CHAPTER 1

Introduction and Literature Review

1.1 Global Warming Situation

Carbon is important as the basis for the food and fiber that sustain and shelter human populations, as the primary energy source that fuels economies, and as a major contributor to the planetary greenhouse effect and potential climate change. Carbon dioxide (CO_2) is the largest single forcing agent of climate change, and methane (CH_4) is also a significant contributor. Atmospheric concentrations of CO_2 and CH_4 have been increased for about two centuries as a result of human activities and are now higher than they have been for over 400,000 years. Since 1750, CO_2 concentrations in the atmosphere have increased by 30% and CH_4 concentrations in the atmosphere have increased by 150%. Approximately three-quarters of present-day anthropogenic CO_2 emissions are due to fossil fuel combustion (plus a small amount from cement production); land-use change accounts for the rest. The strengths of CH_4 emission sources are uncertain due to the high variability in space and time of biospheric sources (IPCC, 2001) production or changing land use and management (e.g., reducing deforestation).

Forest growth and conversion of forests to long-lived wood products increase the carbon stored in the pool of forest products. Better land management practices (e.g., reduced soil tillage in cropping systems), increased agricultural productivity, and conversion from cropland to grassland can increase carbon storage in soil. However, changes in land use and management, such as clearing forests and grasslands and intensive tillage and harvest practices, release CO_2 to the atmosphere.

1.2 Roles of Plantation Forests on Global Warming

The report on emission greenhouse effect in Thailand showed that forestry sector released carbon amount of 16.5 x 10^7 Mg (or 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 the increasing forest plantations and decreasing deforestation (Puangchit, 2004). Reforestation and afforestation are thus important for carbon sequestration and reduced CO_2 emission as well as global warming.

As the Royal Forest Department reported that the forest area in Thailand was descending until remaining 81 x 10^7 rai (25.3% of country area) in 1998, and the forest cover in the north was about 43.06% of total areas (Charuphat, 1998). Most forests in this region cover on mountainous areas which are head watershed of the main rivers. Reforestation in devastated watershed areas is therefore very important, and it has been conducted since 1975 by Watershed Development Units, Royal Forest Department (Watershed Management Division, 1992). Three needle pine, *Pinus kesiya*, is the most common tree species for monoculture plantation in highland according to many advantages. It is a fast growing evergreen species which can grow on poor soil and tolerates to drought, low temperature as well as strong solar radiation.

Growth rate and production of *P. kesiya* in plantations are different during stand development, and varied with sites. Silvicultural practices such as spacing, weeding, pruning and thinning are also affected on the growth and production. 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). Oberhauser (1997) has stated that *P. kesiya* plantations might indeed speed up the succession process. Plant succession in pine plantations is important that will increase ecological production of ecosystem.

Nutrient cycling in pine plantation ecosystem is altered during the stand development. As trees grow biomass accumulations are occurred in the parts of stem, branch, root and needle. Litter fall is increased in early stage and stable in mature stands. Carbon and other nutrients released from decomposing litter are accumulated in soil system. Forest growth results in increasing carbon stored in biomass. Carbon sequestration could accumulate in aboveground biomass (leaf, bark, stem, branch and reproductive organs) and belowground biomass (root) (Pumijumnong, 2004). Carbon fixing is depended on many factors, such as species, growth rate, aging, rotation, rainfall, seasoning, site and location etc. Annual carbon fixing of trees were high in the initial stage of plantation (Ciesla, 1995). In forests anywhere between 15 and 800 years of age, the net carbon balance of the forest and soils is usually positive– meaning they absorb more carbon dioxide than they release. Forests use carbon dioxide as building blocks for organic molecules and store it in woody tissues. In the 1960s, a study from a single plantation suggested that forests 150 or more years old give off as much carbon as they take up from the atmosphere, and are thus "carbon neutral". Historic and current land-use changes and resource management practices impact the overall carbon cycle, such as clearing forests and grasslands and intensive tillage and harvest practices, release CO_2 to the atmosphere (Law, 2008).

1.3 Roles of Forest Soils

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 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 soften heavy rainfalls, and their roots provide a support structure within the soil, two factors that help prevent erosion.

Fallen leaves, and indeed entire fallen trees, are the soil for future forests. This organic matter is crucial because it contains the nutrients that will eventually be re-incorporated into the soil. It is also important in a partially decomposed state. Rotting leaves and wood are able to store moisture like a sponge, and help the forest soil retain rainfall. 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.

Too much precipitation results in the "leaching" of the soil. This happens when the water washes away most of the minerals and other nutrients. Water can also contribute to the soil's acidity, because as it moves through the soil, it removes minerals and leaves hydrogen atoms behind. The more hydrogen in the soil, the more acidic it becomes. This, however, only becomes a problem in areas with frequent, heavy downpours, and in these cases, plants have adapted to grow in poor soils. Leaching of the soil in these areas is natural, and in most other cases water moving through the soil is very beneficial to forests.

At the end of each growing season in a temperate forest, over 70% of the biomass produced that year falls to the ground. This includes leaves, needles, twigs, and other organic material. It is then decomposed by fungi, and the nutrients return to the soil where they are re-used by other plants and trees.

Through their roots, trees bring water up from deep down in the subsoil. A large tree can release over 100 gallons of water into the air each day. This water vapor becomes part of the area's microclimate, which would be much drier without the moisture input from trees.

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 content (35.88-60.37 $g.kg^{-1}$) in the top soil layers, whereas soils formed from slate, phyllite and quartzite under secondary, hill evergreen forest in the Ang Khang area in Chiang Mai province, northern Thailand, had high organic matter content in the surface layer, ranging from 38.67-85.52 $g.kg^{-1}$soil (Anusontpornperm *et al.*, 2004).

Forest type played an important role in contributing organic residues to the soil and later become soil organic matter which was found in substantial amounts under native forest, both in hill evergreen forests and secondary forest. Reforestation using a single, tree species could increase the amount of organic matter at the surface but, without ground cover, this layer was much thinner than that under natural conditions. In addition, forest type could be of importance in terms of reducing water erosion, which carries away fine particles including organic matter particles from soil surface, and subsequently allows the organic matter to be leached downward within soil profiles as indicated by taxonomic units, namely Humults (Anusontpornperm *et al.*, 2008).

1.4 Nutrient Cycling in Forest Ecosystem

Soil organic matter consists of plant and animal residue in various stages of degradation. Inputs come from dead plant and animal tissues, often referred to as detritus, which accumulate at soil surface. A large fraction of the nutrients in forest ecosystems is stored in the soil and detritus. Except in old-growth forests, the organic matter in the surface layers of mineral soils generally comprises most of the total organic matter in forest ecosystems. All but the most recalcitrant fractions constantly undergo chemical breakdown by soil organisms that compose and resynthesize the material to form complex carbon-based compounds. Typically, the organic matter concentration of the surface of forest soils range from 0.5-5% by weight. It has profound effects on the chemical, physical and hydrological properties of forest soils and plays a critical role in forest nutrient. Soil organic matter is a major energy source for soil macro and micro invertebrates and is an important component of the global carbon cycle (Landsberg and Gower, 1997).

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.

Carbon sinks and nutrient accumulations in ecosystem of a series of *Pinus kesiya* plantations Boakaew Watershed Management Station will give information at a local scale as a basis for forest management. Roles of succession tree species in the pine plantations can be assessed by this concept. Changes of carbon-nutrient accumulations in pine plantations can be compared with adjacent fragmented forests in reforestation areas. The data of biomass, carbon and nutrient accumulations in ecosystems of *Pinus kesiya* plantations are very useful for improving reforestation techniques and management.

Biomass is the mass of living organisms in a given area or ecosystem at a given time. It can be measured in term of the dried weight (Kiratiprayoon, 1999). Most studies on biomass in plantations are trees for energy tree including *Acacia auriculaeformis*, *Leucaena leucocephala*, *A. mangium*, *Eucalyptus camaldulensis*, *Cassia siamea* and *Azadirachta indica* (Bunyavejchewin and Puriyakorn, 1985, 1986; Bunyavejchewin *et al*., 1985; Bunyavejchewin and Wisetsiri, 1986; Pransin and Nongnuang, 1996; Pitpreecha *et al*. 1988; 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 t/ha, respectively. Ladpala and PhanUthai (2006) reported that above-ground biomass in mixed deciduous forest at Maeklong, Kanjanaburee province changed during 2003-2005 were 170.96 and 175.19 t/ha, 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 DEF at Sakaerat, Nakornrajchaseema province were higher than MDF at Maeklong. In 2003, above-ground and below-ground biomass at Sakaerat were 297.49 and 139.35 t/ha, respectively, whereas at Maeklong were 172.58 and 81.11 t/ha.

Boonpragob (1996) reviewed about the studies of biomass and carbon content in evergreen, mixed deciduous, dry dipterocarp, pine and mangrove forest were 229, 149, 88, 102 and 162 t/ha at tree biomass; 337, 266, 126, 160 and 200 t/ha at above ground biomass; and 54, 52, 49, 48 and 55% at carbon content of dominant tree, respectively.

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.

In Thailand, Jampanin (2004) revealed that above-ground biomass in hill evergreen (HEF), mixed deciduous (MDF) and dry evergreen (DEF) forests at Kaeng Krachan National Park were in the order of 128.99±32.70, 93.12±43.10 and 35.40±5.55 t/ha. The carbon sequestration in above-ground biomass was the highest in HEF as 129.00±32.70 tC/ha. Those in MDF and DEF were 93.15±43.10 and 37.13±2.63 tC/ha. In HEF, litter production and litter decomposition rates were 4.49 and 3.83 t/ha/yr, and carbon sequestration in above-ground NPP of primary and secondary (disturbed) forests were 7.23 and 6.65 tC/ha/yr, respectively. In MDF, litter production and litter decomposition were 2.76 and 2.35 t/ha/yr, and carbon sequestration in above-ground NPP of primary and secondary (disturbed) forests were 7.67 and 5.02 tC/ha/yr respectively. In DEF, litter production and litter decomposition were 7.90 and 3.55 t/ha/yr, and carbon sequestration in above-ground NPP of primary and secondary (disturbed) forests were 5.44 and 7.31 tC/ha/yr, respectively.

Rangmorya (2005) studied on 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 t/ha. The 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 t/ha, respectively. The biomass increments of 4 permanent plots were calculated as 2.73, 1.62, 1.83 and 1.96 t/ha/yr, respectively. The carbon amounts in litter of 4 permanent plots were measured as 4.34, 1.55, 2.60 and 3.81 tC/ha/yr, respectively. Carbon amounts in soils of 4 permanent plots were 206.36, 96.93, 97.44 and 140.66 tC/ha/m, respectively. Net primary productivity of these deciduous forests were calculated in the order of 15.25, 6.91, 9.28 and 12.52 t/ha/yr (or 7.07, 3.17, 4.43 and 5.77 tC/ha/yr). Carbon sequestration in MDF was larger than DDF.

Ladpala and Junmahasatein (2006) studied carbon contents in stems and leaves of trees in MDF at the Maeklong watershed research station, Kanchanaburi province between 2003-2005. The average contents in stem and leaf of dominant species were 49.01 and 48.81%, respectively. The above-ground carbon stock was calculated as 91.27 t/ha with 87.07 t/ha in living part and 4.20 t/ha in dead part. Variations of carbon contents with different tree height of the same species were not statistically significant but significant difference among tree species were observed. The carbon contents of most species were lower than 50% except for *Xylia xylocarpa* and *Vitex peduncularis* (50.17%).

Diloksumpun *et al.* (2006) studied on carbon cycling in DEF at Sakaerat, Nakhon Ratchasima province and MDF at Maeklong, Kanchanaburi province. In 2003, carbon accumulations in above-ground and below-ground in DEF were 145.56 and 68.41 t/ha, respectively whereas MDF were in the order of 84.24 and 39.59 t/ha. They were higher in DEF than MDF. Junmahasatein *et al.* (2006) found that the mean carbon storages in one-meter soils were 210.89 t/ha for DEF and 223.91 t/ha for MDF.

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.

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 *Acacia mangium*, *A. auriculaeformis*, *Eucalyptus 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 t/ha, respectively. Nutrient accumulations in plants depended on biomass and found that N > Ca > K > Mg > P.

Parathai (2003) studied on carbon and nutrient accumulations in *Pinus kesiya* plantations at Doi Boa Luang Plantations, Chiang Mai province. Organic matter was increased with stands age, varying 17.3-66.8 g/kg. Carbon and nitrogen varied as organic matter. The amounts of organic matter in one-meter soil profile of 7-37 years old stands were 83.86-153.80 t/ha, carbon: 48.64-89.20 t/ha, and nitrogen: 3,243-5,947 kg/ha. Concentrations and amounts of extractable P, Ca and Mg in soil were higher in older stands, but K was adversely lower. Forest fire and soil erosion were important factors affecting soil properties.

Paowongsa (1976) found that the amount of litterfall in DDF at Sakaerat, Nakhon Ratchasima province was 4.66 t/ha/yr whereas that at Doi Saket district, Chiang Mai was 4.34 t/ha/yr (Hongthong, 1994). In a natural pine forest, Ratanawatkul *et al.* (1999) reported that the amount of litterfall was 7.18 t/ha/yr. It composed of leaf, twig, fruit, pollen and others with amounts of 3.34, 2.62, 0.71, 0.02 and 0.48 t/ha/yr, respectively.

1.5 Research Objectives

Objectives of this research are:

1) To study biomass, carbon and nutrient accumulations in ecosystems of a series of *Pinus kesiya* plantations compared to adjacent fragmented forests at the Boakaew Watershed Management Station, Chiang Mai province and
2) To evaluate the ecological roles of *Pinus kesiya* plantations on carbon storages