation purposes, the aim of plantation is for land restoration in the highland watershed. The commercial plantation is divided into two groups; (1) fast growing tree species for short rotation such as *Eucalyptus* spp., and (2) economic tree species such as teak (*Tectona grandis*). The forest plantation in highland is the responsible of government to improve watershed ecosystems. Watershed Development Units under Royal Forest Department took over the plantation establishment in the 1970s, and the plantation establishment was subsequently escalated. Many tree species have been planted including *Pinus kesiya*, *Prunus cerasoides*, *Docynia indica* and *Betula alnoides*. *P. kesiya* is still the most common species for highland plantation. About 150,000 ha of *P. kesiya* plantations in northern Thailand have been reported (RFD, 1993).

1.4 Researches on *Pinus kesiya* Royle ex Gordon

Some research works on *P. kesiya* plantations have been accumulated, Homjeen (1997) reviewed pine growth at Huey Bong Experimental Station, Chiang Mai Province. Annual height increments during 1-10 and 10-20 year-old were 1.22 and 0.66 m, while those of diameter growth were 1.67 and 0.40 cm, respectively. Decreased growth rates during 10-20 year-old were influenced by canopy closure. However, its growth rate may be varied with sites. At Doi Suthep, the annual height and diameter increments of 17 year-old pine were 1.02 m and 1.39 cm, respectively. In natural forest, the height growth at Omkoi district, Chiang Mai, was the best during 20-25 year-old, 1.14 m/yr, whereas the best stem diameter growth was 15-20 year-old, 1.06 cm/yr.

Khamyong (2001) concluded that stem girth and height of *P. kesiya* at Doi Boa Luang Plantations, Chiang Mai, were increased with stand age. The growth rates varied among stands. It was very rapid during the first ten year after planning, very slow during 12 and 32 years, and more rapid from the age of 32 to 37. The yield of these plantations at ages of 7, 10, 12, 18, 21, 28, 32 and 37 years old were 7.25, 53.25, 115.31, 47.06, 298.94, 156.31, 273.81 and 201.94 m^3/ha. Many factors particularly tree density, thinning and nutrient availability are affected on these variations. Decomposition of needles of this pine resulted in strong acid of soils**.**

Nildam (2002) studied on timber volume of *P. kesiya* plantations at Phrao Watershed Management Unit, Chiang Mai, at ages of 9, 12, 15, 18, 21 and 24 years old. They were in the order of 120.82, 149.68, 262.99, 218.52, 379.91 and 316.84 m^3/ha.

Sirikul (1974) carried out a research on the effects of environmental factors on *P. kesiya* growth in two sites of Thailand, one in the south (Surat Thani) and another in the north (Chiang Mai). The initial height growth in the south was about 70% higher than the north. The site in the south was located at 40 m altitude with high rainfall (1,600-2,000 mm/yr) and fertile soil, while the northern site was situated at 800 m altitude with lower rainfall (1,200-1,400 m/yr) and poor soil.

Provenance trial has been taken to select good varieties of this pine. It is found that the best provenance in Thailand was Doi Inthanon, Chiang Mai. The volume increment was 4-9 m^3/ha/yr, and produced 250 m^3/ha in about 28 years at best with the intensive management (Granhof, 1983). Boa Luang provenance had the lower increment volume (1.92-6.00 m^3/ha/yr) (Pousujja, 1984). Silvicultural practices in pine plantation are very important for growth and productivity. Farnum *et al.* (1983 cited by Nambiar, 1984) compared the productivity of two contrasting types of forests in the USA; *Pseudotsuga menziessi* (Douglas fir) in Washington and *P. taeda* (loblolly pine) in the lower coastal plains of North Carolina, and concluded that these plantations increased the productivity by 70 and 300% respectively over natural forests on the same time.

In Thailand, Homjeen (1997) reported that wood production of 10-year-old *P. kesiya* at Doi Boa Luang plantation using 2 x 2 m^2 spacing was 161% higher than

4 x 4 m^2. Intensive plough and weeding in the first three years after planting could increase 157% growth rate of *P. kesiya* (Granhof and Homjeen, 1983). Sakulmeerit and Duangsathaporn (2000) studied the effects of thinning on the growth of *P. kesiya* plantation at Doi Boa Luang plantation in Chiang Mai. They found that width of annual ring was increased 70.3% of unthinned stand.

After 40 years, forest rehabilitation at Khun Khong Watershed Research Station, Chiang Mai province which mainly recover the degraded land by *P. kesiya* shown that the planting stands had no clear aged structure distribution and most planting trees were found in 14.5-24.5 cm DBH class to 24.5-34.5 cm DBH class. The native tree species had established in the lowest class of 4.5-14.5 cm DBH. The rehabilitation of the degraded land through natural watershed recovery period was estimated at least about 84-153 years (Viranant, *et al*., 2008).

1.5 Soil Properties in Plantation Forests

Soil forms from a complex interaction between earth materials, climate, and organisms acting over time. Soils can be enormously complex systems of organic and inorganic components. Soil texture effects many other properties like structure, chemistry, and most notably, soil porosity, and permeability. Bulk density increases with clay content and is considered a measure of the compactness of the soil. The greater the bulk density provided the more compact the soil. Compact soils have low permeability, inhibiting the movement of water. Soil compaction results in reduced infiltration and increase runoff and erosion.

As plant material dies and decays it adds organic matter in the form of humus to the soil. Humus improves soil moisture retention while affecting soil chemistry. Cations such as calcium, magnesium, sodium, and potassium are attracted and held to humus. These cations are rather weakly held to the humus and can be replaced by metallic ions like iron and aluminum, releasing them into the soil for plants to use. Soils with the ability to absorb and retain exchangeable cations have a high cation-exchange capacity. Soils with a high cation-exchange capacity are more fertile than those with a low exchange capacity.

Soil research has shown that soil profiles are influenced by five separate, yet interacting, factors: parent material, climate, topography, organisms, and time. Soil scientists call these the factors of soil formation. These factors give soil profiles their distinctive character. The use of soil survey of the main soil types together with an assessment of tree species and foliar nutrient status within each soil group may be a useful approach to explore the deficiencies and toxicities of elements.

Parent material composition has a direct impact on soil chemistry and fertility. Parent materials rich in soluble ions-calcium, magnesium, potassium, and sodium, are easily dissolved in water and made available to plants. Limestone and basaltic lava both have a high content of soluble bases and produce fertile soil in humid climates. If parent materials are low in soluble ions, water moving through the soil removes the bases and substitutes them with hydrogen ions making the soil acidic and unsuitable for agriculture. Soils developed over sandstone are low in soluble bases and coarse in texture which facilitates leaching. Parent material influence on soil properties tends to decrease with time as it is altered and climate becomes more important.

Climate, interacting with vegetation, also affects soil chemistry. Pine forests tend to dominate cool, humid climates. Decomposing pine needles in the presence of water creates a weak acid that strips soluble bases from the soil leaving it in an acidic state. Additionally, pine trees have low nutrient demands so few soil nutrients are taken back up by the trees to be later recycled by decaying needle litter. Broadleaf deciduous trees like oak and maple have higher nutrient demand and thus continually recycle soil nutrients keeping soils high in soluble bases.

Topography has a significant impact on soil formation as it determines runoff of water, and its orientation affects microclimate which in turn affects vegetation. For soil to form, the parent material needs to lie relatively undisturbed so soil horizon processes can proceed. Water moving across the surface strips parent material away impeding soil development. Water erosion is more effective on steeper, unvegetated slopes. Slope angle and length affects runoff generated when rain falls to the surface.

Organism, both plant and animal, play an important role in the development and composition of soil. Organisms add organic matter, aid decomposition, weathering and nutrient cycling. The richness and diversity of soil organisms and plant life that grows on the surface is, of course, also tied to climate. Soil organisms also affect weathering. The decomposition of pine needles creates a weak acid that can strip soluble ions from the soil. Burrowing animals create passage ways through the soil to help aerate and allow water to infiltrate into it. Burrowing animals help translocate materials and fertilize the soil at depth.

As time passes, the weathering processes continue to act on soil parent material to break it down and decompose it. Horizon development processes continue to differentiate layers in the soil profile by their physical and chemical properties. As a result, older more mature soils have well-developed sequence of horizons. Some geological processes keep soils from developing by constantly altering the surface and thus not allowing parent material to weather over a significant period of time.

Climate interacts with time during the soil development process. Soil development proceeds much more rapidly in warm and wet climates thus reaching a mature status sooner. In cold climates, weathering is impeded and soil development takes much longer.

The physical and chemical properties of a soil are determined by the soil forming process under which they form. Though all soils are created by the various horizon development processes of additions, transformations, translocation and removals, it is the soil forming or, pedogenic processes that determines the kind of soil that is ultimately formed.

Soils under different types of forest have varing colours depending upon the position of each landscape and the type of parent rock. They become more reddish in colour when found in higher positions where weathering and leaching are more intense (Buol *et al.*, 2003).

Soil characteristics were different among the forests at Doi Suthep-Pui National Park, Chiang Mai province, including dry dipterocarp (DDF), mixed deciduous (MDF), dry evergreen (DEF), pine (PF) and montane forests (MF). DDF soil were classified in Order Ultisols, Suborder Ustults. MDF soil was in Order Inceptisols, Suborder Ustepts. DEF, PF and were in Order Ultisols, Suborder Udults. Very low to low densities in upper soils and low to moderately low in subsoils were observed in PF and MF. Extremely acid in upper soil and very strongly acid in subsoil were found in PF and MF. Organic matter contents were different among forests; DDF: low to moderately high; MDF: moderately high to very high; DEF, PF and MF: high to very high. Organic matter accumulations in DDF, MDF, DEF, PF and MF were 117.22, 235.47, 239.68, 212.42 and 229.36 Mg.ha^{-1}, respectively. Nitrogen contents and accumulations varied in similar trend as organic matter. For extractable nutrients in these five forests, phosphorus, calcium and sodium were low to very low. Potassium in the soils was varied; DDF, medium to very high; MDF, medium to high; DEF, low; PF, very low to medium and MF, high. Most soils contained low to very low contents. It was medium in MDF soil. Amounts of carbon accumulated in soil profiles of DDF, MDF, DEF, PF and MF were 127.07, 216.89, 375.36, 233.56 and 281.77 Mg.ha^{-1}, respectively. Carbon accumulation in there biomass were calculated as 59.08, 80.32, 236.35, 110.36 and148.74 Mg.ha^{-1}, where as those amounts in there soils were in the order of 67.99, 136.57, 139.01, 123.20 and 133.03 Mg.ha^{-1}. Carbon accumulation was the highest in DEF ecosystem and the lowest in DDF (Khamyong, 2009).

Many researches on soil properties in pine plantations are conducted in foreign countries, and very few are taken in Thailand (Haberland and Wilde, 1961; Wilde, 1964; Hamilton, 1965; Fisher and Stone, 1969; Fisher and Eastburn, 1974; Wells and Jorgensen, 1975; Gilmore and Boggess, 1976; Burger and Pritchett, 1979; Hart *et al*., 1980; McIntosh, 1980; Crane and Raison, 1981 and so on cited by McColl and Powers, 1984). In Thailand, Parathai (2003) studied on soil properties of *P. kesiya* plantation at Doi Boa Luang, Chiang Mai. It concluded that bulk densities of top soil (0-10 cm) and texture under 7 to 37 year-old plantations were not different among the plantations. It varied between 1.0-1.6 Mg.m^{3}. The pH varied during 4.9-6.1 (moderately acid to strongly acid). It was slightly decreased in the old stands. Organic matter was increased with stands age; varying 17.3-66.8 g.kg^{-1}. Carbon and nitrogen varied with organic matter. The amounts of organic matter in one-meter soil profile of 7 to 37 year-old stands were 83.86-153.80 Mg.ha^{-1}, carbon: 48.64-89.20 kg.ha^{-1}, and nitrogen: 3,243-5,947 kg.ha^{-1}. Concentrations and amounts of extractable P, Ca and Mg in soil were higher in older stands, but K was adversely lower.

1.6 Plant Succession in Plantation Forests

Succession is a directional non-seasonal cumulative change in the types of plant species that occupy a given area through time. It involves the processes of colonization, establishment, and extinction which act on the participating plant species. Most successions contain a number of stages that can be recognized by the collection of species that dominate at that point in the succession. Succession begin when an area is made partially or completely devoid of vegetation because of a disturbance. Some common mechanisms of disturbance are fires, wind storms, volcanic eruptions, logging, climate change, severe flooding, disease, and pest infestation. Succession stops when species composition changes no longer occur with time, and this community is said to be a climax community.

The concept of a climax community assumes that the plants colonizing and establishing themselves in a given region can achieve stable equilibrium. The idea that succession ends in the development of a climax community has had a long history in the fields of biogeography and ecology. One of the earliest proponents of this idea was Frederic Clements who studied succession at the beginning of the 20^{th} century. However, beginning in the 1920s scientists began refuting the notion of a climax state. By 1950, many scientists began viewing succession as a phenomenon that rarely attains equilibrium. The reason why equilibrium is not reached is related to the nature of disturbance. Disturbance acts on communities at a variety of spatial and temporal scales. Further, the effect of disturbance is not always 100 percent. Many disturbances remove only a part of the previous plant community. As a result of these new ideas, plant communities are now generally seen as being composed of numerous patches of various size at different stages of successional development.

The first stage of succession was characterized by the pioneering colonization of annual plant species on bare ground and nutrient poor soils. These annual species had short lifespans (one growing season), rapid maturity, and produce numerous small easily dispersed seeds. The annuals were then quickly replaced in dominance in the next year by biennial plants and grasses. After about 3 to 4 years, the biennial and grass species gave way to perennial herbs and shrubs. These plants live for many years and have the ability to reproduce several times over their lifespans.

Tree regeneration can take place on a spatial and a temporal scale. On deforested sites the first growth cycle is spatial in nature and usually includes pioneer trees that form a secondary forest. When pioneer species begin to die and make gaps into the forest canopy, the second growth cycle of the forest accelerates as the microclimate becomes more favorable for climax species to develop in these gaps, and leads to a climax forest (Whitmore, 1991). Pioneer species can be separated into early secondary and late secondary species. Early secondary species regenerate well in large gaps, whereas late secondary species regenerate well in small gaps. Primary, or climax, species regenerate both under a closed canopy and in gaps (Chandrashekara and Ramakrishnan, 1993). Oberhauser (1997) has stated that *P. kesiya* plantations might indeed speed up the successional process.

Parrotta (1997) described that if the woody undergrowth that has developed after plantation establishment is protected, a mixed forest will replace pure stand. The foster trees may disappear altogether if the species is short-lived and light-demanding. The planted trees can be removed gradually as was done in a *P. caribaea* plantation in Puerto Rico that was thinned with consequences of better possibilities for secondary species to reach the canopy (Lugo, 1992). The latter alternative is highly presumable in the case of *P. kesiya.* This has to do with the fact that *P. kesiya.* pine is found to be the dominant species in natural dry dipterocarp forests (Turakka *et al.*, 1982).

Oberhauser (1997) surveyed the vascular plants of four *P. kesiya* plantations in Chiang Mai with age varying between 7-28 years. In the 7-year-old stand, *P.kesiya* was the dominant species and the ground was densely covered with grasses and herbs and mainly constituting of *Eupatorium adenophorum* Spreng. The 12-year-old plantation, canopy was dense with pines and numerous other species. There were different canopy layers and tree sizes among the non-pine species. The ground cover was light with no pine regeneration. Other species had regenerated and were regularly distributed. Pine mortality could be observed in a 21-year-old plantation, and tree seedlings were found. The 28-year-old site was diverse in tree species although dominated by *P. kesiya*. In this case, the ground cover was light. The density of *P. kesiya* declines and density of other trees increases with time. After the age of 21, an increasing basal area of other trees will substitute for the decrease of basal area of *P.*

kesiya. He also speculated a possibility of gaps created by dying pines and of thinning operations to enhance natural regeneration. .

Carnevale and Montagnini (2002) suggested that canopy shading and litter depth in plantations have an influence on seedling density and richness. They concluded that monoculture plantations with the fastest litter decomposing rates have the smallest density of seedlings in height classes of 0.15-1 m and >2 m, whereas plantations of tree species with slow decomposing rates had the highest seedling density.

Forest regeneration was found to be extensive in *P. kesiya* watershed plantations in northern Thailand. Especially the lower canopy layer, mostly formed by saplings was well developed with densities ranging between 350-4,620 saplings/ha. Seedling densities were high as well, ranging between 5,000-33,750 seedlings/ha. Regeneration of broad-leaved trees in *P. kesiya* plantations was affected by fire disturbance, light intensity and the presence of mature seed producing trees. Seedling recruitment was mainly facilitated by lack of fire disturbance, which caused high litter coverage. The accumulation of litter was more pronounced in plantations that had been undisturbed by fire for a longer period of time and which had high density of saplings. A high mature broad-leaved tree density increased the seed rain, thus also increasing the probability of the establishment of site-adapted seedlings in favorable microhabitats (Kiianmaa, 2005). High canopy coverage causes a decrease in light intensity that hinders the growth of tree seedlings (Whitmore, 1991).

Aksornkoae and Boonyawat (1977) studied on succession in abandoned land after shifting cultivation. It was found that plant succession after shifting cultivation without fire in the first four years was 52 species, but only 37 species were observed in burned area.

Nildam (2002) studied on plant succession in *P. kesiya* at Phrao Watershed Management Unit, Chiang Mai. He revealed that the species richness of succession plant in 9, 12, 15, 18, 21 and 24 year-old plantation were 63, 75, 60, 74, 55 and 56 species, respectively; whereas the sapling species were in the order of 81, 91, 75, 85, 74 and 74 species.

Some researches of plant succession in *P. kesiya* forest were taken at Doi Inthanon mountain region in northern Thailand. Savage (1994) found that the forest structure was undergoing a change. This was because of poor regeneration caused by annual fires and kindling collection that damaged mature trees. The stand structure was sparse. Pine seedlings and saplings over one year old were almost absent. This was due to canopy shade, and for the most part also to annual fires that kill the once numerous first-year seedlings. Non-pine species formed a sparse understory below the pines. The higher stem number of broad-leaved trees compared to that of pines could not be explained by better fire resistance but rather by coppicing of broad-leaved species.

In the climax montane forest, plant diversity is very high. However, forest communities vary with topographic conditions. Khamyong and Seremethakun (1998) studied on plant diversity in lower montane forest at Doi Suthep-Pui, Chiang Mai. The research was conducted between 1,200-1,300 m altitude in two sites; one on the ridge and upper slope, and another on lower slope and valley. They found that tree species on the ridge and upper slope (72 species) were lower than the lower slope and valley (118 species), the same as basal area (33.02 and 49.99 m^2/ha). Panmongkol

(2001) revealed that lower montane forests at 1,000, 1,200, 1,400 and 1,600 m altitude consisted of 64, 59, 65 and 55 species, respectively. The species diversity indexes were in the order of 4.99, 4.74, 4.94 and 4.85.

In a natural pine forest at Ban Wat Chan, Mae Chaem district, Chiang Mai, Khamyong and Seremethakun (2001) divided this forest into two types; pine-montane forest and pine-dry dipterocarp forest of three subtypes based on dominant tree species as *Dipterocarpus obtusifolius*, *D. tuberculatus* and *Shorea obtusa*. These subtypes consisted of 38, 46 and 57 species, respectively; 346, 758 and 1,075 trees/ha of plant density. Plant density in the pine-montane forest was 794 trees/ha with 24 species.

Nongnuang (2006) studied on forest composition of montane forest at the Royal Initiative Project, Doi Ompai Highland Agriculture Development Station, Chiang Mai. It was found that three types of Baan Sam community forest including Pa Koobaan for ceremony, Pa Khunnam for watershed and Pa Anurak for conservation consisted of 60, 70 and 77 species, respectively; and species diversity indexes were in the order of 4.43, 4.81 and 4.37.

Hirunwong (2007) revealed reforestation in the rotational agriculture plots of 1 to 7 years at Lawa Ban Sam, Mae Hong Son. He found that tree species richness in the plots were 22, 33, 32, 44, 46, 50 and 54 species, respectively; and species diversity indexes were in the order of 3.85, 4.26, 3.87, 4.25, 4.10, 4.45 and 4.98.

1.7 Research Objectives

The objectives of this research were:

(1) To study pine growths and wood productions in a series of *Pinus kesiya* Royle ex Gordon plantations in highland watershed at Boakaew Watershed Management Station, Chiang Mai province,

(2) To assess plant succession in a series of *Pinus kesiya* Royle ex Gordon plantations and the potential roles of adjacent fragmented forests on natural succession, and

(3) To investigate changes in soil properties under a series of *Pinus kesiya* Royle ex Gordon plantations