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 20th 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