CHAPTER 1

Introduction and Literature Review

1.1 Reforestation in Northern Thailand

The world's total forest area is just over four billion hectares or 31 percent of the total land area, and the global rate of deforestation is higher (FAO, 2010). Around 13 million hectares of forests were converted to other uses or lost through natural causes each year between 2000 and 2010 as compared to around 16 million hectares per year in the 1990s. South America and Africa had the highest net annual loss of forests in 2000-2010, with 4.0 and 3.4 million hectares, respectively. Asia particularly Southeast Asia had a net loss of some 2.2 million hectares annually during 2000-2010. During the 1980s, Southeast Asia had an average deforestation rate of 1.4% per year, the highest rate among all tropical regions (World Bank, 1992). During the 1990s, the yearly rate of loss in total forest cover was of between 1.4% for Burma and Indonesia, and 0.4% for Laos, with Thailand being halfway at 0.7% per year (FAO, 2000).

Thailand is the country in Southeast Asia that recorded one of the highest rates of deforestation in recent year. In 1950, the forest cover of Thailand was about 53% (Bhumibhamon, 1986), and was unofficially estimated to be 20% (Leungaramsri and Rajesh, 1992). The rate of forest loss peaked in 1977. Although commercial logging in primary forest has been terminated since 1989, the annual rate of deforestation remains about 0.5% (of remaining forest), which lost about 1% of its forest each year between 2000-2005. Illegal logging and agricultural expansion are the main causes of deforestation (Kummer and Turner, 1994). Hirsch (1987) found that deforestation in Thailand was associated with the expansion of commercial agriculture. Lambardini (1994) stated that the main cause of deforestation in Thailand is the demand of agricultural land. Swidden cultivation, also called slash-and-burn or shifting cultivation, is traditionally practiced in northern Thailand (Fox *et al.*, 1995). It involves cutting of forest vegetation in the dry season, allowing it to dry, burning and planting crops in early rainy season. According to the national forest policy of Thailand, at least 25 and 15% of the total area of the country are designated to be protection and economic forests, respectively. At present, the protection forests including national parks, wildlife sanctuaries and watershed areas cover about 26% of the total area, and effective protection of these areas is needed. Because of deforestation, losses of biodiversity and environmental degradation included increasing sedimentation, reducing rainfall amount, and increasing water runoff, flooding during the rainy season, and drought during the dry season (Kanwanich, 1997).

Reforestation is one particular form of forest restoration. The term, "reforestation" means the re-establishment of any kind of tree cover, including plantations and agro-forestry on the land of previously covered forest. The term forest restoration is confined to the re-establishment of entire forest ecosystems, as similar possible to the original forest ecosystems that were present before forest clearing.

Forest restoration involves planting native tree species and extending forest boundaries by artificial and natural regeneration (Bawa *et al*., 1990). Government and non-governmental organizations and local communities have involved in restoring forests.

Forest plantation in Thailand is divided into propose plantation for commercial purpose and watershed restoration. The favorite fast growing tree species used for plantation on highland area is mainly *Eucalypytus camaldulensis* (Anderson, 1993) with produces harvest timber within 3-5 years, Teak (*Tectona grandis*) is the most popular economic native tree species planted on highland area.

In Thailand, tree-planting projects with using mixtures of several native forest tree species have become a popular method to restore forest in degraded areas. The success of such projects depends largely on the selection of suitable tree species and on the size and quality of planted trees. In the past, most tree nurseries in Thailand grew few species of commercial value such as teak, pine and eucalyptus, and usually for the establishment of monoculture plantations. Now a day, a much wider range of native forest trees was produce for high quality saplings, to satisfy a growing interest in restoring forests for conservation and environmental protection.

The northern highlands are considered the country's most important watershed and large areas of degraded forestland require urgent reforestation, through mainly monoculture plantation of pine. At the present many native broad-leaves are introduce in mixed plantation. 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 1960s, and the plantation establishment was subsequently increased. 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. Some advantages of planting *P. kesiya* in the highland are that it can grow very fast on open site with strong solar radiation, fluctuated moisture and poor soil. The roles of adjacent fragmented natural forests on succession in the plantations are significant for forest management and development of pine plantation to the climax montane forest.

Forest plantation 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 recreation value, water flow regulation, soil loss prevention, restoring the soil nutrients, improving microclimate, releasing O_2, carbon sequestration, etc. Economic value of forest restoration through forest plantation to be the climax montane forest is interesting, including both the direct and indirect benefits. In this study, the research will focus on value of timber and carbon-nutrient storage of forest ecosystems.

1.2 *Pinus kesiya* Plantations in Highland Watershed of Northern Thailand

Pinus kesiya (Khasi pine) is a conifer species with an important potential for reforestation in the tropical zone. The *P. kesiya* complex is widely distributed between 30ºN and 12ºN in Southeast Asia. It occurs in Burma, China, India, Laos, Philippines, Thailand, Tibet and Vietnam (Costa e Silva, 2007). The total plantation area of *P.kesiya* is not well known, but Vietnam alone accounts for around 250.000 ha (James and Del Lungo, 2005).

The *P. kesiya* had been widely planted on highland watershed areas of the northern part of Thailand. Establishment of *Pinus kesiya* Royle ex Gordon plantations in Thailand began in the 1960s by the Royal Forest Department. The aim was to reforest abandoned swidden areas and grasslands in order to reduce erosion and to produce timber and fuel wood (Savage, 1994). There are about 150,000 ha of *P. kesiya* plantations in northern Thailand. Most of these plantations areas located within the Protected Area System (RFD, 1993). Khasi pine was selected for plantations because being a native species, fast growing species and produces a high quality, long-fibered, pulp. *P. kesiya* has the capacity to adapt to various environmental conditions. Provided that drainage is good, *P. kesiya* is adaptable to a broad range of soil types, to relating nutrient poor and acid to neutral soils.

P. kesiya 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; Granhof, 1983). 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).

Research on differences in *P. kesiya* was pursued. Oberhauser (1997) surveyed the plants of four *P. kesiya* plantations in the province of Chiang Mai. The age of these plantations varied between 7 and 28 years. Plantation structure changed in relation to age. 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 twelve-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 in the sample plot. Pine mortality could be observed in a 21-year-old plantation, and tree seedlings were found in the ground layer of this stand. A 28-year-old site was diverse in tree species although dominated by *P. kesiya*. Oberhauser (1997) noticed that 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. Many of the tree species recorded were just seedlings or small saplings, which may not even survive; furthermore, few of the seedlings were pines.

Homjeen (1997) surveyed the growth of *P. kesiya* plantations in Huey Bong Experimental Station, Chiang Mai province. Annual height increments during 1-10 and 10-20 years 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 years 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 years old, 1.14 $m.yr^{-1}$, whereas the best stem diameter growth was 15-20 years old, 1.06 $cm.yr^{-1}$. 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 years after planting, very slow during 12 and 32 years old, 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^3ha^{-1}, respectively. Many factors particularly tree density, thinning and nutrient availability might be affected on these variations.

Indeed substantial variation in growth and morphology from trees planted in a wide variety of countries is well documented (Burley and Armitage 1980). As noted by Pousujja (1986) the wide but discontinuous natural range of *P. kesiya* would be expected to result in large provenance differences. For example, 5 year old stands results from a provenance test at Huay Tong in Chiang Mai, Thailand demonstrated substantial difference in height growth among the 18 provenances (Granhof 1978). The best provenance in Thailand was Doi Inthanon, Chiang Mai. The volume increment was 4-9 $m^3ha^{-1}yr^{-1}$, and produced 250 m^3ha^{-1} in about 28 years at best with the intensive management (Granhof, 1983). Boa Luang provenance had the lower increment volume (1.92-6.00 $m^3ha^{-1}yr^{-1}$) (Pousujja, 1984). Silvicultural practices in pine plantation are very important for growth and productivity.

1.3 Biomass and Carbon Sequestration

In recent years, carbon sequestrations due to reforestation have been a world-wide concern. The debate about the global carbon accounting the role of forest biomass as potential carbon sources and sinks receives increasing attention. The increase of carbon dioxide in the atmosphere and its possible greenhouse effect on global climate has become one of today major environment issues. Primarily because of Kyoto Protocol rules, interest in carbon cycling has been focused on modified natural forests and plantation forest. Forests store carbon in form of living trees, forest floor detritus, soil and wood production (Dewar and Channel, 1991). Approximately 680 billion tons of carbon is held in the atmosphere. Forests currently hold approximately 1,088 billion tons of carbon in plants and soils out of 1,814 billion tons in all terrestrial vegetation and soils (Houghton *et al*., 1990; Dixon *et al*., 1994). The report on greenhouse effect in Thailand showed that forestry sector released carbon amount of 16.5 x 10^7 Mg. (or emission of 60.5 x 10^7 of CO_2) in 1994. However, the amount of carbon released in 1994 was about 70% of 1990 because of increasing reforestations and decreasing deforestation (Puangchit, 2004). Reforestation is important for carbon sequestration and reduced CO_2 emission.

Carbon accumulations in forest biomass can be calculated from carbon contents and biomass. Carbon concentration from default value of Intergovernmental Panel on Climate Change (IPCC) was about 50%, so carbon content was about 50% of biomass (IPCC, 1996). However, differences in forest structure and species composition related to variable environment factors (such as, topography, climate etc.) affect on tree growth (Fang and Wang, 2001; Brown, 2001), carbon sequestration would be therefore different.

Most studies on biomass in plantations are trees for energy including *Acacia auriculaeformis*, *Leucaena leucocephala*, *Acacia mangium*, *Eucalyptus camaldulensis*, *Cassia siamea* and *Azadirachta indica* (Bunyavejchewin and Puriyakorn, 1985, 1986; Pransin and Nongnuang, 1986; Nongnuang and Pransin, 1996). In natural forests, Ogawa *et al.* (1965) found that leaf biomass of dominant species in the tropical rain forest, mixed deciduous forest and dry evergreen forest were 7.8, 3.8 and 4.38-5.23 $Mg.ha^{-1}$, respectively. Ladpala and PhanUthai (2006) reported that above-ground biomass in mixed deciduous forest at Maeklong, Kanjanaburi province during 2003-2005 was changed from 170.96 to 175.19 $Mg.ha^{-1}$, and it was the highest in stem as 86.55% of total biomass. Diloksumpun *et al.* (2006) found that above-ground and below-ground biomass in dry evergreen forest (DEF) at Sakaerat, Nakornrajchaseema province were higher than mixed deciduous forest (MDF) at Maeklong. In 2003, above-ground and below-ground biomass at Sakaerat were 296.49 and 139.35 $Mg.ha^{-1}$, whereas at Maeklong were 172.58 and 81.11 $Mg.ha^{-1}$, respectively.

Nualngam (2001) examined the roles of reforestation on carbon sink and some soil properties at Re-afforestation Research and Training Station, Nakhon Ratchasima province. Total carbon accumulations in above-ground biomass and soils in the plots of *A. mangium*, *A. auriculaeformis*, *E. camaldulensis*, *Xylia xylocarpa*, *Dalbergia cochinchinensis*, *Pterocarpus macrocarpus*, *Saccharum spontaneum* and *Imperata cylindrica* were 145.69, 94.01, 93.56, 85,04, 80.74, 62.30, 53.14 and 47.70 $Mg.ha^{-1}$, respectively.

Boonpragob (1996) has reviewed about the studies of biomass and carbon contents in evergreen, mixed deciduous, dry dipterocarp, pine and mangrove forest were 229, 149, 88, 102 and 162 $Mg.ha^{-1}$ at tree biomass; 337, 266, 126, 160 and 200 $Mg.ha^{-1}$ at above ground biomass; and 54, 52, 49, 48 and 55% carbon contents of dominant trees, respectively (Ogawa *et al.*, 1965). Forest structure is different among forest types, and thus affects on carbon sequestration in biomass. Negi *et al.* (2003) reported that carbon sequestration was the highest in coniferous forest, and lower in deciduous, evergreen and bamboo forests.

Rangmorya (2005) investigated carbon sequestration of deciduous forests at Queen Sirikit Botanic garden, Chiang Mai province. The carbon sequestration of dominant species was analyzed by means of CHNO analyzer with the average record of 47.50 and 46.85 $Mg.ha^{-1}$. The mixed deciduous forest (MDF) covered at 700 m altitude where dry dipterocarp forest (DDF) were at 800, 900 and 1,000 msl altitude had biomass of 1458.76, 252.46 and 234.95 $Mg.ha^{-1}$, respectively. The four permanent plots had different biomass increments; 2.73, 1.62, 1.83 and 1.96 $Mg.ha^{-1}yr^{-1}$, the carbon amounts in litter; 4.34, 1.55, 2.60 and 3.81 $MgC.ha^{-1}yr^{-1}$, and soil carbon amounts; 206.36, 96.93, 97.44 and 140.66 $MgC.ha^{-1}m^{-1}$ respectively. Net primary productivity of these deciduous forests was calculated in the order of 15.25, 6.91, 9.28 and 12.52 $Mg.ha^{-1}yr^{-1}$ (or 7.07, 3.17, 4.43 and 5.77 $MgC.ha^{-1}yr^{-1}$). Carbon sequestration in MDF was larger than DDF.

Lichaikul, *et al.* (2006) studied on carbon storage and CO_2 emissions in three land uses in the Sakaerat environmental research station, Nakornratchasrima province. These included a dry evergreen forest (DEF), a plantation of 16-year-old *A. mangium* (AC) and a corn field site (CF), The soil carbon storage in 0-50 cm layer was 118, 66, 60 $MgC.ha^{-1}$ in DEF, AC and CF soils, respectively. The total carbon storages were 418, 164 and 60 $MgC.ha^{-1}$ in DEF, AC and CF soils, respectively. More than 50% of this soil carbon was stored in the top 0-20 cm. The soil under 16-year-old plantation compared to agricultural land resulted in an increase of soil carbon about 10

MgC.ha^{-1}. On the other hand, CO_2 emission from all of these land use types was around 12-17 MgC.ha^{-1}yr^{-1}.

Tangsinmankong, *et al.* (2007) examined carbon stocks in soil of mixed deciduous forest at Huay Kha Khaeng Wildlife Sanctuary and 6, 15 and 24 year-old teak plantations of Thai Plywood Co., Ltd. in Lansak district, Uthathani province. The highest carbon stock in soil was found in 6-year-old teak plantation, followed by 24 and 15-year-old plantations and mixed deciduous forest as 157.03, 105.67, 78.78 and 70.96 MgC ha^{-1} respectively. The dissimilarity of soil organic carbon may be due to forest fire, forest management and topography.

1.4 Soils and Nutrient Cycling in Forest Ecosystems

1.4.1 Forest Soils

A brief review can be expand about forest soil (Fisher and Binkley, 2000). Soils developed under natural forests varied greatly with forest types, parent rocks, topographic conditions and climate. Forest soils in different forests usually have variable colors depending upon the position of each landscape and the type of parent rock. The soils become more reddish in color when they are found in higher position where weathering and leaching are more intense (Boul *et al*., 2003). Fertility level and soil physical properties are reported that were closely to the type of parent rock rather than forest type. In addition, a difference in thickness of soil solum under similar types of forests and parent rocks rather depended upon the position in the landscape where the soil occurred (Anusontpornperm *et al*., 2008).

Soil types are a major factor in determining what types of forest communities in a certain area. Plants use inorganic elements from the soil, such as nitrogen, potassium and phosphorus, but the communities of fungi, bacteria, and other microscopic creatures living within the soil are also vital. These living organisms help with the decomposition of dead plants and animals, breaking them down into soil. Soil is affected by climate and rainfall, geology and vegetation. The combination of sand, silt, gravel and clay gives different soils textures. Healthy, nutrient-rich soils which consist of a mixture of sand, silt, and clay are called "loam" soils. Different minerals give soil colors. Sandy soils are relatively "newly" formed compared to other soil types. It is easy for both air and water to move between the large grains of sand, so this soil type stores water very poorly and is susceptible to drought. The opposite problem occurs with clay soils. They are often waterlogged because the tiny clay particles are packed tightly together, making it hard for air and water to move through. Clay soils can be dense enough to make it difficult for plant roots to spread through them.

Trees are extremely important in soil building. Their roots grow down and break up the bedrock into smaller soil particles and their fallen leaves contribute to the nutrient richness of the soil. Tree branches intercept heavy rainfalls, and their roots provide a support structure within the soil. Both branch and root help protect soil erosion. Fallen leaves and entire fallen trees, are become decomposed and released nutrient into the soil. The organic matter is crucial because it contains the nutrients that will eventually be re-incorporated into the soil. Decomposing leaves and wood are able to store moisture like a sponge, and help the forest soil retain rainwater.

Without the organic matter from trees and other forest plants, the soil would become nothing but rocks and sand.

In temperate deciduous forests, soil is usually relatively rich. This is because every fall, the trees drop the leaves that they grew the previous spring. This vast amount of organic material contributes to the "litter layer" on forest soils. The fallen leaves are a great food source for the fungi and bacteria in the soil. These creatures slowly help the leaves to decompose, and they are eventually turned back into soil which the trees can use to grow new leaves in future seasons. The material at the top of the litter layer is newly fallen and recognizable. Towards the bottom, the older leaves are torn and usually covered with a slimy coating of microorganisms which feels gross, but it's vital to returning nutrients to the soil. Tropical rain forests contain some of the poorest soils of all. This is because of the torrential rains that fall regularly on these regions. The heavy rains dissolve nutrients in the soil, which then wash into streams and rivers and are carried away. In coniferous forests, the litter layer is made up of tough, dry needles and fallen twigs. This layer doesn't decompose easily, and remains on the ground for many years. Usually small fires burn off the fallen needles before they can decompose.

1.4.2 Soil Carbon Stocks

Carbon (C) storage in forest ecosystems involves numerous components including biomass and soil carbon. The total ecosystem carbon stock is large and in dynamic equilibrium with its environment. Because of the large areas involved at regional/global scale, forest soils play an important role in the global carbon cycle (Detwiler and Hall, 1988; Bouwman and Leemans, 1995; Sedjo, 1992). Approximately 60%–70% of carbon in forests is stored as organic material in the soil (Janssens *et al.*, 1999). Land use change causes perturbation of the ecosystem and can influence the C stocks and fluxes. In particular, conversion of forest to agricultural ecosystems affects several soil properties but especially soil organic carbon (SOC) concentration and stock (Post and Kwon, 2000). The conversion to an agricultural land use invariably results in the depletion of SOC stock by 20–50% (Schlesinger, 1985; Post and Mann, 1990. Lasco (2002) found that deforested areas covered with grasses and annual crops, have carbon amounts that are typically less than 40 $Mg\cdot ha^{-1}$. This is much less than the carbon amounts found in natural forests. The conversion of natural forests to tree plantations and perennial crops reduce carbon amount by at least 50% when compared to natural forests.

The SOC concentration in forest soils may range from 0% in very young soils to as much as 50% in some organic or wetland soils (Trettin and Jurgensen, 2003), with most soils containing between 0.3 and 11.5% in the surface 20 cm of mineral soil (Perry, 1994). Similar to SOC density, SOC concentration in mineral soils is lower in tropical forests and higher in montane and boreal forests (Jones, 1989), whereas deforestation of tropical rainforest releases 1.6–1.7 Pg.

A variety of factors may affect the amount and concentration of SOC in forest soils, those include forest management activities, deforestation, afforestation of agricultural soils and subsequent management of forest plantations. Although forestland management is generally less intensive than cropland management, there are several management options that may enhance or increase SOC stock in forests.

Management systems that maintain a continuous canopy cover as regular natural forest are likely to achieve the best combination of high wood yield and C storage (Thornley and Cannell, 2000).

1.4.3 Nutrient Cycling in Forest Ecosystems

Nutrient cycling in forests is a function of the ecosystems which makes the forest dynamics and provides sustainable yields. Many have affected major factors underlying variations in nutrient cycling in forest ecosystems including climate (Van Cleve, *et al.*, 1983), species composition, successional status (time since disturbance) (Bonnann and Likens, 1979; Vitousek and Reiners, 1975) and soil fertility (Vitousek, 1982). The input of nutrients into the ecosystem involves the movement from atmosphere, weathering of minerals, release from litterfall, and the fixing of some nutrients by microorganisms. These nutrients distribute to various parts of the ecosystem. The variations in forest types and species are largely determined by nutrient uptake, nutrient retention and nutrient utilization (Cole, 1986).

Nutrient cycling in tropical forests has been comprehensively reviewed by Vitousek and Sanford (1986), Jordan (1985), Proctor (1987) and in Proctor (1989) Soil nutrient pools are also influenced by the variability imposed by topography, drainage characteristics, disturbance history, and parent material (Jenny, 1980), in most tropical rain forests production is maintained by the turnover of the nutrient capital which is large in relation to the through-flow of element inputs from nitrogen fixation, precipitation and weathering of bedrock and losses through leaching and denitrification. Carbon and nutrient pools in the component plant and soil sub-systems can maintain long-term equilibrium. The organic matter in soil can be divided into active, slow and passive pools (Parton *et al.*, 1987, 1989) with turnover times of months, years and decades, respectively. The stability of soil organic matter (SOM) pools buffers periodic perturbations to the carbon and nutrient cycles caused by tree falls, climatic events, and large-scale disturbance by man. This concept of dynamic equilibrium is considered for biomass, SOM, nutrients and hydrology.

Over 60% of the area extent of soils in the humid tropics is composed of deeply weathered and leached Oxisols and Ultisols of low inherent fertility (Sanchez *et al.*, 1982). Some of the lowest fertility soils support rain forests of massive structure and productivity (Proctor *et al.*, 1983) as a consequence of tight cycling of limiting nutrients between vegetation and soil (Jordan 1985), efficient production of biomass per unit of limiting nutrient (Vitousek and Sanford 1986) and negligible erosion under undisturbed vegetation cover (Wiersum 1985).

The forest floor (litter, roots and soil) often contains at least 50%, and as much as 80%, of the nitrogen and phosphorus in the system and the soil pool size is large relative to annual turnover. The forest floor can contain up to 70% of the total calcium in the system but this varies widely with parent material. Calcium, nitrogen and phosphorus are mineralized quite rapidly in litter (weeks/months) but organic complexes in the larger SOM pools have much slower turnover times (years/decades). The turnover of N between plants and soil pools suggests that it is rarely limiting to production in tropical forests except on some Spodosols and in montane systems where there are temperature or moisture constraints on decomposition processes (Vitousek and Sanford, 1986; Medina and Cuevas, 1989). In contrast, P may be more generally limiting because of the small mass in circulation in most forests, small inputs from the atmosphere to compensate losses from the available pools, and fixation by iron and aluminium oxides in highly weathered, acid soils. Potassium and magnesium are important nutrients for higher plants but rarely limit microbial processes and are rapidly lost from decomposing litter (Anderson *et al.*, 1983). In acid soils with low cation exchange capacity, plant biomass is important for the retention of these nutrients. The ramification of tree roots through litter on the forest floor may reduce leaching losses of nutrients by direct uptake of K, Mg and Ca (Medina and Cuevas, 1989). There is also evidence of direct uptake of P from litter by roots (Herrera *et al.*, 1978) so that the mineral soil pathway is bypassed.

Some researches on nutrient cycling in plantations have been conducted. Jutikitdaecha (1996) studied on nutrient cycling in *Eucalyptus camaldulensis* stands planted with different density. Wichiennopparat *et al.* (1999) did research on nitrogen and phosphorus accumulations in the green foliage, senescent leaves and leaf litter of *E. camaldulensis* and *Acacia auriculaeformis* in mixed species plantations.

Parathai (2003) studied on carbon and nutrient accumulations in *Pinus kesiya* plantations at Doi Boa Luang Plantations, Chiang Mai province. Soil organic matter was increased with stands age, varied between 17.3-66.8 $g.kg^{-1}$. The amounts of carbon in one-meter soil profiles varied between 48.64-89.20 $MgC.ha^{-1}$, and 3,243-5,947 $kg.ha^{-1}$ for nitrogen. Forest fire and soil erosion were important factors affecting soil properties.

Many researches on soil properties in pine plantations have been conducted in foreign countries, and very few are taken in Thailand (McColl and Power, 1984). The pine included many species such as *P. resionosa, P. elliottii* var. *elliottii*, *P. radiata, P. taeda*, P. *resinosa* (red pine), *P. palustris* (slash-longleaf pine), *P. kesiya*, *P. contorta* (lodgepole pine), etc. In Thailand, Parathai (2003) studied on soil properties under *P. kesiya* plantation at Doi Boa Luang, Chiang Mai. He concluded that bulk density of the top soil (0-10 cm) and texture during 7-37 year-old plantations were not different among the plantations. It varied between 1.0-1.6 $Mg.m^{-3}$. The pH varied between 4.9-6.1 (moderately acid to strongly acid). It was slightly decreased in the old stands. Organic matter was increased with stand age and varied between 17.3-66.8 $g.kg^{-1}$. The amounts of organic matter, carbon and nitrogen in one-meter soil profiles of 7-37 year-old stands were 83.86-153.80 $Mg.ha^{-1}$, 48.64-89.20 $kg.ha^{-1}$, and 3,243-5,947 $kg.ha^{-1}$, respectively.

Some other chemical properties, base saturation, extractable acidity and cation exchange capacity were influenced by both parent material and vegetation. Soils formed from granite, diorite, gneiss, phyllite and quartzite under mixed deciduous forest, secondary forest and cultivated teak plantation in Kanchanaburi province, west of Thailand, all soils were moderately fertile and rich in organic matter contents (35.88-60.37 $g.kg^{-1}$) in the top soils, whereas soils formed from slate, phyllite and quartzite under secondary, hill evergreen forest in Ang Khang area in Chiang Mai province, northern Thailand, had high organic matter contents in the surface layer, ranging from 38.67-85.52 $g.kg^{-1}$ (Anusontpornperm *et al.*, 2004).

1.5 Economics Valuation of Ecosystem Services

1.5.1 Ecosystem Services

Ecosystems are recognized around the world as natural capital assets supporting and supplying services highly valuable to human livelihoods (MEA, 2005). There is a growing appreciation of the important role that ecosystems play in providing goods and services that contribute to human welfare, as well as a growing recognition of the impact of human actions on ecosystems.

These ecosystem ‘services’ are provided free-of-charge as a gift of nature. Examples of ecosystem services include the purification of air and water; regulation of rainwater run-off and drought; waste assimilation and detoxification; soil formation and maintenance; control of pests and disease; plant pollination; seed dispersal and nutrient cycling; maintaining biodiversity for agriculture, pharmaceutical research and development and other industrial processes; protection from harmful ultraviolet radiation; climate stabilization (for example, through carbon sequestration); and moderating extremes of temperature, wind, and waves. Fisher *et al.* (2009) define ecosystem services as the aspects of ecosystems utilized (actively or passively) to produce human well being. Based on this definition, they provide a classification with four levels: (1) Abiotic inputs: such as sunlight, rainfall or nutrients; (2) Intermediate services: like soil formation, primary productivity, nutrient cycling, photosynthesis, pollination, etc.; (3) Final services: water regulation, primary productivity; and (4) Benefits: water for irrigation, drinking water, electricity from hydro-power, food, timber, non timber products. These final benefits are what they value in economic terms and are always derived from intermediate or final services. The Millennium Ecosystem Assessment (MEA) classifies the services that ecosystem can provide into provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services, such as nutrient cycling, that maintain the conditions for life on Earth. These categories illustrate the diverse ways in which ecosystems contribute to human well-being (MEA, 2005). Despite the services they provide, natural ecosystems worldwide are under tremendous pressure.

This awareness has lead to the recent interest in integrating ecology and economics (Polasky, 2009). The estimation of the economic value of ecosystem services is expected to play an important role in conservation planning and ecosystem-based management (Plummer 2009; Stenger *et al.*, 2009), as well as for ensuring that human actions do not damage the ecological processes necessary to support the continued flow of ecosystem services on which welfare of present and future generations depends (MEA, 2005). A lack of economic valuation could underestimate the importance of such resources and leave to a detriment on the ecosystem services supply. As a consequence, there is an increasing consensus about the importance of incorporating the “ecosystem services approach” (MEA, 2005) into resource management decisions. However, quantifying the levels and values of these services has proven difficult (Nelson *et al.*, 2009).

1.5.2 Valuing ecosystem services

Economists typically classify ecosystem goods and services according to how they are used. The main framework used is the Total Economic Value (TEV) approach (Pearce and Warford, 1993). The breakdown and terminology vary from analyst to analyst, but generally include (1) direct use value; (2) indirect use value; (3) option value; and (4) non-use value. The first three are generally referred to together as ‘use value’.

(1) Direct use values refer to ecosystem goods and services that are used directly by human beings. They include the value of *consumptive uses* such as harvesting of food products, timber for fuel or construction, and medicinal products and hunting of animals for consumption; and the value of *non-consumptive uses* such as the enjoyment of recreational and cultural activities that do not require harvesting of products. Direct use values are most often enjoyed by people visiting or residing in the ecosystem itself.

(2) Indirect use values are derived from ecosystem services that provide benefits outside the ecosystem itself. Examples include the natural water filtration function of wetlands, which often benefits people far downstream, the storm protection function of coastal mangrove forests, which benefits coastal properties and infrastructure, and carbon sequestration, which benefits the entire global community by abating climate change. These functions often affect activities that have directly measurable values, allowing their value to be estimated.

(3) Option values are derived from preserving the option to use in the future ecosystem goods and services that may not be used at present, either by oneself (*option value*) or by others/heirs (*bequest value*). Provisioning, regulating, and cultural services may all form part of option value to the extent that they are not used now but may be used in the future.

(4) Non-use values refer to the enjoyment people may experience simply by knowing that a resource exists even if they never expect to use that resource directly themselves. This kind of value is usually known as *existence value* (or, sometimes, *passive use value*).

1.5.3 Valuation techniques

Many methods for measuring the utilitarian values of ecosystem services are found in the resource and environmental economics literature, e.g., Production function (also known as ‘change in productivity’), Replacement cost (and variants, such as relocation cost) Travel cost methods (TCM), Hedonic pricing methods, Contingent valuation (CV), Choice modeling and Benefits transfer (Pearce and Moran, 1994; Pagiola, 1996). A common feature of all methods of economic valuation of ecosystem services is that they are founded in the theoretical axioms and principles of welfare economics. Most valuation methods measure the demand for a good or service in monetary terms, that is, consumers willingness to pay (WTP) for a particular benefit, or their willingness to accept (WTA) compensation for its loss (Hanneman, 1991; Shogren and Hayes, 1997). These valuation techniques have been used extensively in recent years, and a growing literature exists on their application (Hufschmidt, *et al.*, 1983; Pearce and Markandya, 1989; Braden and Kolstad, 1991;

Pearce, 1993; Dixon, *et al.*, 1994; Freeman, 2003; Pagiola, 1996). These techniques can and have been applied to a very wide range of issues, including efforts to estimate the benefits of entire ecosystems such as forests (Bishop, 1999), wetlands (Barbier, 1994), and watersheds (Aylward, 2004; Kaiser and Roumasset, 2002). Other studies have focused on the value of particular ecosystem goods and services such as carbon storage (Fankhauser, 1995), non-timber forest products (NTFPs) (Lampietti and Dixon, 1995), biodiversity (Pearce and Moran, 1994; Barbier, *et al.*, 1995; Pearce, *et al.*, 2002). Some of these techniques are widely used, others only selectively so (Dixon, *et al.*, 1994).

A variety of methods has been applied in order to compare outcomes from different methods on a given issue (Van den Bergh, *et al.*, 1999 and Florax, 2002). For example, when using the travel cost method, researchers estimate the economic value of recreational sites by looking at the generalized travel costs of visiting these sites (Bockstael, *et al.*, 1991). Conversely, practitioners of the hedonic price method estimate the economic value of an environmental commodity, say, clean air, by studying the relation between house prices and air quality (Palmquist, *et al.*, 1991). The averting behavior or production cost function methods is characterized by exploring the relationship of the environmental commodity through a generalized cost function (Cropper and Freeman, 1991). For instance, improvement of air quality can be assessed on the basis of expenditures made to avert or mitigate the adverse effects of air pollution. Avoided damage costs, preventive expenditures, repair costs (or restoration), compensation costs, replacement costs, and relocation costs are specific instances of this method. Replacement cost approach has been the most commonly applied in the economic evaluation of soil services, especially as related to developing countries (Grohs 1994; Bojö 1996) and it uses a wide array of valuation techniques as developed by the environmental economics literature (Dixon *et al.*, 1994; Organization for Economic Cooperation and Development, 1995).

1.5.4 Economic Valuation of Tropical Forest in Thailand

Wangwacharakul and Bowonwiwat (1995) investigated the economic evaluation of protected forests in Thailand. The Khao Yai national park had been identified for the main benefits of the park as watershed protection (water supply and soil stabilization), maintenance of biodiversity, tourism, research and education. The total quantifiable benefits of the Khao Yai national park (watershed protection, tourism and research) were approximately US$ 8 million yr^{-1}. With the remaining forest area of 1,918 km^2. (1.92 million ha) in 1985, out of a total area of 2,257 km^2., the benefits of the Khao Yai national park were US$ 4.2 $ha^{-1}yr^{-1}$. However, the economic benefits of this national park are probably much higher than those of other parks, because it is near Bangkok, and is a popular recreational destination. It is also an important source of water for the Lum Ta Khong reservoir, the most important water source for Nakhon Ratchasima province.

The only economic evaluation of the largest wildlife sanctuary in Thailand, Huay Kha Kaeng/Thung Yai, was conducted by the World Wide Fund for Nature (Dobias *et al.*, 1998). The main quantifiable benefits of the sanctuary, watershed protection and research uses, were estimated to be US$ l4 million yr^{-1}. Since the land areas associated with these benefits, 5.8 million ha, the annual per-ha benefits amounted to US$ 2.4. Sherman and Dixon (1989) estimated the recreational benefits of the non-hunting area of Thale Noi in southern Thailand to be about US$ O.2 million, while Loypha (1989) estimated the recreational benefits of the same area to be US$ O.44 million. Loypha noted a substantial difference in estimates using the travel cost and contingent valuation approaches. Total benefits using the later approach were only US$ O.13 million. In a non-hunting area, Bueng Borapet in Nakorn Sawan province the travel-cost approach was also used. The per-ha benefits in 1990 were calculated to be only US$ 2.5. The other wildlife sanctuaries are relatively small and less attractive than the areas discussed above. The average benefits from these areas are likely to be lower. It is assumed in this paper that the recreational benefits of wildlife sanctuaries and national parks are US$ 1.2 and US$ 2.0 $ha^{-1}yr^{-1}$, respectively. The benefits of watershed forests are more difficult to quantify. Although the main benefits often cited are the protection of water resources and prevention of erosion and sedimentation, no study to date specifically attributes a monetary figure to these based on the Khao Yai national park and Huay Kha Khaeng/Thung Yai cases, the watershed area protection benefits are assumed to be US$ 1.2 $ha^{-1}yr^{-1}$.

In 1995, Wangwacharakul and Bowonwiwat (1995) studied the benefit-cost analysis approach to evaluate the potential of the forestry sector in Thailand to reduce carbon emissions of the country. Protecting conserved forests can avoid a substantial amount of carbon emission from deforestation, although certain costs are attached. Reforestation also enhances carbon sequestration and, in most cases, incurs no cost to society. Under the present government's commitment to fully protect the conserved forests and reforest the deforested areas in the country, Thailand could reduce the growth of carbon emission by as much as 260 million tons over the next two decades. The costs to society, if any, would be small given other, non-quantifiable, benefits of the forests.

1.6 Research Objectives

(1) To evaluate economic values of forest plantation ecosystems (a series of *Pinus kesiya* plantations with plant succession) in terms of wood production as direct benefit, and carbon and nutrient storages as indirect benefits,

(2) To make comparison of economic values between forest plantation ecosystems and adjacent fragmented forests as well as climax montane forest on highland watershed