CARBON SEQUESTRATION POTENTIAL IN ABOVEGROUND BIOMASS OF THONG PHA PHUM FOREST ECOSYSTEM

Miss Jiranan Terakunpisut

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science in Zoology

Department of Biology
Faculty of Science
Chulalongkorn University

Academic Year 2003
ISBN 974-17-5280-6

ศักยภาพการสะสมธาตุคาร์บอนในมวลชีวภาพเหนือพื้นดินของระบบนิเวศป่าทองผาภูมิ

นางสาวจิรนันท์ ธีระกุลพิศุทธิ์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
สาขาวิชาสัตววิทยา ภาควิชาชีววิทยา
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Thesis Title	CARBON SEQUESTRATION POTENTIAL IN ABOVEGROUND BIOMASS OF THONG PHA PHUM FOREST ECOSYSTEM
By	Miss Jiranan Teerakunpisut
Field of Study	Zoology
Thesis Advisor	Associate Professor Nantana Gajaseni, Ph.D.

Accepted by the Faculty of Science, Chulalongkorn University in Partial Fulfillment of the Requirements for the Master's Degree

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จิรนันท์ ธีระกุลพิศุทธิ์: ศักยภาพการสะสมธาตุคาร์บอนในมวลชีวภาพเหนือพื้นดินของระบบนิเวศป่าทองผาภูมิ (CARBON SEQUESTRATION POTENTIAL IN ABOVEGROUND BIOMASS OF THONG PHA PHUM FOREST ECOSYSTEM) อาจารย์ที่ปรึกษา: รศ.ดร.นันทนา คชเสนี 129 หน้า. ISBN 974-17-5280-6.

การศึกษาครั้งนี้มีวัตถุประสงค์ที่จะวิเคราะห์ศักยภาพการสะสมธาตุคาร์บอนในมวลชีวภาพเหนือพื้นดินและผลผลิตขั้นปฐมภูมิสุทธิของป่าทองผาภูมิ โดยแบ่งการประเมินข้อมูลออกเป็น 2 ส่วน คือ 1) มวลชีวภาพเหนือพื้นดิน 2) ผลผลิตขั้นปฐมภูมิสุทธิ ในส่วนแรกทำการวัดเส้นผ่าศูนย์กลางระดับอกขนาด ≥ 4.5 เซนติเมตร ของต้นไม้ทุกต้นในแปลงตัวอย่างแล้วคำนวณจากสมการอัลโลเมตริก การสะสมธาตุคาร์บอนเหนือพื้นดินคำนวณโดยนำค่ามวลชีวภาพคูณด้วย conversion factor ซึ่งมีค่าเท่ากับ 0.5 ผลการศึกษาพบว่าการสะสมธาตุคาร์บอนแตกต่างกันในป่าแต่ละประเภท โดยป่าดิบชื้น (ต้นไม้ยักษ์และบ้านพัสดุกลาง) มีค่าสูงกว่าป่าดิบแล้ง (KP 27) และป่าเบญจพรรณ (โป่งพุร้อน) โดยค่าที่ได้ตามลำดับเป็นดังนี้ 137.73±48.07, 70.81±1.08, 70.29±7.38 48.14±16.72 ตัน คาร์บอน/ เฮกแตร์ เนื่องจากความหลากหลายในแง่ของที่อยู่อาศัยในป่าแต่ละประเภทส่งผลให้การสะสมของมวลชีวภาพ องค์ประกอบของพันธุ์ไม้ และความสัมพันธ์อัลโลเมตริกที่ใช้ในป่าแตกต่างกันไป รูปแบบการกระจายของขนาดต้นไม้ในพื้นที่ที่ทำศึกษามีความคล้ายกัน คือต้นไม้ที่พบมากสุดคือขนาด ≥ 4.5 – 20 เซนติเมตร ซึ่งต้นไม้ที่มีขนาดเล็กเหล่านี้เป็นขนาดของกลุ่มไม้มีศักยภาพต่ำสุดในการสะสมธาตุคาร์บอนแต่จะเป็นตัวหลักบอกถึงศักยภาพของป่าในอนาคต โดยกลุ่มไม้เหล่านี้จะเจริญต่อไปนั่นหมายถึงไม้กลุ่มนี้มีความสามารถที่จะเพิ่มการสะสมมวลชีวภาพและธาตุคาร์บอนได้ขึ้นไปอีก

ส่วนการประเมินหาอัตราผลผลิตขั้นปฐมภูมิสุทธิอยู่บนพื้นฐานของการใช้ Miami model โดยปัจจัยที่คำนึงถึงได้แก่อุณหภูมิและปริมาณน้ำฝนเฉลี่ยรายปี จากการศึกษาพบว่าอัตราผลผลิตขั้นปฐมภูมิสุทธิส่วนที่อยู่เหนือพื้นดินประเมินได้เท่ากับ 10.34 ตัน คาร์บอน/ เฮกแตร์/ ปี และพบว่าปริมาณน้ำฝนเฉลี่ยรายปีใช้เป็นดัชนีชี้วัดค่าผลผลิตขั้นปฐมภูมิสุทธิได้ดีกว่าอุณหภูมิเฉลี่ยรายปี อาจเป็นเพราะว่าพื้นที่ในการศึกษาตั้งอยู่ในเขตร้อนที่ซึ่งปริมาณแสงและอุณหภูมิไม่ได้เป็นปัจจัยจำกัดสำหรับผลผลิตขั้นปฐมภูมิสุทธิของป่า

ภาควิชา.................ชีววิทยา.............. ลายมือชื่อนิสิต....Jiranan Terakunpisut....
สาขาวิชา................สัตววิทยา............ ลายมือชื่ออาจารย์ที่ปรึกษา....[signature]....
ปีการศึกษา.............2546.................ลายมือชื่ออาจารย์ที่ปรึกษาร่วม........–........

4472238423: MAJOR ZOOLOGY
KEY WORD: carbon sequestration / aboveground biomass / net primary productivity / allometric equation / Miami model

JIRANAN TERAKUNPISUT: CARBON SEQUESTRATION POTENTIAL IN ABOVEGROUND BIOMASS OF THONG PHA PHUM FOREST ECOSYSTEM. THESIS ADVISOR: ASSOC. PROF. NANTANA GAJASENI, Ph.D. 129 pp. ISBN 974-17-5280-6.

The aim of this study is to assess the potential of carbon sequestration in aboveground biomass and net primary productivity (NPP) of Thong Pha Phum forest. Following two procedures are applied data estimation: 1) aboveground biomass estimation 2) NPP estimation. The method of the first one was based on inventory for DBH stem at ≥ 4.5 cm by allometric equation an aboveground carbon stock was calculated by multiplying conversion factor as 0.5 of biomass. As the results, carbon sequestration had varied in different types of forests that tropical rain forest (Ton Mai Yak and Ban Passadu Khlang station) is higher than dry evergreen forest (KP 27 station) and mixed deciduous forest (Pong Phu Ron station) as 137.73±48.07, 70.81, 70.29±7.38 and 48.14±16.72 tonne C/ha, respectively. Because the variables of habitats have caused differences in biomass accumulation, species composition and the allometric relationships of forests. In the study area, all forest have a similar pattern of tree size class, with a dominant size class at ≥ 4.5 – 20 cm, these smaller trees have the lowest carbon sequestration potential but they are relevant mainly in terms of their future potential to go to the further size classes and they will be able to increase biomass and store more carbon.

The other one, NPP estimation is based on the Miami model extended by functions considering annual mean temperature and precipitation. The aboveground NPP is 10.34 tonne C/ ha/ year and the result indicates that the best estimate of NPP in this study is from the annual mean precipitation rather than annual mean temperature cause of the study area is located in the tropical zone where the light intensity and temperature are unlikely to be the limiting factors for the NPP.

Department...............Biology............... Student's signature............Siranan Terakunpisut
Field of study.............Zoology..............Advisor's signature............Nantana Gajaseni
Academic year..........2003.....................Co-advisor's signature...................................

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ABBREVIATIONS

CO_2	=	Carbon dioxide
AGBM	=	Aboveground biomass
NPP	=	Net primary productivity
GPP	=	Gross primary production
DBH	=	Diameter at breast height
Ht	=	Height of tree
IVI	=	Important value index
H′	=	Shannon – Wiener index

CHAPTER I

INTRODUCTION

1.1 Overview of the study

The world's forests are prominent sites to study of climate change, not only in terms of total net emissions but also in terms of global storage capacity, because the processes regulating nutrient uptake and cycling in forest ecosystems are linked to climate and thus highly influenced by changes in temperature or precipitation regimes as well as by changes in the carbon dioxide (CO_2) concentration of the air.

The carbon in forests originates from the atmosphere, and it continuously cycles between forests and the atmosphere. Thus, changing carbon stocks in forests can affect the amount of carbon in the atmosphere. If more carbon accumulates in forest through photosynthetic process, the forest will be a sink of atmospheric carbon. If the carbon stocks in forests decrease and release carbon into the atmosphere, the forests will become a source of atmospheric carbon. The carbon stocks of forests can change in two ways, on the one hand as a result of changes in forest area and on the other hand as a result of changes in carbon stocks on the existing forest area. The importance of forests for atmospheric CO_2 levels was acknowledged as countries negotiated about their quantified reduction commitments of greenhouse gas emissions in Kyoto in December 1997. According to Article 3.3 of the agreed Kyoto Protocol, some CO_2 sources and sinks of forests shall be used to meet the commitments (UNFCCC, 1997). The sources and sinks to be used were measured as verifiable changes in carbon stocks in each commitment period starting 2008 - 2012.

Thailand is a member of the United Nation Framework Convention on Climate Change (UNFCCC), which is negotiated by the nations of the world in June 1992 (Michaelowa and Rolfe, 2001). The ultimate objective of the UNFCCC is to stabilize the atmospheric greenhouse gas concentrations at a level that avoid dangerous anthropogenic interference with the climate system. The emission reduction of greenhouse gas from a member of industrialized countries is called for in

Kyoto Protocol. Under the recent convention on climate change, governments are actively pursuing policies to reduce greenhouse gases with a range of policy measures like tradable emission permits, fiscal measures (carbon taxes and subsidies), regulatory legislation, and land use policy (Rama *et al.*, 1997). To develop global carbon markets, specified in the Kyoto Protocol for climate change, thus accuracy of forest aboveground biomass estimation is very essential to obtain a reliable value of carbon stocks in terrestrial ecosystems with increasing interest in tropical forests and changes, they are undergoing in relation to their role in global biogeochemical cycles, atmospheric chemistry, and biodiversity issues. The global role of tropical forests heightened interest in quantifying the biomass they contain because this determines the atmospheric CO_2 emissions from clearing and burning forests.

So this study is focusing on the carbon sequestration in terms of aboveground biomass because biomass estimates are also important for a variety of other scientific and management issues such as forest productivity, nutrient cycling, and inventories of fuel wood and pulp. In addition biomass is a key variable in the annual and long – term changes in the global terrestrial carbon cycle and other earth system interactions. It is also important in the modeling of carbon uptake and redistribution within ecosystems. Of most interest is live wood biomass, which involves the regulation of atmospheric carbon concentrations. Thus its dynamics must be understood if annual spatial variations are to be related to spatial weather and climate variables. It is also important variable needed for future projections of atmospheric CO_2 concentrations. Other computations which require an accurate estimate of biomass along with carbon emission and carbon sequestration rates are those defining the carbon status and flux in a given geopolitical unit for the assessment, for example carbon taxes and similar international CO_2 mitigation measures.

1.2 Objectives of the study

1. To collect data on aboveground biomass at different forest types of Thong Pha Phum National Forest, Kanchanaburi Province.
2. To evaluate aboveground biomass and carbon sequestration of different forest types.
3. To estimate net primary productivity (NPP) by using Miami model for improve the ability to assess the role of each forest type in the global carbon cycle.

1.3 Scope of the study

This study is calculated on aboveground biomass of different forest types. The measure will be emphasis on the carbon sequestration of aboveground biomass only. The selected study area is located at Thong Pha Phum National Forest, Kanchanaburi Province which is a pool of biodiversity in western Thailand. This area is composed of evergreen forest (tropical rain forest and dry evergreen forest) and deciduous forest (mixed deciduous forest). To estimate ecological indexes and biomass, each one is based on total forest inventory for woody stem ≥ 4.5 cm diameters at breast height (DBH, 1.3 m height from the ground) as well as species diversity. The allometric equations are applied for calculating the aboveground biomass and the size class analysis will evaluate the status of forest ecosystem. The mixed deciduous forest will use the equation developed by Ogawa *et al.* (1965) and the tropical rain forest and dry evergreen forest will use the equation developed by Tsutsumi *et al.* (1983). Finally, the physical data such as temperature and precipitation are applied to NPP value by Miami model (Leith, 1972, 1973, 1975). Figure 1 indicates the scope of the study in detail.

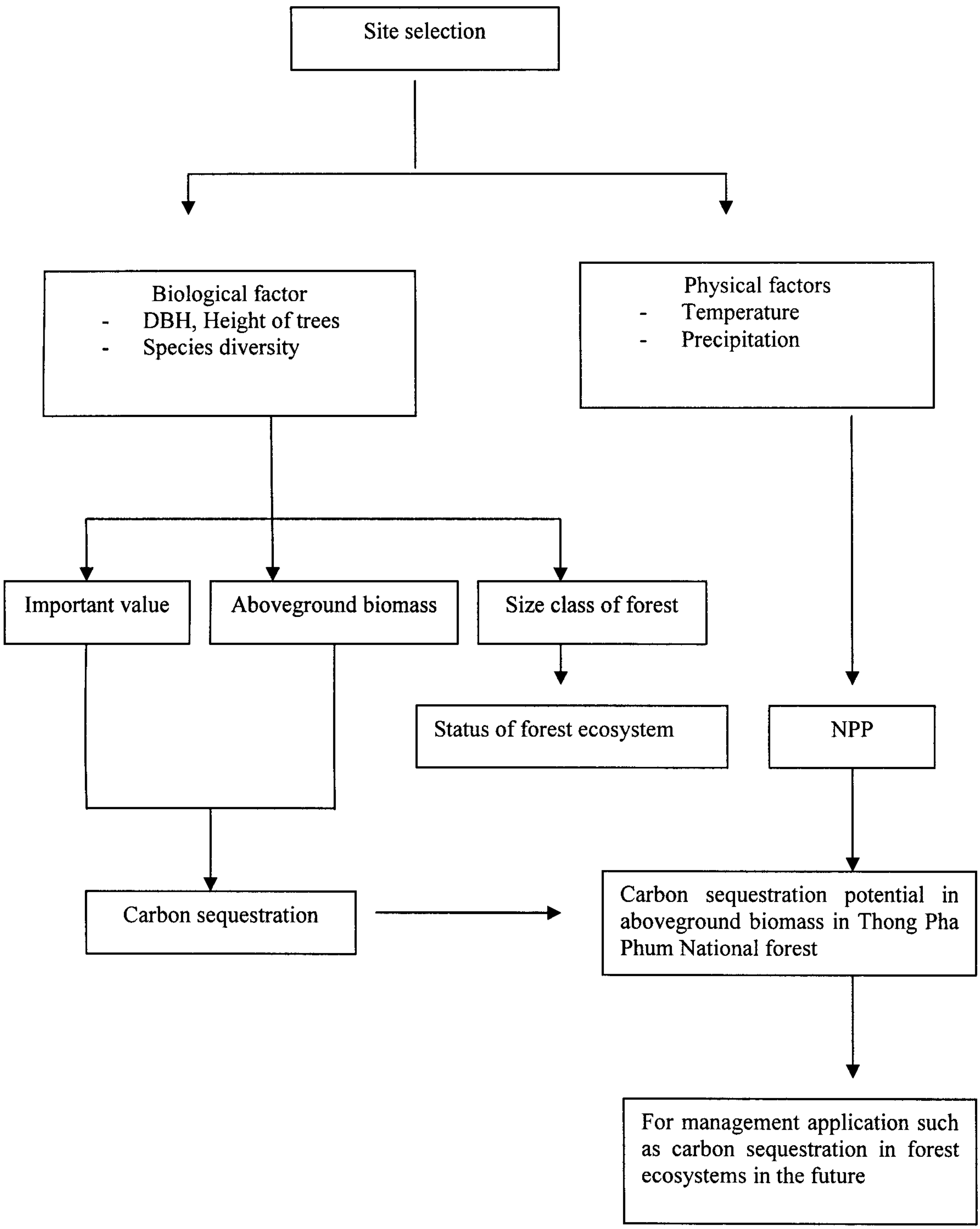


Figure 1 Scope of the study

CHAPTER II

LITERATURE REVIEW

Terrestrial ecosystems and climate system are closely coupled, by cycling of carbon between biotic components as vegetations and abiotic components as the atmosphere. It has been suggested that if it changes in climate and atmospheric CO_2 concentrations have modified the carbon cycle so as to render terrestrial ecosystems as s ubstantial c arbon sinks, but direct evidence for this is very limited. Changes in ecosystem carbon stocks caused by shifting stable climatic states have been systematically evaluated, but the dynamic responses of ecosystem carbon fluxes to transient climate changes are still poorly understood. The major parameter at ecosystem level must be considered as biomass, NPP, and carbon storage; therefore, this chapter will focus on the literature review about the carbon cycle that is the main related to climate change and global warming and the method for aboveground biomass and NPP in forest ecosystem studies in the past.

2.1 Carbon cycle and climate change

The carbon cycle (Figure 2), a global gaseous cycle, is based on CO_2 gas, which makes up 0.036 % of the volume of the troposphere and is also dissolved in water. CO_2 is a key component of nature's thermostat because carbon cycle readily regulates among the biosphere, the atmosphere, and the hydrosphere, it should be possible to influence the store of carbon in the atmosphere by managing the store of carbon in the biosphere. If the carbon cycle removes too much CO_2 from the atmosphere, the atmosphere will cool, but if the cycle generates too much, the atmosphere will get warmer (Zhang and Xu, 2003). Thus, even slight changes in the carbon cycle can affect climate and ultimately evolve the types of life that can exist on various parts of the world.

Cannell and Milne (1995) described the method to fix carbon by processes of trees photosynthesis (carboxylation) and eventually returned to the atmosphere by processes of decomposition and decay involving other organisms (oxidation). From the photosynthesis, terrestrial producers remove CO_2 from the atmosphere, and then they convert CO_2 into simple carbohydrates such as glucose ($C_6H_{12}O_6$). The cells in oxygen – consuming producers, consumers, and decomposers carry out aerobic respiration. This linkage between photosynthesis in producers and aerobic respiration in producers, consumers, and decomposers circulate carbon in the biosphere and is a major part of the global carbon cycle. Pearce and Moran (1994) indicated that all forests store carbon thus, if they are cleared for agricultural land, there will be a release of CO_2. Then it will contribute to acceleration of the greenhouse effect and cause for global warming.

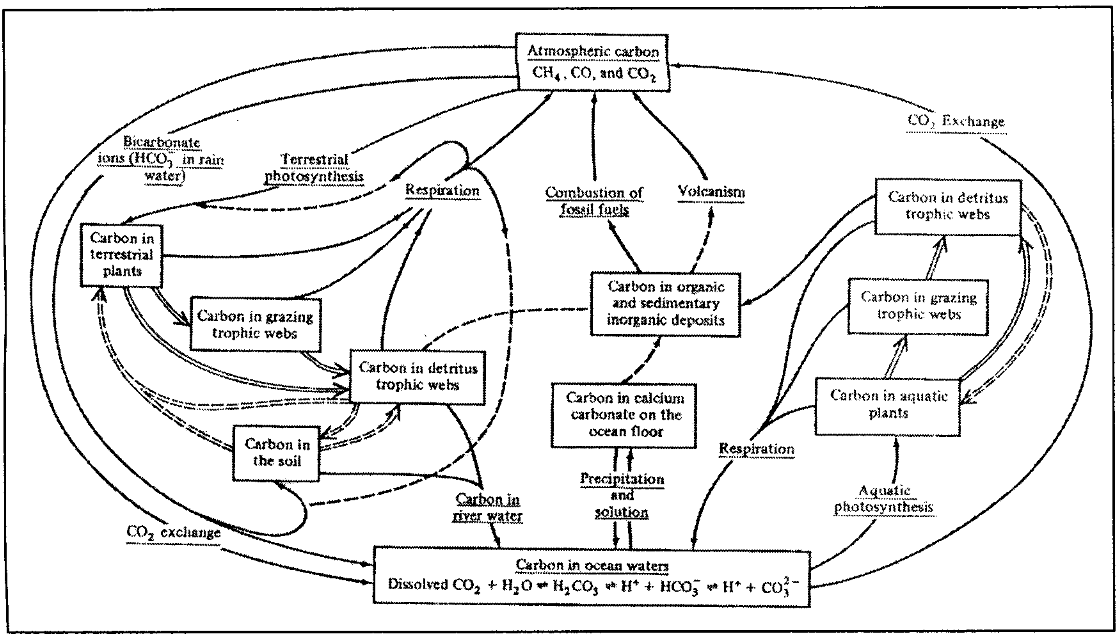


Figure 2 Distribution and transfers of carbon in the biosphere. Solid lines indicate major transfers, dashed lines transfers of secondary importance. Double lines indicate the biogeochemical cycle, single lines the geochemical cycle (Kimmins, 1997).

The International Panel on Climate Change (IPCC) estimated that the global mean temperature of the earth's surface had increased by 0.3 to 0.6°C over the past 100 years (IPCC, 2000). Prediction are that global warming will cause significant variations in climatic patterns over the next century that may have negative impacts on regional and global biomes. Global warming as a consequence of rapid rise in human related emissions of greenhouse gases (GHGs) has caught widespread attention and become important international environmental issues.

Within a few years the study about climate change has evolved from a minority scientific interest to a major perceived environmental threat, because it would have severe ecological and economic impacts, including a rise in sea level, increased drought frequencies in parts of the world, changed precipitation patterns, higher hurricane frequency and in a long term perspective, altered patterns of productivity of agricultural crop and forests, a change in diversity and distribution of unmanaged ecosystems (Graham *et al.*, 1990). Among greenhouse gases, including CO_2, carbon monoxide (CO), methane (CH_4), nitrous oxide (N_2O), and oxides of nitrogen (NO_x), CO_2 has received greatest attention in the scientific and policy debates, because of its long residency time in the atmosphere and the scale of its contribution to the warming potential and account for some 65 % of the greenhouse effect (Manne and Richels, 1991). Mark and Thomas (2001) reported that CO_2 has increased in atmospheric concentration by about 30 % from the beginning of the industrial revolution to 1992 (Figure 3) has been caused by

- The use of fossil fuels, which release large amount of the greenhouse gases CO_2 into the troposphere
- Deforestation and clearing and burning of grasslands to raise crops
- Cultivation of rice in paddies and use of inorganic fertilizers, which release CH_4 and N_2O into the troposphere

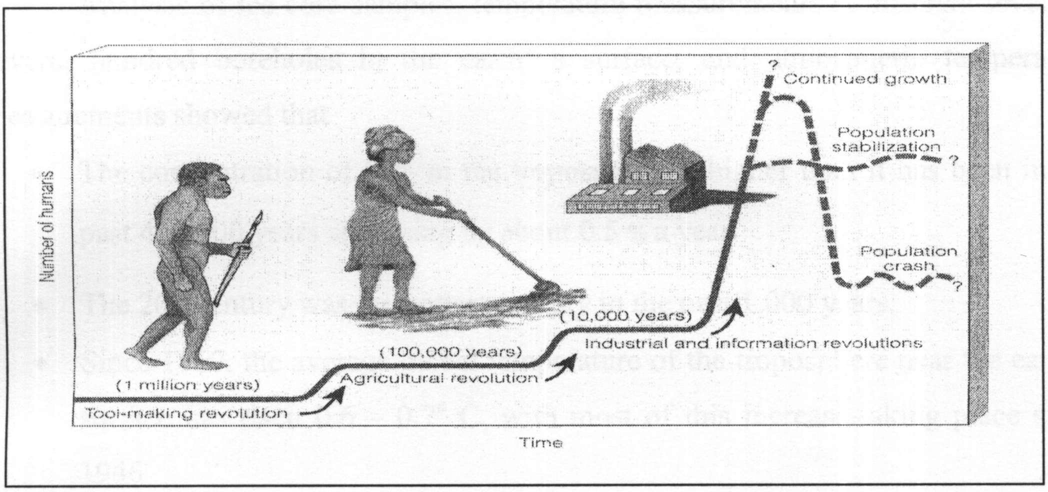


Figure 3 Technological innovations have led to greater human control over the rest of nature and expanding human population. Environmental impacts are increased rapidly because of increased resource use, pollution, and environmental degradation (Miller, 2002).

It is hypothesized that increased inputs of CO_2 from human activities could enhance the earth's natural greenhouse effect and raise the average global temperature of the atmosphere near the earth' s surface. This enhanced greenhouse effect usually is called global warming. Much of the conflict between man and nature is centered in areas of high plant productivity. With human agricultural and other intensive uses of land, i. e. for urbanization, have replaced the natural ecosystems that once supported a large area of forests. Human manipulation of the planet's high productivity environments tends to increase the short – term rate of carbon uptake over that of the original natural ecosystems. However, human manipulation generally reduces the total amount of carbon stored in the system by keeping plant size small through harvests and by increasing the rate of decomposition of dead plant material. The impacts of human management on the biodiversity of these productive areas are primarily through the loss of natural habitat and landscape complexity. Any human efforts to regulate atmospheric CO_2, understanding the relationship between biodiversity and productivity should allow us to minimize the negative effects on biodiversity and essential ecosystem services of any land – use changes designed to decrease atmospheric CO_2 (Huston and Marland, 2003).

Analysis of ice core samples, temperature measurements at different levels in several hundred boreholes in the earth' s surface, and atmospheric temperature measurements showed that

- The concentration of CO_2 in the troposphere is higher than it has been in the past 420,000 years and rising by about 0.5 % a year.
- The 20^{th} century was the hottest century in the past 1,000 years.
- Since 1860, the average global temperature of the troposphere near the earth's surface has risen 0.6 – 0.7° C, with most of this increase-taking place since 1946.

Other observed signs of a warmer troposphere during recent decades include

- Increased temperatures and melting of ice caps and floating ice at the earth' s poles
- Retreat of some glaciers on the tops of mountains in the Alps, Andes, Himalayas, and northern Cascades of Washington
- Northward migration of some warm – climate fish and trees
- Bleaching of coral reefs in tropical areas with warmer water

It is clear that during the past 200 years human activities have been changing the chemical composition of the atmosphere more rapidly than it has changed at any time during the last 10,000 years. Regardless of the cause, significant climate change is caused by atmospheric warming or cooling over several decades to a hundred years has important implications for human life, wild life, and the world' s economies. Such rapid climate change can affect the availability of water resources by altering rates of evaporation and precipitation, shift cultivation areas where crops can be grown, change average sea levels, and alter the structure and location of the world' s biomes.

At the 1992 Earth Summit in Rio de Janeiro, Brazil, 106 nations approved a convention on Climate Change in which developed counties committed themselves to reducing their emission of CO_2 and other greenhouse gases to 1990 levels by the year 2000. However, the convention did not require countries to reach this goal, and most counties did not achieve this goal. In December 1997, more than 2,200 delegates from

161 nations met in Kyoto, Japan, to negotiate a new treaty to help slow global warming. The resulting treaty would

- Require 38 developed counties to cut greenhouse emissions to an average of about 5.2 % below 1990 levels between 2008 to 2012
- Not require developing counties to make any cuts in their greenhouse gas emissions
- Allow emission trading

Some analysts praise the Kyoto Protocol as a small but important step in dealing with the problem of global warming and hope that the condition of the treaty will be strengthened in future negotiating sessions. There is also controversy over what role-developing counties should take in reducing their CO_2 emissions. Developing counties were not required to reduce their emissions in the first phase of the treaty because these counties argued that

- Developed counties should be the first to reduce their CO_2 emissions because of their higher total and per capita emissions. For example, average per capita CO_2 emissions in developed counties are about six times higher than in developing counties; the average American is responsible for nearly eight times as much CO_2 emissions per person as the average of Chinese.
- They are just beginning to expand some of their economies and should be entitled to some increases in CO_2 emissions, as the developed counties had during the early stages of their economic growth and development.

Some analysts suggest that the stalemate between developed and developing counties over reducing greenhouse gas emissions might be eased by

- Giving developing counties a 10 – year grace period before they are required to meet specified reductions
- Setting up an international fund financed by developed counties to transfer energy – efficiency and renewable energy technologies to developing counties

These two strategies were used to develop an international treaty that is gradually reducing inputs of ozone depleting chemicals in to the stratosphere. Scientists are evaluating several ways to remove CO_2 from the atmosphere or from smokestacks and store (sequester) it in

- Immature trees
- Plants that store it in the soil
- Deep underground reservoirs
- The deep ocean

One way to remove CO_2 from the atmosphere temporarily would be to plant trees over an area equivalent to the size of Australia in a massive global reforestation program. However, the rate of removal of CO_2 from the atmosphere by photosynthesis decreases as tree mature and grow as a slower place. In addition, trees release their stored CO_2 back into the atmosphere when they die and decompose or if they catch fire. Studies suggested that a global reforestation program (requiring each person in the world to plant and tend to an average of 1,000 trees every year) would offset only about 3 years of our current CO_2 emissions from burning fossil fuels.

2.2 Aboveground biomass and carbon sequestration studies

2.2.1 Aboveground biomass studies

Forest biomass data can be used to understand changes in forest structure resulting from succession or in differentiating between forest types. An important use of biomass density (dry mass / unit area) in recent years has been to track carbon cycling between the atmosphere and the terrestrial biosphere, related to global climate change (Cairns *et al.*, 2000). Biomass change represents the potential for carbon (~ 50 % of dry weight biomass) emissions to the atmosphere when forests are degraded or replaced through processes of deforestation and biomass burning. Conversely, growth results in accumulation of biomass and represents atmospheric CO_2 – C sequestration in the terrestrial biosphere. Thus forest biomass can act as either a source or sink for atmospheric CO_2 concentration. Developing global carbon markets, specified in the Kyoto Protocol for climate change, require accurate and reliable methods to quantify these sources and sinks.

There is increasing interest in estimating the biomass of tropical forests for both practical forestry issue and scientific purposes. The high rates of decomposition of detritus on the forest floors of tropical forests, results in most nutrients in the system are stored and internally recycled in live biomass in tropical forests, not in soils (Jordan, 1985). For instance, the low – latitude tropical forests are estimated to contain 60 % of the total aboveground carbon in world forest vegetation and 27% in soils (Dixon *et al.*, 1994). It indicates that the activities of detritivores are important to the nutrient cycles to provide nutrient inputs through the systems. Forest biomass is important for commercial uses (e.g. fuel wood assessment) and national development planning, as well as for scientific uses such as studies of ecosystem productivity, energy and nutrient flows, and for assessing the contribution of changes in tropical forestlands to the global carbon cycle. A better understanding of tropical biomass distribution, one avenue for improving estimates of carbon stocks is to improve our understanding of factors causing within landscape variation in forest structure, because aboveground carbon stocks are primarily determined by the size – frequency distribution of trees (Schimel, 1995). By forest structure, that means the size – frequency distribution of stems, the percentage contribution of major life forms.

However, there is only a limited database on biomass estimates for the tropics (Cannell, 1982). Most biomass studies have been done by tropical ecologists. Their data are carefully collected, but are generally limited to small, non – randomly selected areas and are thus inadequate for the global focus of projects such as atmospheric carbon research (Brown *et al.*, 1989). Inventory data such as these can be used to make inferences about total aboveground biomass in tropical forests. However, the minimum diameter of sampled trees in many tropical forest inventories is often > 35 cm, reflecting the dominant interest in lager commercial timber. This is acceptable for inventories of commercial volumes, But unacceptable for biomass estimation unless adjustments are made for the missing trees.

Reliable estimates of the biomass are needed for the calculation of greenhouse gases emissions from deforestation. There are different approaches in estimating biomass density. These include destructive sampling and weighing of the total plant biomass in a sampling plot, allometric regression, etc.

2.3.1.1 Destructive sampling and weighing of the total plant biomass in a plot

The best and most direct way of measuring biomass is to harvest the plants and weigh the biomass. Biomass tables can be developed using a minimum of 30 well – selected trees (MacDicken, 1997). However, because of cost, time and ecological constrains, this is rarely done in mature forest trees. Kawahara *et al.* (1981) conducted destructive sampling on three plantation species namely *Paraseriathes falcataria, Sweitenia macrophylla,* and *Gmelina arborea.* One square experimental plot, 30 x 30 m^2 or 20 x 20 m^2 in size, is set up in each stand. Stem diameters of all trees more than 4.5 cm are measured 1.3 m height above the ground (DBH). Height of trees and their local names are recorded. Diameter tape is used for measurement, and the height of the standing trees is estimated by the use of hypsometer. All the trees inside the plot are measured.

Seven sample trees of various sizes are felled on each plot. After recording diameters at 0.3 m and 1.3 m above the ground, total heights, and the height of the lowest living branch of each sample tree, the fresh weights of the stems, branches, and leaves are determined separately by the stratified – clip technique on one meter of stratum located away from the top and base. Small samples of the respective tree components are determined for over – dry weight and leaf area. The stand biomass on each plot is estimated by the proportional allocation method.

2.3.1.2 Allometric regression

Appropriate conversion factors or ratios relating commercial standing crop and volume increment to total biomass can be derived for every forest (Chan, Y., 1982). Multipliers or ratios that can be used to convert data from forest inventories to biomass estimates are

1. The weighted green – volume specific gravity (dry mass per unit volume of freash wood and bark) of trees required to convert the volume estimate to dry weight
2. The ratio of total aboveground tree volume to volume of all trees over 30.5 cm in diameter (timber index)
3. The ratio of total biomass (above and belowground) to aboveground biomass (tree: shoot ratio)

DBH is measured by calipers or diameter tapes and recorded for all trees with DBH $\geq$ 4.5 cm falling within the 100 m^2 quadrats. Trees with at least 50 % of their diameter within the quadrate are measured. Adjustments are made for tree buttressing by measuring the diameter above buttress (Brown and Lugo, 1990). For tree branching below breast height, DBH of all branches is measured separately (Brown and Lugo, 1982). However, Ketterings *et al.* (1999) reported that errors and uncertainty in aboveground biomass estimates for a specific forested site are induced by any method that does not involve the cutting and weighting of every single tree within the site. Those errors may be unacceptably large when allometric equations that relate an easily measurable parameter such as tree diameter and height to biomass are used without site-specific calibration. Reducing these errors is a major challenge in research on carbon stocks, CO_2 emission and deforestation.

To estimate live tree biomass, diameters of all trees are measured and converted to biomass and carbon estimates (carbon content = 50 % of biomass) generally using allometric biomass regression equation. Sampling a sufficient number of trees to represent the size and species distribution in a forest to generate local allometric regression equations with high precision, particularly in complex tropical forests, is extremely time consuming and costly, and generally beyond the means of most projects. The advantage of using generic equations, stratified by, e.g., ecological zones, is that they tend to be based on a large number of trees (Brown, 1997) and span a wider range of diameters; this increases the accuracy and precision of the equations. It is very important that the database for regression equations contain large diameter trees, as these tend to account for more than 30 % of the aboveground biomass in mature tropical forests (Pinard and Putz, 1996).

A disadvantage is that the generic equations may not accurately reflect the true biomass of the trees in the project. However, relatively inexpensive field measurements (e.g., diameter and height relationships of the larger trees) performed at the beginning of a project can be used to check the validity of the generic equations. For plantation or agroforestry projects, developing or acquiring local biomass regression equation is less problematic as much work has been done on plantation and agroforest species (Lugo, 1997: cited in Brown, 2000).

Total root biomass is another important carbon pool. Others have reported variable root: shoot ratios but, in general, root biomass is approximately 25 % of the aboveground biomass and can represent up to 40 % of total biomass (Cairns *et al.*, 1997). However, quantifying this pool can be expensive and no practical standard field techniques yet exist. Instead, the recent reviews of literature based on research studies of all examples of the world forests are available for estimating root biomass carbon based on aboveground biomass carbon.

2.2.2 **Carbon sequestration studies**

IPCC defines carbon sequestration as an increase in carbon stocks other than in the atmosphere (IPCC, 2000). Consistent with this, the Kyoto Protocol prescribes that emission by sources and removals by sinks resulting from direct human – induced land use change and forestry activities are to be measured as verifiable changes in carbon stocks (Huston, 1994). Carbon accumulates in forest ecosystems through the absorption of atmospheric CO_2 and its assimilation into biomass. Carbon is stored in living biomass, including standing timber, branches, foliage and root; the other is stored in dead biomass, including litter, wood debris, soil organic matter and forest products. While the word's forests are absorbing carbon, they are also releasing it. Any activity that affects the amount of biomass in vegetation and soil has potential to sequester carbon from, or release carbon into the atmosphere. Globally, they account for about 1,146 billon ton of carbon, 37 % of this is at low latitudes (tropical and subtropical forests), 14 % in mid – latitudes, and 49 % at high – latitudes. Over two – thirds are in soils and peat deposits. Deforestation is a major form of land use change in the tropics with forest resources undergoing degradation from the influence of logging and conversion to other uses, which produces a source of CO_2 and exacerbates the rise in atmospheric CO_2 (Detwiler and Hall, 1998).

Until the late nineteenth century, most forest clearing and degradation took place in temperate regions. In the twentieth century, the area of temperate forest largely stabilized and tropical forests became the primary source of carbon emissions from terrestrial ecosystems. Tropical deforestation is believed to be causing a net release of about 1.6 billon ton of carbon per year, compared with fossil fuel release of about 5.4 billon ton (Dixon *et al.*, 1994). However, it has been suggested that the terrestrial biosphere could be managed over the next 50 years to conserve or sequester 60 to 87 Gt of carbon in forests and another 23 to 44 Gt of carbon in agricultural soils (Brown *et al.*, 1996).

FAO (2001) reported that the carbon density and stock of vegetation and soils were different in each ecosystem. The data in Table 1 are indicated that boreal forests are accounted for more carbon than any other terrestrial ecosystem (26% of total terrestrial carbon stocks), while tropical and temperate forests are accounted for 20 and 7 %, respectively. The stored carbon in the soil and litter of forest ecosystems also makes up a significant proportion of the total carbon pool. Globally, soil carbon represents more than half of the stock of carbon in forests. However, there are considerable variations among ecosystem and forest types. Between 80 to 90 % of the carbon in boreal ecosystems is stored in the form of soil organic matter, whereas in tropical forests the carbon is fairly equally distributed between vegetation and soil. The primary reason for this difference is the influence of the temperature on the relative rates of production and decay of organic matter. At high latitude, such as in cooler climates, soil organic matter accumulates because it is produced faster than it can be decomposed, whereas at low latitudes, warmer temperatures encourage the rapid decomposition of soil organic matter and subsequent recycling of nutrients.

Table 1 Carbon density and stock of vegetation and soils for different ecosystems (FAO, 2001)

Ecosystem	Country/region	Vegetation carbon density (tonne/ha)	Soil carbon density (tonne/ha)	Vegetation carbon stock (Gt)	Soil carbon stock (Gt)	Total carbon stock (Gt)
Boreal	Russian Federation	83	281	74	249	323
	Canada	28	484	12	211	223
	Alaska	39	212	2	11	13
Temperate	United States	62	108	15	26	41
	Europe	32	90	9	25	34
	China	114	136	17	16	33
	Australia	45	83	18	33	51
Tropical	Asia	132-174	139	41-54	43	84-97
	Afirica	99	120	52	63	115
	Americas	130	120	119	110	229

The stored carbon in U. S. forests was increased by 38 % between 1952 and 1992 (Birdsey *et al.*, 1993). A similar pattern of increase has been reported from Scandinavia and Europe. Canadian forests are similarly increasing in biomass and carbon storage (Kurz *et al.*, 1995). Reforestation of abandoned farmland is one reason for the increase, while reduction of forest loss to wildfire is another. An increase in carbon storage in northern forests is believed on account for much of the substantial difference between carbons released to the atmosphere by fossil fuel burning (about 5.4 billon ton per year in 1980) and the observed increase in atmospheric carbon (about 3.4 billon ton per year) (MacKenzie, 1994).

In the case of Canada, which account for 10 % of the world' s forests, only a small proportion of the area is disturbed annually. There was a shift toward an older average age in Canadian forests during the 1920 – 1970 periods because of a reduction in forest disturbance; consequently, these unmanaged forests were net carbon sink during this period (Kurz and Apps, 1993). However, natural disturbance increased in the 1970 – 1989 periods, reducing the role of these forests as a carbon sink. Forests that are subject to large-scale fluctuations in natural disturbance on a time scale comparable to tree life times do not appear to reach carbon exchange equilibrium over these time scales (Kurz *et al.*, 1995).

A study of the effect on carbon storage of conversion of west coast old growth forests of the Pacific Northwest U. S. to young forest (Harmon *et al.*, 1990) concluded that the conversion of 5 million ha of old growth to younger forests in the last 100 years has released 1.5 to 1.8 billon tons of carbon to the atmosphere. The quantity of carbon stored in these old growth forests is considerably greater than the carbon stored in a managed second growth, and through the use of a computer simulation model, it was estimated that it would take about 100 years for the secondary forest to achieve 80 % of the carbon storage of the old growth forest, and this forest would have to be left to grow for about 250 years to equal it.

Tropical forest structure and biomass are known to vary with soil type, climate and topographic condition (Iverson *et al.*, 1994), so carbon sequestration potential in different types of forest ecosystem should be different. To develop global carbon markets, specified in the Kyoto Protocol for climate change, thus, accuracy of forest aboveground biomass estimation is very essential to obtain a reliable value of carbon stocks in terrestrial ecosystems. Tropical forest biomass has been estimated with several methods (Brown and Iverson, 1992). Because of the urgent need for regional and national scale biomass and carbon density data, Brown (1997) reported methods for using existing forest inventory data to estimate biomass densities of tropical forest trees. That report presented biomass regression equations derived from data for harvested trees of many species in tropical forests of four climatic zones (very dry, dry, moist and wet). Most natural forests in the tropics are uneven – aged, containing trees of all size and age classes. Although smaller trees have less volume than larger trees, the smaller size classes tend to contain relatively more trees than the larger size classes, so that in certain cases the smaller size classes may contain important proportions of total stand biomass.

The study about composition and aboveground biomass of a dry semi – evergreen forest on Mexico' s Yucatan Peninsula by Cairns *et al.* (2003), showed that there are the dynamic of land use in the Yucatan, which dominated during the past several decades by net loss of forest cover in favor of agricultural land uses. In either case, accurate knowledge of the biomass and C content of the forest and other land cover types is essential for understanding the direction and magnitude of C fluxes in terrestrial systems. Deforestation on the Yucatan Peninsula has increased during the last 15 years because of the pressures of agriculture, cattle ranching, tourism development, and urbanization (Olmsted *et al.*, 1999; cited in Cairns *et al.*, 2003). Cairns *et al.* (2000) reported an annual average deforestation rate of 1.9 % in an eight – state region of Mexico between 1977 and 1992. There has been a decrease in mature forest and simultaneous increases of non – vegetated areas and secondary vegetation in the Yucatan. To understand carbon sources and sinks, it is essential to estimate the biomass for these forests. In the Yucatan Peninsula, biomass data derived from destructive sampling and weighing of the total plant biomass in a plot, to develop an appropriate series of aboveground biomass allometric regression equations for common species occurring in a semi – evergreen forest in the state of Quintana Roo the Yucatan Peninsula (Mizrahi *et al.*, 1997). The results showed that the dominant species, in terms of biomass, were *Brosimum alicastrum* Sw., *Manilkara zapota* (L.) Royen, *Luehea speciosa* Wildl., *Pouteria unilocularis* (Donn. Sm.) Baehni, *Trichilia minutiflora* Standl., and *Spondias mombin* Linn. Tree heights ranged up to 30 m and DBH to 82.1 cm. Total aboveground tree biomass was estimated to be 225 Mg ha $^{-1}$, and was dominated (85 %) by the biomass of a large trees compose of 191.5 Mg ha $^{-1}$ of the aboveground biomass for individuals with DBH > 10 cm, combined with the biomass for individuals with DBH < 10 cm (33.5 Mg ha $^{-1}$). The biomass of the small trees (33.5 Mg ha $^{-1}$) comprises approximately 15 % of the total biomass density (225 Mg ha $^{-1}$) in this forest.

The importance of intensive biomass studies to provide data for global allometric equations is exemplified by the 31 % difference between actual total dry weights of the trees in this study and dry weights calculated with the dry forest allometric equation reported by Brown (1997). There is a tendency for Brown's equation to underestimate aboveground biomass. Calculated biomass was less than actual biomass for 29 of the 33 species, caused of unusual geometric forms and height is not proportional to diameter. Brown's equation, originally reported by Brown *et al.* (1989) is based on 29 trees 5 – 40 cm DBH in dry forest in India. It is not surprising that biomass estimates from the Brown's equation differs from actual biomass because the basis for that equation is from a set of trees of entirely different species growing in different edaphic conditions. This research adds to the knowledge of dry tropical tree biomass, it should be realized the best allometric equation that developed from a destructive harvest of trees in the region of interest.

In Thailand, the amount of biomass in each forest type reported in various studies is variable and out of date, dating back to two to three decades ago (Table 2). This information was used in the ALGAS report for the lack of a better one. There is a need to update the amount of biomass in each forest type, especially in addressing the level of intervention, which affects the level of biomass.

Table 2 Aboveground biomass in Thailand (tonne / ha) (Khummongkol *et al.*, 1996)

Forest type / Species	Aboveground biomass (tonne / ha)	Source
Tropical rain forest	358	Ogawa *et al.*, 1965
Mixed deciduous forest	311	Ogawa *et al.*, 1965
Dry evergreen forest	126	Ogawa *et al.*, 1965
Pine forest	162	Sabhasri, 1978

Regarding to Chittachumnonk *et al.* (2002) studied on aboveground biomass of Teak plantation in Thailand, there were four study areas located in northern and western regions included Mae Mai Plantation at Muang District, Lampang, Thong Pha Phum Plantation at Thong Pha Phum District, Kanchnaburi, Sri Satchanalai Platation at Sri Satchanalai District, Sukhothai, and Khao Kra Yang Plantation, Wong Thong District, Phitsanulok. The study showed that all aboveground biomass of Teak plantation was equal to 78.15 tonne/ha or equivalent to 646,997.19 tonne of total aboveground biomass of area, which total study area, is 8,278.50 ha. In the estimate of carbon sequestration of Teak plantation were 36.98 tonne/ha.

Viriyabuncha *et al.* (2002) studied the evaluation system for carbon storage in forest ecosystems in Thailand. The result showed that the aboveground biomass Doi Suthep – Pui National Park, Chiang Mai, evergreen forest and mixed deciduous forest were in the range 31.95 – 903.29 tonne/ha. The maximum biomass was found in dry evergreen forest because it was old forest and have been strictly controlled the illegal logging. The minimum biomass was found in dry dipterocarp forest, which was a young forest. The study also showed biomass of mixed deciduous forest was in the range 31.95 – 175.50 tonne / ha.

2.3 Net primary productivity and MIAMI model

2.3.1 Net primary productivity

NPP is defined as the difference between total carbon uptake through photosynthesis and losses through maintenance or growth respiration. NPP is a fundamental property contributing to ecosystem performance. It is dependent on the characteristics and interactions of the vegetation, soil, and weather, and integrates these effects in a spatially explicit manner. Because of its direct relationship to atmospheric CO_2 it plays a major role in the global climate system.

In the past, NPP has not been measured systematically or frequently because of the limitations of measurement methods. It is difficult to measure NPP directly in the field because many constrains, such as Gross primary production (GPP) cannot be measured directly, and estimating total plant respiration at the ecosystem level remains difficult. It also involves significant uncertainties and important finding is that stem biomass, although a major carbon store, generally requires less than 10 % of annual GPP to maintain the small fraction of living cells associated with sapwood and phloem (Ryan *et al.,* 1996; cited in Clark *et al.,* 2001). NPP is defined as the total new organic matter produced during a specified interval. Although the components of this production are readily conceptualized (Figure 4), they cannot be directly measured in the field because transformations such as consumption, decomposition, and mortality undergo during the measurement interval.

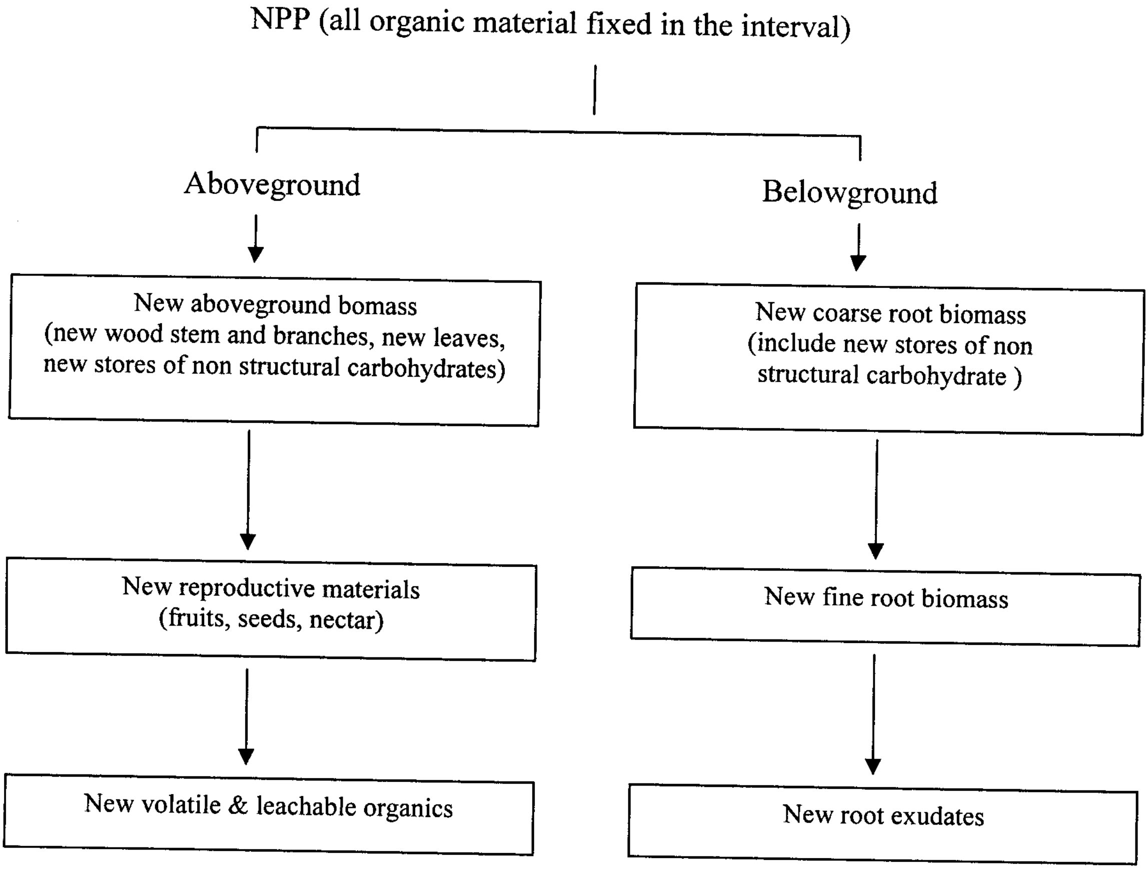


Figure 4 The components of forest NPP, the sum of new organic matter that is retained by live plants at the end of the study interval, and the amount of organic matter that was both produced and lost by plants during the same interval (Clark *et al.*, 2001)

NPP can also be estimated from information about biomass dynamics (Clark *et al.*, 2001):

$$\text{NPP} = \Delta\,(\text{standing biomass}) + \text{losses} \qquad \text{(Equation 2.1)}$$

Where the losses are from biomass produced during the interval (Δt).

Measurements of aboveground standing biomass, and changes in it over time are (at least in principle) relatively simple to make, as are measurements of litter fall. However, root production and turnover are notoriously difficult to measure directly. Estimates of coarse – root production are fairly conservative, and generally average < 20 % of aboveground production for a wide range of species and coarse – root production is directly correlated with growth in stem diameter (Waring *et al.*, 1998). But fine – root production and turnover are difficult to measure and the carbon costs associated with fine roots are highly variable, depending on factors such as soil type and fertility and water status (Landsberg and Waring, 1997).

An important current research need is to develop a better understanding of NPP in the world' s forests, ecosystems that play a major role in the global carbon budget (Dixon *et al.,* 1994). While unprecedented atmospheric concentrations of the greenhouse gas CO_2 continue to increase due to anthropogenic activities, large uncertainties affect current understanding of the world' s carbon budget (Melillo *et al.,* 1996). One such uncertainty is the balance between NPP and heterotrophic respiration in forests globally. The design and evaluation of global – scale carbon models require field estimates of forest NPP and how it is responding to these global changes. In addition, a better grasp of NPP would help improve assessments of forest – level carbon exchange with the atmosphere developed from measurements.

Figure 5 summarizes the conversion of solar radiation into harvested biomass (economic production), and the major determinants of this process. After carbon is absorbed by plants through photosynthesis in its green parts, the carbon assimilate is transported and partitioned between the different plant tissues, such as leaves, branches, stems and roots. During this process some carbon is lost through respiration.

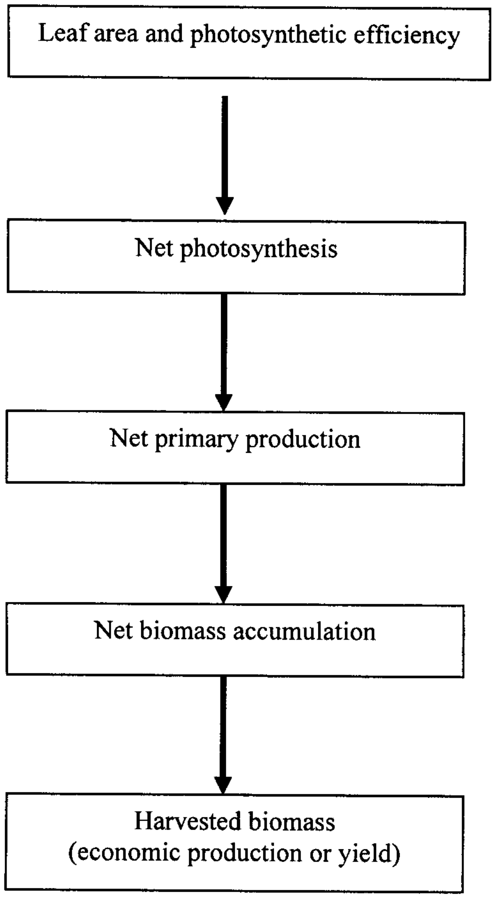


Figure 5 The major determinants of economic production (yield) in forest ecosystems (Kimmins, 1997).

The remaining carbon is stored and creates a carbon sink of living biomass to the root system or to leaf and stem growth. The allocation is through to represent the plants's attempt to maintain optimum ratios between carbon and other nutrients. Each type of plant tissue has a specific turnover time and most carbon stored in a plant decreases sooner or later to become part of one of the several dead biomass pools in and on the soil. Different lifetimes can also be assigned to these pools. The total soil carbon pool is estimated to be almost three times of aboveground biomass pool.

The terrestrial biosphere contains large amounts of carbon, global estimates range from 560 to 650 Gt carbons for the living biomass (King and Neilson, 1992; cited in Goldewijk and Leemans, 1995) and 1500 to 2100 Gt carbon for soil organic carbon. The apparent balance between uptake and release is a dynamic one, which is influenced by a range of environmental influences on the processes involved. Moisture and nutrient availability or temperature, for example, strongly influence photosynthetic and respiration rates. This influences NEP and consequently the sink or source size of an ecosystem and, in turn, the terrestrial biosphere.

Human activities can modify or convert land cover, which often leads to carbon emissions to the atmosphere. Anthropogenic influences are nowadays an important part of the global carbon cycle and their importance will probably become more pronounced in the near future. Land use changes can release large amounts of carbon into the atmosphere rapidly by burning of biomass or also more slowly by accelerating the decomposition rates in the soil. On the other hand, plants can profit from increased CO_2 concentrations in the atmosphere by more easily absorbing more CO_2, which could lead to enhanced growth and lessen water loss. These processes alter the fluxes between the biosphere and atmosphere and therefore influence carbon sequestration potentials. Such feedbacks are defined here as processes which directly or indirectly influence the exchange of greenhouse gases among the atmosphere, terrestrial biosphere and the oceans, thus influencing the residence time of those gases in the different compartments. GPP, NPP, and heterotrophic respiration (R_h) and their corresponding geographical and seasonal variation are key components in the terrestrial carbon cycle. As highlighted during the international negotiation process for the United Nations Framework Convention on Climate Change (UNFCCC), a better grasp upon the controls and distribution of GPP, NPP, and R_h is pivotal for sustainable human use of the biosphere.

Destructive methods are required to directly estimate the NPP for a given period of accumulation, but these often ignore certain trophic flows or component of NPP, and thus rarely give a complete account of the net carbon flux. Therefore the aggregation of existing observations to develop estimates of the regional or global total flux involves significant uncertainties, and must partly rely on simulation models (Cramer *et al.,* 1996; cited in Scurlock *et al.,* 1999). Most studies of the global carbon cycle either use much generalized data or develop their biome – specific methods and paradigms for the interpretation of the available data.

In recent years, the ability to calculate the amount of CO_2 assimilated by photosynthesis (GPP) has improved significantly as a result of the development of new experimental and modeling techniques. These models still provide good estimates of GPP over longer intervals when compared against daily and monthly eddy flux data and annual whole – tree carbon balances (Williams *et al.*, 1997). Calculation of GPP is only the first step. The result required from stand growth models, either aimed at predicting forest productivity, or calculating carbon balances, is usually not GPP but NPP. However, it has proved difficult to calculate NPP accurately from GPP because of the uncertainties associated with the estimation of respiration.

A broad range of models exists now, and they are being used to investigate the magnitude and geographical distribution of primary production at the global scale. These models range in complexity from regressions between climatic variables and one or more estimates of biospheric trace gas fluxes to quasi – mechanistic models that simulate the biophysical and ecophysiological processes. Each approach is based on simplifying assumptions about how ecosystems are structured and how vegetation may response to changes in the environment. Different models use different environmental variables, leading to different estimates of net primary production.

Carbon cycle models can be classified in several ways. First, distinguish between static (equilibrium) models on the one hand and dynamic models on the other. A second way of classified different carbon cycle models is based on the degree which they have an empirical or mechanistic basis.

- Static models calculate an equilibrium steady state and can be used to compare different equilibrium states with each other to assess changes under different environmental conditions.
- Dynamic models allow an assessment of the carbon cycle through the continuous changes in time.
- Empirical models use highly parameterize relationships between environmental and carbon cycle characteristics. They are constructed by using regression between experimental measurement of NPP and driving variable. Some regression, based on carbon cycle models, use empirically derived relationships between climate and NPP. The most well – known and widely used example of this approach is the Miami model by Lieth (1975). This model consists of two-regression equations, one for temperature and one for precipitation. The NPP at a particular locality is calculated with the function that yields the lowest value, therefore assuming that climatic factor is limiting. The model is derived from a small series of scattered NPP values and climate stations that were selected for their representativeness of different biomes.

Evaluating regional – scale models in a constructive way presents unique challenges for two reasons. First, regional – scale and local – scale models have different goals. Modeling goals are important to consider when designing meaningful comparisons with data. Second, assembling field measurements that can be used in such comparisons on a regional scale often presents practical difficulties. Generality is an important goal for ecological models used to address regional issues. Because they focus on important large – scale patterns, such models are expected to sacrifice local precision in favor of global adequacy. Therefore, it is more important for model predictions to reproduce regional patterns observed in nature than to reproduce site – specific measurements.

2.3.2 Miami model

The Miami model was first used as an empirical description of worldwide patterns in NPP by Lieth (1975). This empirical regression serves a purpose in the study that was used to describe the relationship between NPP and environmental gradients. The empirical model was adopted by two factors; mean annual temperature (T) and mean annual precipitation (P) without any accounting neither solar radiation nor ambient CO_2 concentration. Because of its simplicity and its empirical basis, this model is still used as a baseline for evaluation while more sophisticated mechanistic models are developed.

The Miami model was adopted for three reasons. First, the Miami model assumed that one environmental factor, the limiting factor, controls productivity. When temperature is low, temperature limits production and when precipitation is low, precipitation controls the rate of production. The Miami model takes the minimum of two NPP estimates

- NPP_T is a nonlinear function of mean annual temperature
- NPP_P is a nonlinear relationship with mean annual precipitation.

Second, the asymptotic form of the Miami, which reaches a maximum NPP, N_{max} at high values of precipitation and temperature, is more appropriate than a linear model over a wide range of temperature and precipitation. Others have found a linear relationship between NPP and precipitation within particular regions or vegetation types. Field data span a wide range of climatic conditions, although the relationship of subsets of data limited by one factor did not deviate much from linear.

Third, the Miami model gave better predictions of field NPP than alternative models. It explained 46 % of variation, with much better predictions at precipitation – limited sites (> 90 %) than at temperature – limited sites (Jager *et al.*, 2000).

CHAPTER III

METHODOLOGY

Estimations of carbon sequestration from forest are complicated due to complex biological factors, lack of data or reliable data, and complexity of human impacts on forest resources. The present study is used the nested plot to determine a minimal sampling plot, and tree species in the different forest types are considered as species indicators. There are different approaches in estimating tree biomass density. One kind of method for estimation is based on allometric regression and estimating carbon stock is converted by conversion factor as 0.5 of biomass In addition, Miami model is used to analyze results of tree biomass density and generate for NPP prediction.

3.1 Study area

Thong Pha Phum National Forest, the selected study area, is located at Thong Pha Phum District, Kanchnaburi Province, Thailand. Altitudes range from 100 to 1,249 m, with 3-month dry season from February through April. Receiving approximately 1,650 mm mean annual rainfall which mostly falls during rainy season, starts from April to October (Suksawang, 1995). Detail descriptions of the average air temperature in the forest are about 25^{o} C. It is richly endowed with a diverse range of natural forests reported by Vitinantakit (1999), including:

- Tropical rain forest, the dominant type of evergreen forest in Thailand. This type of forest accounts for 43.3 % of the total forest area and is concentrated in regions with high rainfall (more than 2,000 mm per year). Tropical rain forests are widely distributed throughout southern of Thailand and the mountainous areas of the North and West and they are a type of broadleaf evergreen forest. Many plants have evolved specialized ways to grow in tropical rain forests. Climbing vines, called lianas, most rooted in the soil, wind upward around the trunks of larger trees until their leaves reach the sunlit canopy. Orchids, bromeliads and other epiphytes attach themselves to the trunks and branches of canopy trees and obtain nutrients from bits of organic matter falling from the canopy. Many plants dwelling in the pale light of the understory and shrub layer survive by using huge, dark green leaves to capture enough sunlight. This ability to thrive under low light levels makes them good houseplants. The roots of even the largest trees tend to be shallow and spread out in the nutrient – poor, moist and thin layer of soil. Many of the large trees are supported by large bulges at their bases called buttresses. Dominant tree species are *Parashorea stellata, Dipterocarpus alatus, Hopea sp., Shorea henryana,* ferns, and *Calamus sp.* provide the undergrowth and ground cover.

- Dry evergreen forest, occupying about 30 % of the total forest area. Dry evergreen forest is the main forest type in the North and Northeast, occupying a wide range of elevations. Main species include *Dipterocarpus tuberculatus, D. obtusifolia,* and *Pentacme suavis.*

- Mixed deciduous forest, largely found at low elevations in the North and West, covering about 22 % of the total forest area. These forests have a lower canopy than tropical rain forests and dry evergreen forests. Deciduous forests are characterized by leaf – shedding during the dry season. Tree species include *Xylia kerrii, Pterocarpus macrocarpus, Lagerstroemia* sp., *Adina cordifolia, Terminalia* sp., and *Tectona grandis.*

The forest sites selected for study are consist of four sites. The geographical characteristics of the study areas are recorded in Table 3 and Figure 6.

Table 3 Outlines of the localities of the study area and forest types at Thong Pha – Phum National Forest.

No.	Locality	Forest type
1	Ton mai yak station (1609720 N and 0470402 E)	Tropical rain forest
2	Ban passadu khlang station (1608962 N and 0474501 E)	Tropical rain forest
3	KP 27 station (1613596 N and 0470585 E)	Dry evergreen forest
4	Phong phu ron station (1619296 N and 0474970 E)	Mixed deciduous forest

3.2 Data collection

Data from each forest in field surveys is collected by a randomised sampling method to cover of the study area at different plot size. The best approach to estimating the biomass of a forest would appear to be used of the minimal area principle. It is clear that such an approach needs to be taken for plots of different sizes, in order to cope with the various scales of pattern in the forest due to species-area technique. To generate species – area curves, the entire 1 ha plot was divided into square quadrats with no overlapping, and recorded the number of species present in each subplot. The mean number of species in each size quadrat gave a species – area curve. The minimal area depends on the kind of community and varies within wide limits. The total number of species is in itself an important characteristic of a community type (Kimmin, 1997).

The minimal area is determined by initially lining out a small area, for example, 25 x 25 m (625 m^2) and by recording all species that occur within this small area. Then the sample size area is enlarged to twice, finally it become to four and eight times of the size. The additionally occurring species are listed separately for each enlarged area. The sample area is increased until the species added to the list become very few. Figure 7 shows the arrangement of the sample quadrats in the form of nested plot.

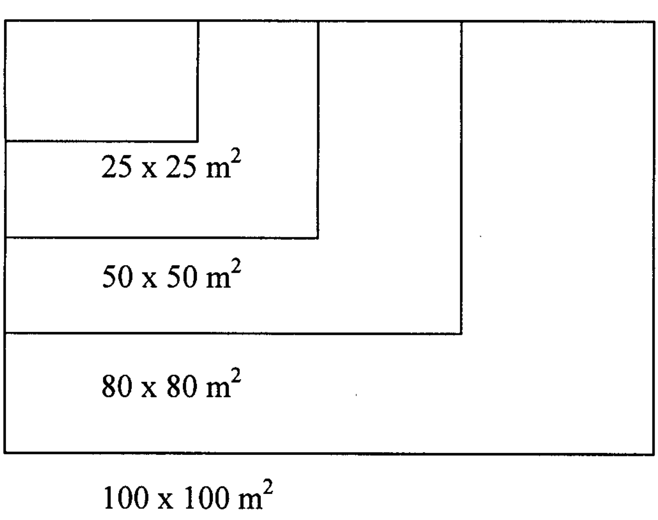


Figure 7 A system of nested plots for establishing minimal area.

In the study area, the form of the species – area curve from all three forests in field surveys is available at different densities and a square mesh of one plot. It is a similar pattern, when area increased, reflecting an increase in the proportion of total species (Figure 8).

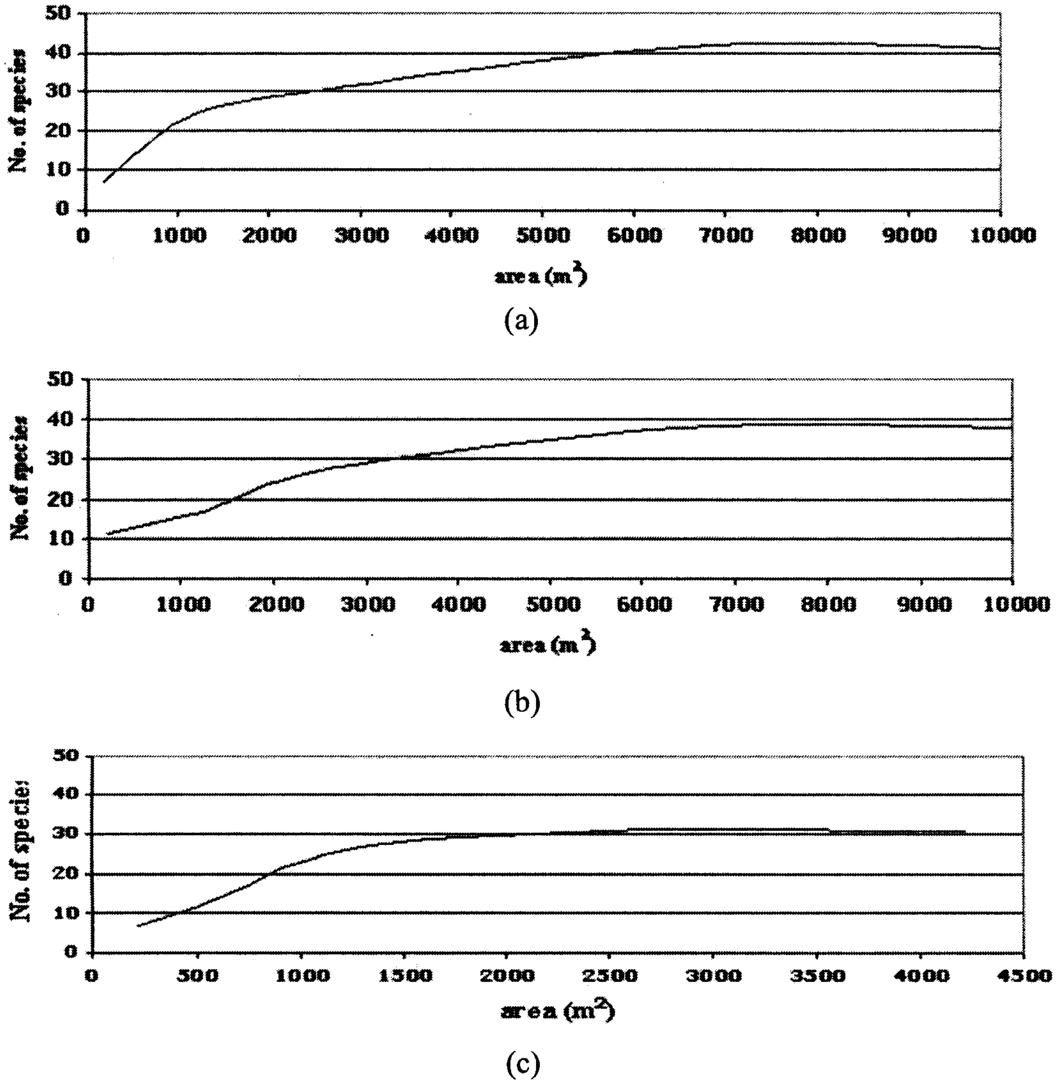


Figure 8 A sampling plot from each forest type a) tropical rain forest b) dry evergreen forest c) mixed deciduous forest

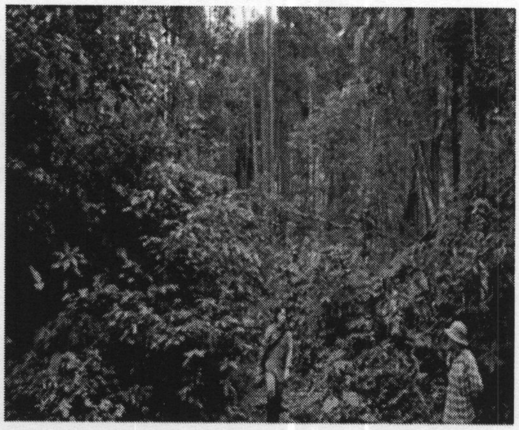
Each plot in tropical rain forest, dry evergreen forest and mixed deciduous forest has a square plot with 80 x 80, 80 x 80, and 50 x 50 m^2 respectively. The replications of plot number in tropical rain forest at Ton mai yak and Ban passadu khlang station are 3 and 1 plots in orderly, dry evergreen forest at KP 27 are 4 plots, and mixed deciduous forest at Phong phu ron station are 5 plots. At Ban passadu khlang station, the sample plot is collected one due to political and sensitive condition near Thai and Myanmar border.

There are two types of data collection for this study as follow:

3.2.1 Primary data collection

The period of data collection was planned to collect during in November 2002 to Aprial 2003. The selected study areas are composed of 4 stations, such as Ton mai yak station, Ban passadu khlang station, KP27 station and Phong phu ron station as shown in Figure 9.

(a)



(b)

(c)

(d)

Figure 9 A sampling plot from each forest type a) Ton mai yak station b) Ban passadu khlang c) KP 27 station d) Phong phu ron station

Quadrats are randomly selected for identification of vegetation types and size. All live trees in three different forests, woody stem DBH at ≥ 4.5 cm are identified, tagged, and measured diameter. For irregularities of trunk three, the measurement is taken at the nearest lower point where the stem was cylindrical, or above the buttresses on large trunks. DBH is measured by used of diameter tape. Trees with multiple stems connected near the ground are counted as single individuals. After that measure tree height (H_t) by the use of hypsometer and measuring pole and using a minimum of 40 well – selected trees in various sizes in order to calculate and analyze the relationship between DBH and Ht by hyperbolic equation or D – H curve (Ogawa, Yoda and Kira, 1961) of SILVIC Program.

3.2.2 Secondary data

Data from the Department of Meteorology provided twenty-nine year record (during 1973 – 2002) for the meteorological characteristics in study area as follows (Table 4):

- Annual mean temperature in degree Celsius
- Annual mean precipitation in millimeters

Table 4 Annual mean temperature and annual mean precipitation at Thong Pha Phum District, Kanchnaburi Province, Thailand for 29 year – period (1973 – 2002).

Year	Annual mean temperature (° Celsius)	Annual mean precipitation (mm)
1973	26.4	1908.7
1974	26.1	2247.1
1975	26.4	1792.2
1976	25.8	1606.2
1977	26.2	1629.8
1978	26.8	1595.7
1979	27.1	1454.5
1980	27.2	1317.3
1981	n.a	2438.9
1982	n.a	1852.7
1983	27.1	1410.1
1984	26.8	1715.3
1985	26.8	1990.0
1986	26.4	1531.2
1987	26.6	1581.8
1988	26.2	1788.4
1989	26.2	1533.0
1990	26.5	1728.1
1991	26.7	2103.8
1992	26.3	1487.4
1993	26.3	1459.7
1994	26.6	2005.4
1995	26.6	1789.3
1996	26.6	2129.2
1997	26.8	2058.0
1998	27.7	1155.0
1999	26.4	2130.6
2000	26.5	1624.0
2001	26.9	1780.3
2002	27.1	2010.6

Note: n.a. is not available data

3.3 Data analysis

The statistic analysis about the data of species composition are tested by Correspondence analysis that has been widely used as a method to describe the relationships between forest types, based on their species composition (Hair *et al.*, 1998). For species diversity the Shannon – Wiener index is used as an index for each ecosystem and statistically tested among three forest types by one – way ANOVA. In addition, non – destructive method is used to estimate the aboveground biomass and used SILVIC Program that was applied from the regression equation by Ogawa, Yoda and Kira (1961) in order to estimate tree height

3.3.1 Species compositions

Ever tree in the sampling plot with diameter greater than 4.5 cm at 1.30 m height are recorded. Species composition is represented by the species in terms of taxonomic classification identifie into Genera or Species,. providing both local and scientific names by Smitinand (2001). The researchers of BRT and foresters at Thong Pha Phum, assist in taxonomic classification and identification.

3.2.2 Important Value Index (IVI)

To express the floristic composition of each plot, an Important Value Index (IVI), which is a combined measure of the percentage relative frequency, abundance and dominance for each species or genus identified (Krebs, 1972), is calculated.

I.V. = R.A. + R.D.+ R.F......Whittaker (1970) (Equation 3.1)

Where I.V. = Important value index of each species

$$R.A. = \text{Relative abundance} = \frac{\text{total number of each species}}{\text{total nuber of all species}} \times 100$$

$$R.D. = \text{Relative dominance} = \frac{\text{basal area of each species}}{\text{basal area of all species}} \times 100$$

$$R.F. = \text{Relative frequency} = \frac{\text{chance to find each species}}{\text{chance to find all of species}} \times 100$$

3.2.3 Species diversity

To estimate the diversity of species, the Shannon – Wiener index method is commonly used. In this method, the proportion of number of individuals of a species to the overall number of individuals in the sample plots is used to express the diversity of species in the studied ecosystem (Krebs, 1999). In theory, Shannon – Wiener index (Shannon and Wiener, 1949) indicates that a higher index value higher species diversity and can reach very large values. In practice, for biological communities H' does not usually exceed 5.0 (Washington, 1984; cited in Gajaseni, 2000).

$$H' = -\sum_{i=1}^{s} (p_i)(\log_2 p_i) \qquad \text{(Equation 3.2)}$$

Where H' = Index of species diversity

s = Species number in the sample

p_i = Proportional abundance of the i th species = (n_i /N)

Remember that the Shannon – Wiener index has a minus sign in the calculation so the index actually becomes > 0

3.2.4 Aboveground biomass and carbon sequestration

SILVIC Program that is developed from the relationship between DBH and Ht by hyperbolic equation or D – H curve (Ogawa, Yoda and Kira, 1961) is used to tree height estimation (H_t) by using a formerly minimum of 40 well – selected trees in various sizes in the sample plot as following the equation:

$$1/H_t = 1/A(DBH)^h + 1/H^* \qquad \text{(Equation 3.3)}$$

Where Ht = height of tree (m)

DBH = diameter at breast height (cm)

A, h, H* = constant

Ogawa (1969) showed that H was approximately equal to one for most mature forests. Assuming that h equal one, the other coefficients, A and H* for each stand were calculated by using the non – linear least square method, and their curves were drawn.

After the trees are harvested, diameter and height are estimated with SILVIC Program, applied these data to the allometric regresstion equations for estimate the total aboveground biomass. Calculated aboveground biomass by summing the stem, branches and leaf mass of the individual trees, the procedure for estimating aboveground biomass follow the allometric correlation method by using a llometric equation of Tsutsumi *et al.* (1983) for tropical rain forest and dry evergreen forest, and Ogawa et al. (1965) for mixed deciduous forest. These are as follow:

- Equation by Tsutsumi *et al.* (1983)

$$\text{Stem (WS)} = 0.0509*(D^2 H)^{0.919} \qquad \text{(Equation 3.4)}$$
$$\text{Branch (WB)} = 0.00893*(D^2 H)^{0.977}$$
$$\text{Leaf (WL)} = 0.0140*(D^2 H)^{0.669}$$

- Equation by Ogawa *et al.* (1965)

$$\text{Stem (WS)} = 0.0396*(D^2 H)^{0.9326} \qquad \text{(Equation 3.5)}$$
$$\text{Branch (WB)} = 0.003487*(D^2 H)^{1.027}$$
$$\text{Leaf (WL)} = ((28.0/ WS + WB) + 0.025)^{-1}$$

Where Ws = stem mass (kg/ individual tree)

Wb = branches mass (kg/ individual tree)

Wl = leaf mass (kg/ individual tree)

Ht = height of tree (m)

DBH = diameter at breast height (cm)

After biomass estimates are calculated then calculate the carbon content in each forest type. It is calculated from aboveground biomass by converted from biomass to carbon stock. From the reports (Atjay *et al.*, 1979; Brown and Lugo, 1982; Iverson *et al.*, 1994; Dixon *et al.*, 1994 and Cannell and Milne, 1995) carbon content would be about 50 % of the amount of aboveground biomass.

3.2.5 Net Primary Productivity

NPP is the difference between total photosynthesis (GPP) and total plant respiration in ecosystem. NPP data are more widely available than other estimates of biosphere exchange of carbon such as GPP. In the field, it is not possible to measure forest NPP in terms of this difference, such as GPP cannot be measured directly. In addition, estimating total plant respiration at the ecosystem level remains difficult and involves significant uncertainties (Ryan *et al.,* 1996; cited in Clark *et al.,* 2001). There are many approaches to estimate NPP, destructive methods are required to directly estimate the NPP for a given period of accumulation, but these often ignore certain trophic flows or components of NPP, and thus rarely give a complete account of the net carbon flux. However, there are aggregations of observations to develop the method to estimate NPP rely on mathematical models or physioecological measurement of individual plants, thus in this study are used Miami model.

For this study, the Miami model is considered adequate. The Miami model is a simple and practicable method to estimate NPP, which are not only use simple measurements but also allow general application of results to regional and global scale. The model is adopted by two factors; mean annual temperature (T) and total annual precipitation (P) without any accounting neither solar radiation nor ambient CO_2 concentration. Because of its simplicity and its empirical basis, this model is still used as a baseline for evaluation while more sophisticated mechanistic models are developed (Leith, 1972, 1973, 1975).

$$NPP_T = 3000 / [1 + e^{1.315 - 0.119 (T)}] \quad \text{(Equation 3.6)}$$

$$NPP_P = 3000 [1 - e^{-0.000664 (P)}] \quad \text{(Equation 3.7)}$$

$$NPP = \min (NPP_T, NPP_P) \quad \text{(Equation 3.8)}$$

Where T = mean annual temperature
P = mean annual precipitation

The secondary data of temperature and precipitation is used from the department of meteorology that collected until 1973 to 2002. NPP (g/m^2/year) is estimated as the minimum of two functions (Equation 3.6 and 3.7), which limit productivity. The Miami model continues to be used as a benchmark for simulation of global NPP (Foley, 1994; cited in Gajaseni, 2000).

CHAPTER IV

RESULTS AND DISCUSSIONS

The main challenge in measurement of biomass is the sampling of large trees. And nowadays, foresters have developed non – destructive methods so it is apparent that a biomass study improved more than in the past. Species composition in each forest type is based on taxonomic knowledge merged with the indigenous knowledge of local people for providing identification. The stored carbon in the forest is estimated by combining study of biomass partition. The aboveground biomass is measured at the different vegetation in order to indicate the proportion of biomass in the different forest types. As the results of carbon stock in aboveground biomass have varied in different types of forests that tropical rain forest is higher than dry evergreen forest and mixed deciduous forest.

4.1 Physical factor

4.1.1 Meteorological characteristics

The physical factors are collected as annual mean temperature and annual mean precipitation. Data from the Department of Meteorology provide twenty-nine year record (during 1973 – 2002) for the meteorological characteristics as follows:

- Annual mean temperature in degree Celsius (Figure 10 and Table4)
- Annual mean precipitation in millimeters (Figure 11 and Table4)

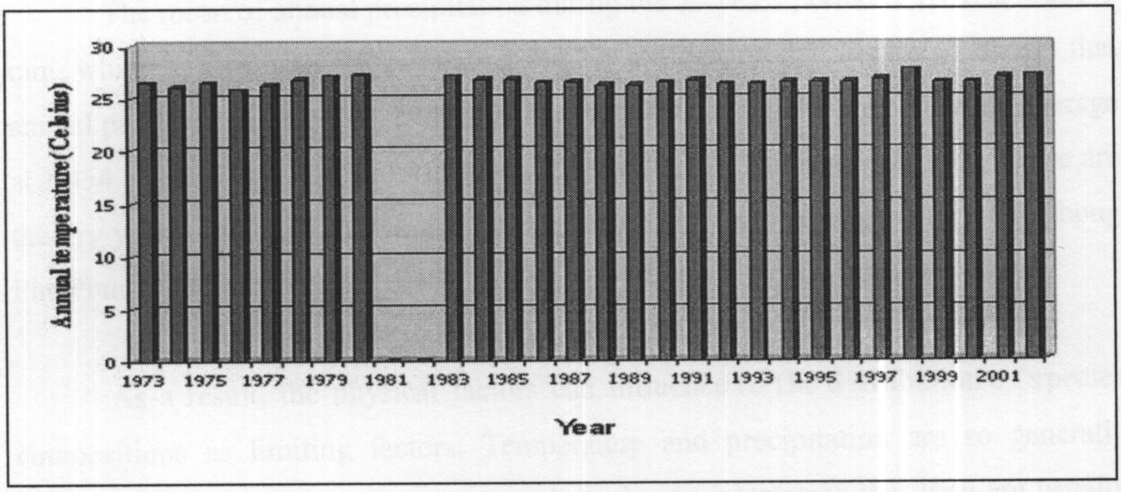


Figure 10 Annual mean temperatures at Thong Pha Phum District, Kanchanaburi Province for 29 year- period (1973- 2002).

At every moment at any spot on the earth, the troposphere has a particular set of physical properties. Examples are temperature and precipitation. These short-term properties of the troposphere at a particular place and time are weather (Miller,2002). Figure 10 and 11 is represented the meteorological conditions at study area. The mean of annual temperature is 26.6 ± 0.4 degree Celsius, which is used for estimating NPP by Miami model. Figure 10 shows that no annual temperature data record in 1981 and 1982. As the result, the mean of annual temperature in this area seems to be small fluctuation in each year.

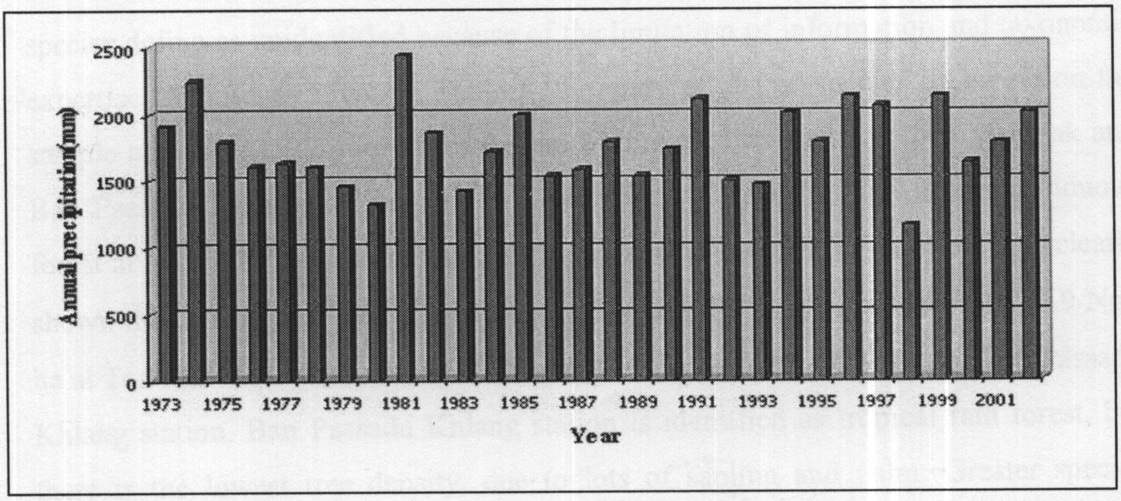


Figure 11 Annual mean precipitations at Thong Pha Phum District, Kanchanaburi Province for 29 year- period (1973- 2002).

The mean of annual precipitation during the 29 years period is 1,761.2 ± 296.8 mm, which is also used for estimating NPP by Miami model. Figure 11 shows that annual precipitation in 1979, 1980, 1983, 1992, 1993 and 1998 are below the average at 1,454.5, 1,317.3, 1,410.1, 1,487.4, 1,459.7 and 1,155.0 mm respectively. These are the dry years which might cause the lower water flow and reduce NPP in the Thong Pha Phum National Forest.

As a result, the physical factors can influence to the distribution of species compositions as limiting factors. Temperature and precipitation are so generally important in terrestrial environments and so closely interacting that they are usually conceded to be the most important part of climate. Thus, it may be well to consider them together before proceeding to other factors. The temperature can indicate the availability of moisture in atmosphere, which associates with NPP by stimulating biological functions.

4.2 Vegetation analysis in the field

4.2.1 Species compositions

Appendix 2 gives full datasets on species compositions in different areas in three forests. The local and scientific names are indicated in Appendix 2, with some species define as unidentified because of the limitation of information and taxonomic expertise. As already given in Table 5, the number of tree species occurring on the sample area with DBH more than 4.5 cm in tropical rain forest at Ton Mai Yak and Ban Passadu Khlang station, dry evergreen forest at KP 27, and mixed deciduous forest at Pong Phu Ron station are 59, 74, 57 and 53 species respectively. It is clearly shown that the highest tree density is found in tropical rain forest as 745±142.9 No./ ha at Ton Mai Yak station while the lowest tree density as 399 No./ ha at Ban Passadu Khlang station. Ban Passadu Khlang station is identified as tropical rain forest, but there is the lowest tree density, due to lots of sapling and palm. Greater species compositions might occur in systems with higher productivity where the energy is sufficient to support the higher total number of individuals of all species (DeAngelis, 1995; cited in Gajaseni, 2000) so that number of species compositions usually uses to indicate the strong correlation with available energy in the ecosystem. In addition, the greater number of species compositions are most in ecosystems that have long time evolution, because organisms may develop mechanisms to conserve or more efficiently acquire any of the other limiting resources by certain physical or abiotic factors of the environment such as temperature, precipitation, light and soil.

Table 5 A comparisons of the species compositions and tree density in different forest types.

Forest ecosystem	Tropical rain forest		Dry evergreen forest	Mixed deciduous forest (Pong Phu Ron station)
	Ton Mai Yak station	Ban Passadu Khlang station	(KP 27 station)	
Species – composition	59	57	74	53
Tree density (No./ ha)	745±142.9	399	560±68.8	544±98.3

Note: There is only one quadrat at Ban Passadu Khlang station due to the sensitive area near the border

4.2.2 Important Value Index (IVI)

Community classifications are based on major structural features such as dominant species are rather specific for certain environments. Natural communities may have an even larger number of species. Even so, a relative few species often control the community and are classified as dominant. It does not mean that the other species are not important. Removal of the dominant species would result in important changes not only in the biotic community but also in the physical environment such as light or temperature (Krebs, 1972); whereas removal of a nondominant species would produce much less change. Generally, dominant species are species in their trophic groups that have the largest productivity and largely account for the energy flow in each trophic group.

Table 6 A comparison of the dominant and co – dominant species in the different study site rank from the highest to the lowest value.

Site studies	Dominant species (Common name)	Scientific name	Important Value Index (IVI)
Ton Mai Yak station	Yang Daeng	*Dipterocarpus turbinatus* C.F. Garetn.	25.97
	Khai Khiao	*Parashorea stellata*	22.86
	Phra Chao Ha - Phra Ong	*Dracontomelon dao* (Blanco) Merr. &Rolfe	17.62
	Som Phong	*Tetrameles nudiflora* R. Br.	15.03
	Wa	*Syzygium sp.*	11.26
	Yom Hom	*Toona ciliata* M. Roem.	10.23
	Ta Khian Kaeo	*Hopea sangal* Korth.	10.13
Ban Passadu Khlang station	Khai Khiao	*Parashorea stellata*	27.00
	Ta Suea	*Aphanamixis sp.*	15.18
	Sai	*Ficus sp.*	13.52
	Yang Pai	*Dipterocarpus costatus* C.F. Garetn.	13.23
	Chang Rong Hai	*Borassodendron machadonis* (Ridl.) Becc.	13.12
	Kra Bao Yai	*Hydnocarpus sp.*	13.04
	Lueat Khwai Bai-Yai	*Knema furfuracea*	11.82
	Chakkachan	*Millettia xylocarpa*	11.68
KP 27 station	Yang Daeng	*Dipterocarpus turbinatus* C.F. Garetn.	26.99
	Yang Na	*Dipterocarpus alatus* Roxb.	22.36
	Lamyai Pa	*Paranephelium sp.*	13.11
	Ta Baek	*Lagerstroemia spp.*	11.22
	Wa	*Syzygium sp.*	10.77
	Som Phong	*Tetrameles nudiflora* R. Br.	10.18
	Ta Suea	*Aphanamixis sp.*	10.09

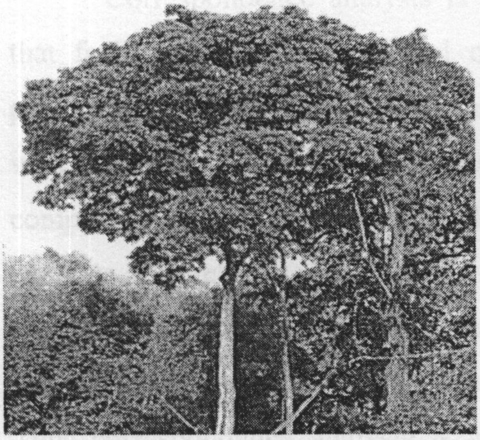
Table 6 A comparison of the dominant and co – dominant species in the different site studies rank from the highest to the lowest value (continued).

Site studies	Dominant species (Common name)	Scientific name	Important Value Index (IVI)
Pong Phu Ron station	Ta Baek	*Lagerstroemia spp.*	42.21
	Kra Thum Noen	*Mytragyna sp.*	21.84
	Salao	*Lagerstroemia sp.*	17.95
	Ta Khro	*Schleichera sp.*	14.70
	Kra Phi Chan	*Millettia sp.*	14.69
	Nam Ma Khet	*Canthium parvifolium* Roxb.	13.84
	Kha Nang	*Homalium tomentosum* (Vent.) Benth.	13.76
	Samo Phi Phek	*Terminalia bellerica* (Gaertn.) Roxb.	12.71
	Pheka	*Oroxyium indicum* (L.) Kurz	12.63
	Plao	*Croton spp.*	11.44
	Taptao Ton	*Diospyros ehretioides*	9.76
	Mok Man	*Wrightia sp.*	9.02
	Daeng	*Xylia xylocarpa* (Roxb.)	8.79

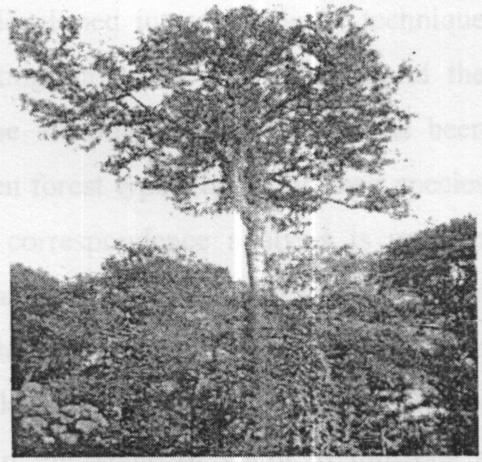
This study identified the dominant species according to the important value index (IVI), which is combined measure of the percentage relative frequency, abundance and dominance for each species (Krebs, 1972). The full datasets on IVI are given in Appendix 3. The result as already given in Table 6, which ranks from the highest value to lower value and some dominant species are shown in Figure 12. The result indicates that IVI in tropical rain forest with 2 site studies, at Ton Mai Yak station are greatest for species *Dipterocarpus turbinatus* C.F. Garetn. and *Parashorea stellata* and 5 co-dominant species as *Dracontomelom dao* (Blanco) Merr. & Rolfe., *Tetrameles nudiflora* R. Br.., *Syzygium sp.*, *Toona ciliata* M. Roem. and *Hopea sangal* Korth. Ban Passadu Khlang station, *Parashorea stellata* is a dominant species and composed 7 of co-dominant species as *Aphanamixis sp.*, *Ficus sp.*, *D. costatus* C.F. Garetn., *Borassodendron machadonis* (Ridl.) Becc., *Hydnocarpus sp.*, *Knema furfuracea* and *Millettia xylocarpa*.

In case of dry evergreen forest, KP 27 station is dominated by *D. turbinatus* C. F. Gaertn. and *D. alatus* Roxb. and 5 co-dominant species as *Paranephelium sp.* and *Lagerstroemia* spp., *Syzygium sp.*, *Tetrameles nudiflora* R. Br. and *Aphanamixis sp.*. The main conclusion from Table 7, Trees in Dipterocarpaceae Family are naturally distributed in tropical rain forest and dry evergreen forest that correlate the result in this study.

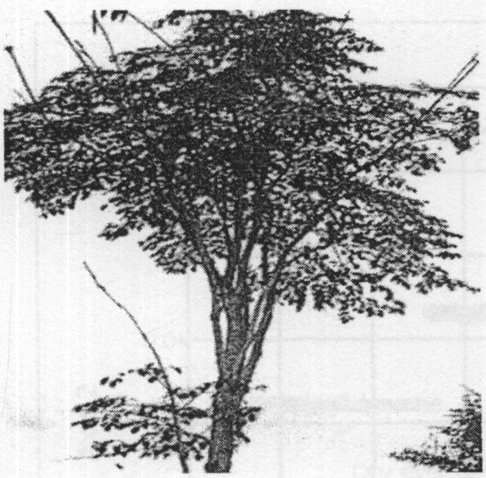
The contribution of the dominant species in mixed deciduous forest at Pong Phu Ron station are classified as *Lagerstroemia* spp. and 12 co-dominant species as *Mitragyna* sp., *L. tomentosa.*, *Schleichera sp.*, *Millettia sp.*, *Canthium parvifolium* Roxb., *Homalium tomentosum* (Vent.) Benth., *Terminalia bellerica* (Gaertn.) Roxb., *Oroxyium indicum* (L.) Kurz, *Croton spp.*, *Diospyros ehretioides*, *Wrightia sp.* and *Xylia xylocarpa* (Roxb.).



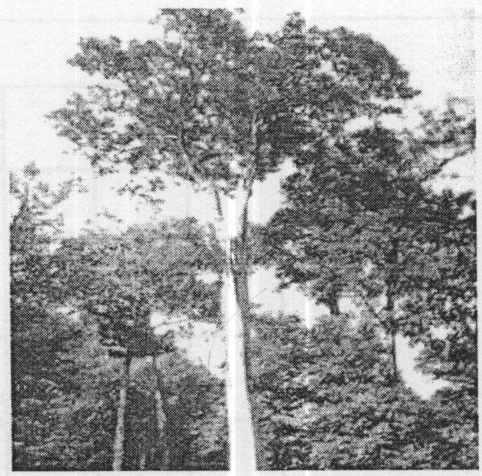
(a) *Dracontomelom dao* (Blanco) Merr. & Rolfe.



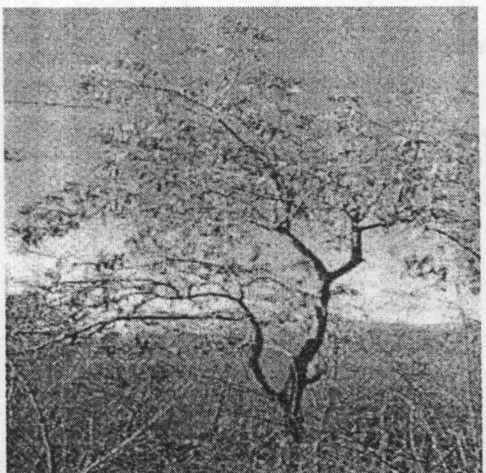
(b) *Terminalia bellerica* (Gaertn.) Roxb.



(c) *Oroxyium indicum* (L.) Kurz



(d) *Lagerstroemia sp.*



(i) *Millettia sp.*

(j) *Wrightia sp.*

Figure 12 Some dominant species in this study.

Correspondence analysis is a recently developed interdependence technique that facilitates both dimensional of object rating on a set of attributes and the perceptual mapping of objects relative to these attributes. This method has been widely used to describe the relationships between forest types, based on their species composition (Hair *et al.*, 1998). In addition, correspondence analysis is used to evaluate the relative influence of the environmental variables on the vegetation composition and to look for species characteristic of untouched and managed deciduous forests in Denmark (Grace and Hesjkaer, 1997; cited in Gajaseñi, 2000). Thus correspondence analysis is appropriate in this stage of study to illustrate a perceptual mapping of forest type related to species composition (Figure 13).

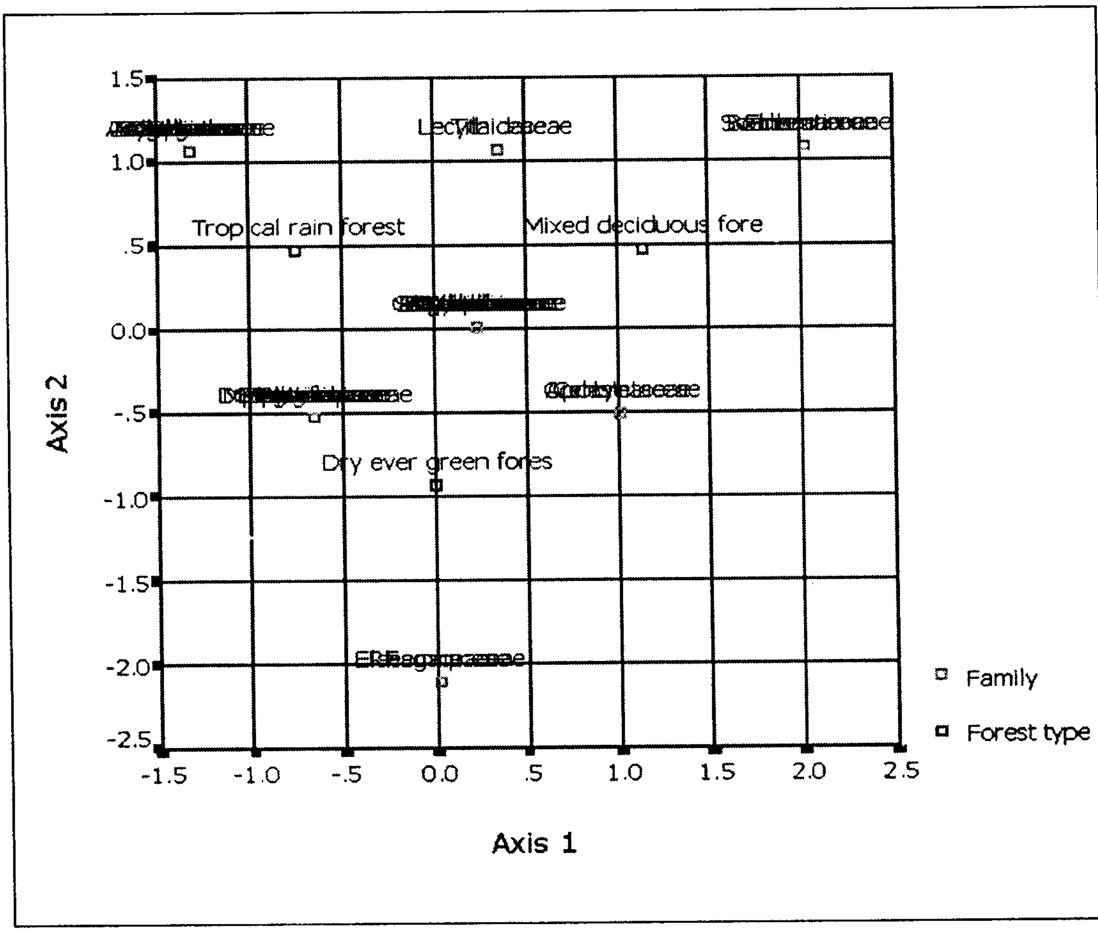


Figure 13 A perceptual mapping of forest types and related to species distribution

Using the ordination technique of detrened correspondence analysis compared the species distribution by used family level at the four site communities, which are divided to three forest types. Correspondence analysis has been widely used as a method to examine the relationships between vegetation types based on their species compositions. The correspondence analysis mapping in Figure 15 is done to examine and describe the relationships between the individual species distribution and the three forest types. Each type of species is considered for its potential distribution in the different forests. Thus some family of plant species overlap in their distribution among the different forest types, for example, the species in family as Annonaceae, Anacardiaceae, Bignoniaceae, Ceasalpiniaceae, Euphobiaceae, Elacourtiaceae, Lythraceae, Meliaceae, Mimosaceae, Myrtaceae, Papilinaceae, Rubiaceae, Sapindaceae, Simaroubaceae, and Sterculiaceae, which occur in all forest types and the pattern, indicates links to all forests. Because of the similarity of climate such as annual precipitation and annual temperature, the species compositions of each forest type have features in common and only a few rare species are specific to a single forest type.

The species as *Parashorea stellata* (Khai Khiao) in Dipterocarpaceae is indicator in only tropical rain forest (Ton Mai Yak station and Ban Passadu Khlang station), which have high important value index. In addition, Khai Khiao is usually occurred in tropical rain forest in the South of Thailand (Kutintara, 1999) that related to the result of this study. In addition, Dipterocapacae is usually used as indicator species in tropical rain forest and dry evergreen forest (Visarat *et al.*, 2000) that corresponded to the result of correspondence analysis in this study. The result of correspondence analysis showed that Dipterocarpacae are dominant in both tropical rain forest and dry evergreen forest, for example, *Dipterocarpus turbinatus* C.F. Garetn. (Yang Daeng), *Dipterocarpus costatus* C.F. Garetn. (Yang Pai), and *Dipterocarpus alatus* Roxb. (Yang Na).

Table 7 A statistical comparison of the relationships of species distribution between the different forest types.

Categories	χ^2	**ρ - value**
Forest type vs. species distribution (Faimly level)	317	0.563

The result in Table 7 illustrates that the species distribution of tree among forest types is not significantly different between the different forest types at $\chi^2 = 317$, $\rho = 0.56$. Because some family of plant species overlap in their distribution among three forest types.

To conclude the correspondence analysis, it shows that there are many species in common between three forest types, so each forest type has not a distinctive of species distribution.

4.2.3 Species diversity

To estimate the diversity of species, The Shannon – Wiener index method is commonly used, assumes that all species are represented in the sample and are randomly sampled. In this method, the proportion of number of individuals of a species to the overall number of individuals in the sampled plots is used to express the diversity of species in the studied ecosystem (Krebs, 1972). The species diversity represented in Table 8 by a value of H' which the value in Ton Mai Yak station, Ban Passadu Khlang station, KP 27 and Pong Phu Ron station as 3.52, 3.48, 3.62 and 3.09 respectively. The index is maximal at 3.62 in the KP 27 station and minimal at 3.09 in Pong Phu Ron station. The high species diversity can exist in the spatially heterogeneous environment where the disturbances influence to the species in different degree. In practice, for biological communities H' does not usually exceed 5.0 (Washington, 1984; cited in Gajaseni, 2000) that the results from this study are not exceeding this value.

Table 8 A summary of species diversity index.

	Tropical rain forest		Dry evergreen forest (KP 27 station)	Mixed deciduous forest (Pong Phu Ron station)
	Ton Mai Yak station	Ban Passadu Khlang station		
The Shannon – Wiener index (H′)	3.52	3.48	3.62	3.09

This is a useful method of comparing the diversity of different habitat, especially when a number of replicates have been taken. The most important source of error comes from the failure to include all species from the community in a sample, but this error decreases as the proportion of species represented in the sample increases and this error is minimal as it approaches the total actual number of the species in the community.

Table 9, the species diversity index values measured and calculated from different forest ecosystems in Thailand have been listed and compares with this study. The species diversity values in dry evergreen forest and mixed deciduous forest are not much different from others study. The main conclusion is clearly demonstrated that the highest species diversity is from the tropical rain forest and the lowest species diversity is from the mixed deciduous forest because there are rich in resource such as diverse of habitat types and a large extent on food available in tropical rain forest more than in other forest types. However, the result from this study shows that dry evergreen forest at KP 27 station has a higher in species diversity values than tropical rain forest. And compare to other study in tropical rain forest, show that species diversity values in this study has quite lower than species diversity values that study by Kiratiprayoon (1986). It may be concluded that the site study of tropical rain forest at Ton Mai Yak station performs relatively poorer in the distribution pattern of species than that of the dry evergreen forest and relate to the age of forest, too. Because the result of Kiratiprayoon (1986) came from Khao Chong forest, Southern Thailand that classified as old – growth forest (Ogawa *et al.*, 1965). Similarly, the mixed deciduous forest with teak forest has a poorer distribution of species than that of the mixed deciduous forest without teak that correlate to this study.

Table 9 A comparison of species diversity index under different forest ecosystems in Thailand among this study and the others.

Forest ecosystem	Shannon – Wiener diversity index	References
Tropical rain forest	3.48 - 3.52 5.0 – 6.2	This study Kiratiprayoon, 1986
Dry evergreen forest	3.62 3.5 – 4.9	This study Sahunalu *et al.*, 1979
Mixed deciduous forest	3.09 3.5 – 3.9	This study Sahunalu *et al.*, 1979
Teak forest	2.9	Dhanmanonda and Sahunalu, 1992

4.2.4 Aboveground biomass and carbon sequestration

The aboveground biomass is assessed at the different vegetation forms in order to indicate the proportion of biomass. Appendix 4 gives full datasets on biomass weight and for all species in different areas in all three forests four stations.

From the surveying, it is found that DBH and height of trees are clearly distributed in data of different size class. The characteristics of size class of three different forests are compared in Figure 14 that show the relationship between DBH and tree density in each size class. This would tend to make the biomass differences even greater. The frequency distribution curves of DBH are all L- shaped, the frequency patterns are more or less exponentially toward larger diameter classes with a maximum at the left- end or smallest DBH size classes.

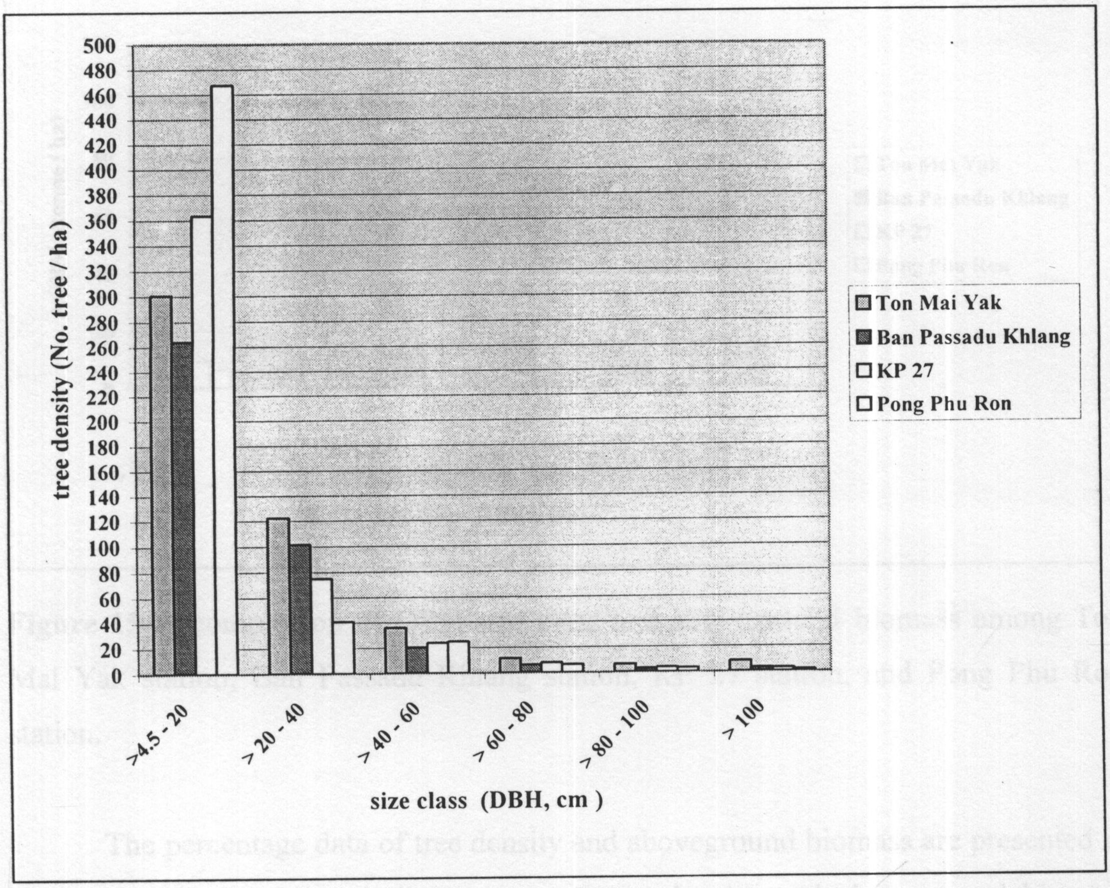


Figure 14 A comparison of DBH size class and tree density among Ton Mai Yak station, Ban Passadu Khlang station, KP 27 station, and Pong Phu Ron station.

In Figure 15 shows that aboveground biomass accumulation is the highest in tropical rain forest, while the aboveground biomass in dry evergreen forest is lower than mixed deciduous forest at DBH size class over 100 cm. Although mixed deciduous forest has many tree species and number, but most of DBH size class have smaller than 20 cm in the highest frequencies in a typical uneven – aged stand and caused the lowest individual volume and biomass. The main conclusion shows an opposite relationship between biomass and tree size class. The most aboveground biomass accumulation is found in big trees of size class at ≥ 80 –100 and ≥ 100 cm. Because these trees are highest stem volume and large diameter, although they are the smallest group of tree densities.

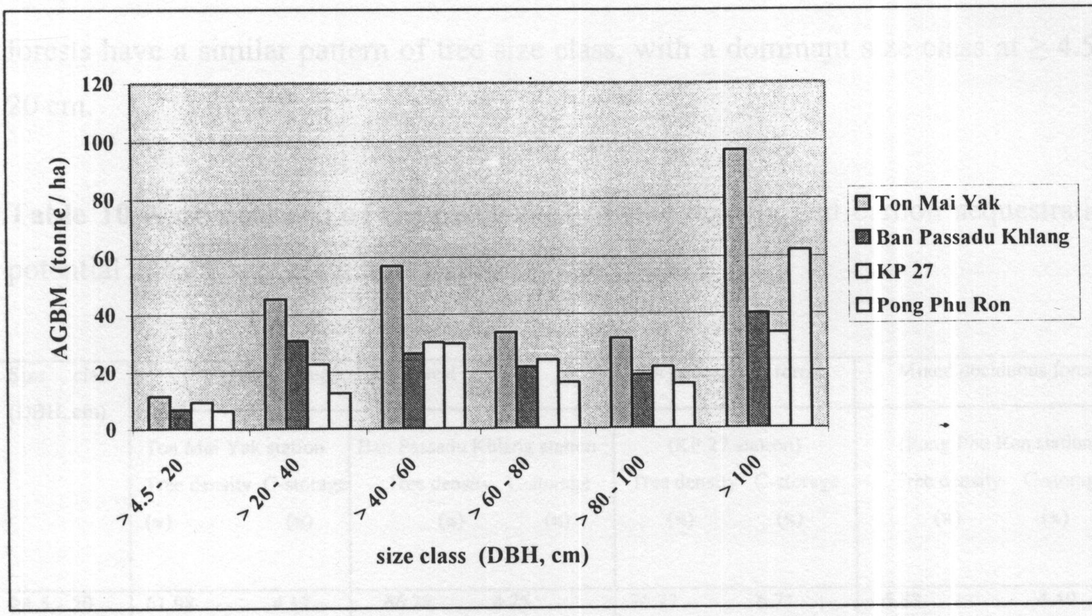


Figure 15 A comparison of DBH size class and aboveground biomass among Ton Mai Yak station, Ban Passadu Khlang station, KP 27 station, and Pong Phu Ron station.

The percentage data of tree density and aboveground biomass are presented in Table 10 and show the similar pattern of tree density and aboveground biomass existing in each size class. In the sample plot, all forests have a tree size class, with the dominant size class at ≥ 4.5 – 20 cm, are accounted for 85.88, 76.22, 66.28 and 61.98 % at Pong Phu Ron station, KP 27, Ban Passadu Khlang station, and Ton Mai Yak station respectively. On the other hand, this size class of all forests has the lowest aboveground biomass accumulation that comprises approximately ranging from 4.17 – 6.71% of the total biomass density in this study, due to low stem volume, low basal area and short trees with small diameters.

Comparison of the size class distribution and aboveground biomass show some evidences of biomass reduction in size class of tree at > 60 – 80 and > 80 – 100 cm, is resulted from selective logging in all forest types. Logging in excess of regrowth is also a significant cause of loss, particularly in Asian forests (Stiling, 1999) and usually destroyed the small size of tree during the tree felling and log dragging process (Gajaseni and Jordan, 1990), which reflects the reduction of size class > 20 – 40 and > 40 – 60 cm in the mixed deciduous forest. In the sample plot, all forests have a similar pattern of tree size class, with a dominant size class at ≥ 4.5 – 20 cm.

Table 10 A comparison of the percentage of tree density and carbon sequestration potential in each size class in the different study sites.

Size class (DBH, cm)	Tropical rain forest				Dry evergreen forest		Mixed deciduous forest	
	Ton Mai Yak station		Ban Passadu Khlang station		(KP 27 station)		(Pong Phu Ron station)	
	Tree density (%)	C-storage (%)	Tree density (%)	C-storage (%)	Tree density (%)	C-storage (%)	Tree density (%)	C-storage (%)
≥4.5 – 20	61.98	4.17	66.28	4.75	76.22	6.71	85.88	4.49
>20 – 40	25.24	16.50	25.50	21.34	15.74	16.05	7.50	8.82
>40 – 60	7.41	20.66	5.10	18.23	5.01	21.42	4.56	20.83
>60 – 80	2.36	12.13	1.57	14.90	1.64	17.03	1.18	11.31
>80 – 100	1.29	11.39	0.79	13.00	0.82	15.19	0.59	10.89
>100	1.72	35.15	0.79	27.80	0.58	23.61	0.30	43.67

Furthermore, the main conclusion in Table 10 is carbon sequestration potential in different forest types that correlate to DBH size class. In both tropical rain forest and dry evergreen forest, the main tree size classes that have a great potential in carbon sequestering are small and medium tree size at >20 – 40 and >40 – 60 cm. While, the main tree size classes that have the highest potential in carbon sequestering in mixed deciduous forest are medium tree size at > 40 – 60 cm.

For example, in Ton Mai Yak station, the smallest tree in size class ≥4.5 – 20 cm have biomass accumulation or carbon sequestration potential only 4.17 %. When plan growth further in size class at >20 – 40 cm, these trees have a highest carbon sequestration potential. And in size class at >40 – 60 cm, trees have a high carbon sequestration potential but not as much as in size class at >20 – 40 cm. These evidences are the same pattern in Ban Passadu Khlang and KP 27 station. While, in mixed deciduous forest are found in tree at size class >40 – 60 cm that have the highest potential in carbon sequestering as much as five times at the beginning size class.

The result from Table 11 indicates that carbon sequestration potential does not only correlate to tree size but also species compositions. The relationship among species compositions, DBH size class, and carbon sequestration potential in three forest types shows the same pattern. The smallest tree size has the lowest carbon sequestration but it has potential to increase in medium tree size. For example, dominant species in tropical rain forest at Ton Mai Yak and Ban Passadu Khlang station, dry evergreen forest at KP 27 station, and mixed deciduous forest at Pong Phu Ron station at size class ≥ 4.5 – 20 cm have the lowest carbon sequestration as 1.97, 3.41, 0.81, and 0.41%, while the great to sequester the carbon are found in size class >20 – 40 and > 40 – 60 cm. These results are likely in co- dominant species, except in mixed deciduous forest shows the high carbon storage at 27.05%. At Pong Phu Ron station, dominant species have the highest potential at size class > 40 – 60 and > 60 – 80 cm, while the highest percentage of carbon sequestration in co-dominant species are found at size class > 20 – 40 cm.

Table 11 A comparison of the percentage of carbon sequestration potential in each size class of dominant and co-dominant species in the different study sites.

Size class (DBH, cm)	Tropical rain forest				Dry evergreen forest		Mixed deciduous forest	
	Ton Mai Yak station		Ban Passadu Khlang station		(KP 27 station)		(Pong Phu Ron station)	
	C-storage(%)		C-storage (%)		Carbon storage (%)		Carbon storage (%)	
	Dominant species	Co-dominant species	Dominant species	Co-dominant species	Dominant species	Co-dominant species	Dominant species	Co-dominant species
≥4.5 – 20	1.97	3.06	3.41	5.81	0.81	3.67	0.41	27.05
>20 – 40	7.12	21.52	20.61	20.93	12.18	9.33	5.86	30.06
>40 – 60	25.10	19.90	15.35	44.15	22.20	6.95	27.86	18.16
>60 – 80	10.94	27.46	17.47	29.10	14.13	20.55	25.90	16.15
>80 – 100	25.88	-	43.16	-	22.68	16.77	18.54	8.58
>100	28.99	28.07	-	-	28.01	42.73	21.43	-

Table 12 shows percentage of tree density in each size class among dominant and co-dominant species in the different study sites that correlate to result in Table 10 and 11. The carbon sequestration potential from Table 10 indicate that tree sizes of tropical rain forest and dry evergreen forest have the highest potential at size class > 20 - 40 and > 40 – 60 cm and Table 11 shows that dominant and co-dominant species have highest potential to carbon sequestering at size class > 20 - 40 and > 40 – 60 cm, too. From Table 12, tree density of dominant and co-dominant species has a likely trend that dominant species have tree density higher than co-dominant species in size class at > 20 - 40 and > 40 – 60 cm. It is mean that dominant species have better carbon sequestration potential than co-dominant species because trees at these size classes have the greatest carbon sequestration potential. For example, dominant species at Ton Mai Yak station such as Yang Daeng and Khai Khiao have the density at size class > 20 - 40 and > 40 – 60 cm more than Yom Hom and Ta Khian – Kaeo, except Phra Chao Ha Phraong, Som Phong and Wa. The result in Ton Mai Yak, Ban Passadu Khlang and KP 27 station is likely, while the result at Pong Phu Ron station is different from other study sites. At Pong Phu Ron station, the result in Table 10 show carbon sequestration potential is highest at > 40 – 60 cm and the result in Table 12 show that all co-dominant species in size class at > 40 – 60 cm have tree density less than dominant species. For example, Kra Thum Noen, Salao, Ta Khro, Kra Phi Chan, Nam Ma Khet, Kha Nang and Plao have the number less than dominant species, Ta Baek. So it can conclude that dominant species in tropical rain forest, dry evergreen forest and mixed deciduous forest have the higher carbon sequestration potential than co-dominant species, but some co-dominant species in tropical rain forest and dry evergreen forest have the greatest carbon sequestration potential than dominant species.

Table 12 A comparison of the percentage of tree density in each size class among dominant and co-dominant species in the different study sites.

Study sites	Dominant species	Size class (DBH, cm)					Co-dominant species	Size class (DBH, cm)				
		≥4.5 –20	>20- 40	>40- 60	>60- 80	>80- 100		≥4.5– 20	>20- 40	>40- 60	>60- 80	>80- 100
Ton Mai Yak	Yang Daeng	63.2	17.0	14.2	2.0	2.8	Phra Chao - Ha Phraong	23.6	52.7	10.9	7.3	-
	Khai Khiao	30.6	22.5	26.6	8.2	6.2						
							Som Phong	24.3	42.4	18.2	12.1	3.1
							Wa	30.8	40.6	13.5	8.2	-
							Yom Hom	64.0	12.0	12.0	8.0	-
							Ta Khian - Kaeo	83.3	12.5	4.2	-	-
Ban Passadu Khlang	Khai Khiao	53.9	34.6	3.9	3.9	3.9	Ta suea	66.7	22.2	5.6	5.6	-
							Yang Pai	66.7	11.1	11.1	11.1	-
							Chang Rong-Hai	86.4	13.6	-	-	-
							Kra Bao Yai	72.2	22.2	5.6	-	-
							Lueat Khwai Bai Yai	73.4	13.4	13.3	-	-
							Chakkachan	22.2	33.4	44.4		
KP 27	Yang Daeng	20	47.2	21.5	4.3	4.3	Lamyai Pa	89.6	9.4	1.1	-	-
	Yang Na	24	38	22	4	8	Ta baek	50.0	27.0	3.9	11.6	3.9
							Wa	35.3	23.6	5.9	23.5	5.8
							Som Phong	50.0	8.4	25.0	-	8.3
							Ta suea	85.5	14.5	-	-	-

Table 12 A comparison of the percentage of tree density and carbon sequestration potential in each size class among dominant and co-dominant species in the different study sites (continued).

Study sites	Dominant species	Size class (DBH, cm)					Co-dominant species	Size class (DBH, cm)				
		≥4.5 –20	>20-40	>40-60	>60-80	>80-100		≥4.5–20	>20-40	>40-60	>60-80	>80-100
Pong Phu Ron	Ta baek	29.1	13.0	38.7	9.7	6.5	Kra thum noen	96.5	2.4	1.2	-	-
							Salao	53.3	26.7	13.4	6.7	-
							Ta Khro	96.0	2.0	2.0	-	-
							Kra Phi Chan	94.3	3.8	1.9	-	-
							Nam ma Khet	73.0	27.1	-	-	-
							Kha Nang	98.2	1.9	-	-	-
							Samo Phi Phek	64.3	-	14.3	14.3	7.2
							Pheka	100	-	-	-	-
							Plao	71.5	7.2	21.5	-	-

Therefore, it is possible to conclude that the tropical rain forest has the highest potential of carbon sequestration and following by the dry evergreen forest and the mixed deciduous forest respectively. In addition the trend of carbon sequestration potential of dominant species is higher than co – dominant species but some groups of co-dominant species give the different result.

This evidence indicates the potential for growth to reach the climax stage of succession in the near future. These smaller trees are not the highest carbon sequestration potential but they are relevant in terms of their future potential to grow up. Species compositions in forests bring to a different in carbon sequestration potential in each step of their growth. These trees will be able to increase biomass and store more carbon, if these forests naturally grow without any serious disturbances. In addition, Thong Pha Phum Forest is preparing to register as Thong Pha Phum National Forest soon and ilegal logging have been strictly control too.

Table 13 Aboveground biomass of tree and carbon sequestration at four study sites.

Study sites	Tree density (No./ha)	Stem mass (tonne/ha)	Branch mass (tonne/ha)	Leaf mass (tonne/ha)	Total AGBM (tonne/ ha)	Carbon sequestration (tonne C/ ha)	Calculated root biomass* (tonne C/ ha)
Ton Mai Yak station	745 ± 142.3	217.241± 52.62	54.667± 40.960	3.554± 0.790	275.46± 96.15	137.73± 48.07	34.43
Ban Passadu Khlang station	399	104.296	35.366	1.952	141.61	70.81	17.70
KP 27 station	560 ± 68.9	103.391± 11.16	34.911± 30.487	2.297± 0.493	140.58±14.76	70.29±7.38	17.57
Pong Phu Ron station	544 ± 98.3	110.256± 50.63	30.657± 29.96	0.151± 0.005	96.28±33.44	48.14±16.72	12.03

Note: root biomass* is approximately calculated 25 % of aboveground biomass (Cairns *et al.*, 1997)

The result of aboveground biomass and carbon sequestration is in Table 13 that shows the total plant biomass of forest increased with increasing moisture in the environment. Average aboveground biomass in Ton Mai Yak and Ban Passadu Khlang station (tropical rain forest), KP 27 station (dry evergreen forest) and Pong Phu Ron station (mixed deciduous forest) are 275.46±96.15, 141.61, 140.58±14.76 and 96.28±33.44 tonne/ ha respectively. Aboveground biomass changed from plot to plot in forest area due to different stage of forest growth cycle, habitat variation, and tree density. The stem weight, especially tree biomass of bigger trees, is the largest component of a forest biomass (Ogawa *et al.*, 1965).

The results include only the tree components as aboveground. Others have reported variable root: shoot ratios but, in general, root biomass is approximately 25 % of aboveground biomass (Cairns *et al.*, 1997), so the calculated root biomass in Ton Mai Yak station, Ban Passadu Khlang station, KP 27 station and Pong Phu Ron station are about 68.87, 35.40, 35.15, and 24.07 respectively.

In the estimation of carbon content, the estimations are calculated from aboveground biomass with the references of Atjay *et al.*, 1979; Brown and Lugo, 1982; Iverson *et al.*, 1994; Dixon *et al.*, 1994 and Cannell and Milne, 1995. They estimate that carbon content would be about 50 % of the amount of total aboveground biomass. Therefore, the carbon sequestration of three forest types are calculated, the carbon is stored at Ton Mai Yak station as 137.73±48 and follow by Ban Passadu Khlang, KP 27 and Pong Phu Ron station are 70.81, 70.29±7.38 and 48.14±16.72 tonne C/ ha respectively (Table 10).

Data on carbon sequestration in the different forest types show that the highest carbon is stored in the biomass of tropical rain forest at Ton Mai Yak station. Ban Passadu Khlang, KP 27 station and Pong Phu Ron station have about half of carbon sequestered when compare to Ton Mai Yak station. Because tree sizes at Ton Mai Yak station are quite large when compare to other stations so calculated carbon sequestration are highest in this station. It does not mean that other forest types are not important, because the mainly groups of small tree sizes at ≥ 4.5 – 20 cm will grow to bigger size in the near future. They will have greater potential for future sequestration if the forests are under appropriate management without human disturbance. Huston and Marland (2003) have shown that carbon sequestration depend not only on rates of productivity but also on the size of the tree. Disturbance of these landscapes can result in rapid release of large amount of carbon that will be recaptured slowly as forest regrowth.

The statistical analysis of one – way ANOVA, shows that the aboveground biomass accumulation among forest types is significantly different at F = 6.325 ($\rho \leq 0.05$) (Table 14). Thus, each forest types have different carbon sequestration potential, relate to the environmental conditions.

Table 14 A statistical comparisons of the relationships of aboveground biomass accumulation and the different forest types in this study by one – way ANOVA.

	Sum of Squares	df	Mean Square	F	Significance
Between group	61,867.175	3	20,622.392	6.325	0.013
Within group	29,343.672	9	3,260.408		
Total	91,210.847	12			

The result from Table 15 indicates that there is different aboveground biomass accumulation among study sites at the 0.05 significant levels. Aboveground biomass accumulation at Ton Mai Yak and Ban Passadu Khlang station that classified as tropical rain forest is not significantly different at ρ = 0.73. Aboveground biomass accumulation at Ton Mai Yak station is significantly different when compared to KP 27 and Pong Phu Ron station at ρ = 0.00. The other one of tropical rain forest, at Ban Passadu Khlang station, is not significantly different when compared to all study sites. At KP 27 station, aboveground biomass accumulation is significantly different when compared to Ton Mai Yak and Pong Phu Ron station.

Table 15 Multiple comparisons among four study sites.

Study sites I	Study sites II	Mean difference (I and II)	Significance
Ton Mai Yak station	Ban Passadu Khlang station	0.319950	0.73
	KP 27 station	0.429883*	0.00
	Pong Phu Ron station	0.479840*	0.00
Ban Passadu Khlang station	Ton Mai Yak station	-0.319950	0.73
	KP 27 station	0.109933	0.53
	Pong Phu Ron station	-0.140110	0.45
KP 27	Ton Mai Yak station	-0.429883*	0.00
	Ban Passadu Khlang station	-0.109933	0.53
	Pong Phu Ron station	-0.250043*	0.00
Pong Phu Ron	Ton Mai Yak station	-0.479840*	0.00
	Ban Passadu Khlang station	0.140110	0.45
	KP 27 station	0.250043*	0.00

In Table 16, the comparison of biomass accumulation and carbon sequestration in the different forest types shows the largest biomass in the tropical rain forest and the lowest biomass in the mixed deciduous forest. The results from this study the range of aboveground biomass at tropical rain forest, dry evergreen forest and mixed deciduous forest as 141.61 – 275.46, 140.48, and 96.28 tonne/ ha, and calculate to carbon sequestration as 70.81 – 137.73, 70.29, and 48.14. Ogawa *et al.* (1965) reported aboveground biomass data of different forests in Thailand such as tropical rain forest, dry evergreen forest and mixed deciduous forest at 358, 126 and 311 tonne/ ha, and calculate to carbon sequestration as 179, 60.30, and 155.50, based on direct measurement by destructive method. The study area of the three principal types of forest such as tropical rain forest is situated in the Forest Reserve of Khao Chong, Trang Province of peninsular Thailand, as well as dry evergreen forest and mixed deciduous at Ping Kong, Chaing Mai Province. As the results of this study, carbon sequestration was considerably lower than the Ogawa *et al.* study, which may suggest that these forests are more disturbed and affected to change in forestland due to different initial time study, site qualities, carbon sequestering carrying capacities and reflect that the tropical rain forest in this study is an immature forest. Flint and Richards (1996) studied that carbon sequestration was estimated in Southeast Asia including India, Thailand, Cambodia, Malaysia and Indonesia ranging from 17.5 tonne C/ ha or less in severely degraded tropical dry forest to almost 350 tonne C/ ha in relatively undisturbed mature tropical rain forest. The lower biomass values often reflect an immature forest.

Table 16 A schematic of aboveground biomass and carbon sequestration in different forest types between this study and other studies.

	Tropical rain forest		Dry evergreen forest		Mixed deciduous forest		Source
	AGBM (tonne/ha)	C- sequestration (tonne C/ha)	AGBM (tonne/ha)	C- sequestration (tonne C/ha)	AGBM (tonne/ha)	C- sequestration (tonne C/ha)	
Thailand	141.61- 275.46	70.81 – 137.73	140.58	70.29	96.28	48.14	This study
Thailand	358	179	126	60.30	311	155.50	Ogawa *et al.* (1965)
Thailand	-	-	252	126.00	-	-	Drew *et al.* (1978); cited in Gajaseni (2000)
Thailand	-	-	-	-	31.95 - 175.50	15.97-87.75	Viriyabuncha *et al.* (2002)
Malaysia	225-446	112.50-223.00	-	-	-	-	Brown and Lugo (1982)
Cameroon	238-341	119.00-170.50	-	-	-	-	
Sri Lanka	153-221	76.50-110.50	-	-	-	-	

Brown and Lugo (1982) summarized the total carbon sequestration estimates of tropical forest in three countries including Malaysia, Cameroon and Sri Lanka, ranging from 76.50 tonne C/ ha in disturbed tropical rain forest to 223 tonne C/ ha in relatively undisturbed mature tropical rain forest based on direct measurement was the highest in Malaysia (a range of 112.5 - 223 tonne C/ ha), followed by Cameroon (119 – 170.5 tonne C/ ha), and Sri Lanka (76.5 – 110.5 tonne C/ ha). The ranges of biomass lower than the other forest areas often reflect an immature forest, which may suggest that it dues to human population pressure.

By comparison of the carbon sequestration of tropical rain forest between this study and the study by Brown and Lugo (1982), the result shows that the average total aboveground biomass in Thailand is 137.73 tonne C/ ha, which is in the range of carbon sequestration in Malaysia and Cameroon. From annual precipitation data of Thailand, Malaysia and Cameroon, it indicates the same amount of precipitation as 1400, 2000 and 3000 mm / yr., respectively (Brown and Lugo, 1990).

Another factor that possibly cause of sequestered carbon lower than the other forest areas is tree height. Ogawa *et al.* (1965) reported the calculated carbon sequestration of tropical rain forest at Khao Chong Forest Reserve, Thailand was 179 tonne C/ ha that lower than calculated biomass from Malasia because of the difference in tree height. The tallest tree actually measured there was only 36 m in height, whereas the maximum tree height of tropical rain forest in Malaysia often reaches 60 m (Ogawa *et al.*, 1965). Therefore, plant biomass in Malaysia was greater than here. Thus, the accuracy to estimate biomass by used allometric equations with containing both diameter and total height is better than diameter alone.

Regarding to Chittachumnonk *et al.* (2002) studied on carbon sequestration of Teak plantation in Thailand, there were four study areas located in northern and western regions included Mae Mai Plantation at Muang District, Lampang, Thong Pha Phum Plantation at Thong Pha Phum District, Kanchnaburi, Sri Satchanalai Platation at Sri Satchanalai District, Sukhothai, and Khao Kra Yang Plantation, Wong Thong District, Phitsanulok. The study showed that all aboveground biomass of Teak plantation was equal to 78.15 tonne/ha or equivalent to 646,997.19 tonne of total aboveground biomass of area, which total study area are 8,278.50 ha. In the estimate of carbon sequestration of Teak plantation were 39.08 tonne C/ ha. The carbon sequestration in Teak plantation is seemingly near by the natural mixed deciduous forest (48.14 tonne C/ ha).

Viriyabuncha *et al.* (2002) studied the evaluation system for carbon storage in forest ecosystems in Thailand. The result showed that the carbon sequestration at Doi Suthep – Pui National Park, Chiang Mai, evergreen forest and mixed deciduous forest were in the range 15.97 – 87.75 tonne C/ ha. The maximum biomass was found in dry evergreen forest because it was old forest and have been strictly controlled the illegal logging. The minimum carbon sequestration was found in dry dipterocarp forest, which was a young forest. The study also showed carbon storage of mixed deciduous forest was in the range 15.97 – 87.75 tonne C/ ha. Comparison of the carbon sequestration from this study and Viriyabuncha *et al.* (2002), it is in the same range and the same pattern that tropical rain forest sequestered carbon higher than dry evergreen forest and mixed deciduous forest as 137.73, 70.29 and 48.14 tonne C/ ha respectively. It indicated that carbon sequestration varies from forest types and age of forest and carbon sequestration potential is rely on tree size class. Mixed deciduous forest, tree sizes at > 40 – 60 cm has trend of carbon sequestration potential more than other size classes, while size class at > 20 – 40 and > 40 – 60 cm in dry evergreen forest and tropical rain forest has more carbon sequestration potential than other size classes.

In general conclusion from biomass and carbon sequestration studies, under the different disturbance, old – growth forest has more carbon sequestration than logged forest and secondary forest respectively. Each size class has a different carbon sequestration potential. Almost medium sizes of trees have a greater potential for carbon sequestering than big trees because the growth rate will slowly in bigger trees. So, to conserve the small tree at ≥ 4.5 – 20 and > 20 – 40 can increase carbon sequestration potential in the near future. If the forest is deforested and changed to become slash – and – burn area, it will potentially cause the carbon loss to atmosphere from terrestrial ecosystems in relation to deforestation.

4.2.5 Net Primary Productivity

The calculation of NPP is based on the Miami model (Leith, 1975) extended by functions considering annual mean temperature and annual mean precipitation for 29 year – period (during 1973 – 2002) in Table 5 (Figure 11 and 12) based on the climate of the study area. Influences of radiation are not taken into account. This relationship has been determined from NPP measurements of natural vegetation more or less in equilibrium with climate and the long-term mean climate at the measurement sites. Therefore, the Miami model emphasizes more the long-term processes leading to the establishment of a vegetation type and adapted to the prescribed climate. Then, the short-term processes cause to carbon fluxes are not recognized. NPP simulations of this study by using the Miami model implicitly contain the assumption that the vegetation type is always adapted to the prevailing climate. Table 17 contains the estimate NPP that generate from the Miami model.

Table 17 A comparison of NPP (g/ m^2/ year) in Thong Pha Phum National Forest by using climate data (during 1973 – 2002).

Physical factor	NPP (g/ m^2/ yr)	NPP (tonne/ ha/ yr)	NPP (tonne C/ ha/ yr)
Annual mean temperature	2,592.97	25.93	12.96
Annual mean precipitation	2,068.75	20.69	10.34

NPP as a function of climatic driving data, so the study by Leith (1975) suggests that NPP is best estimated by the minimum of two functions, annual mean temperature and annual mean precipitation. Thus, NPP (g/ m^2/ year) is estimated from the minimum of two functions between equation 3.6 and 3.7, which may be limiting productivity. The calculated NPP by Miami model based on annual mean temperature and annual mean precipitation are 12.96 and 10.34 tonne C/ ha/ yr respectively. The result indicates that the best estimate of NPP is calculated from the annual mean precipitation rather than annual mean temperature. Miller (2002) said that water avalability is an important factor limiting NPP on land; for example, the trees in the dry evergreen forest are smaller and productivity is lower than tropical rain forest. In addition, Dai and Fung (1993) found that global NPP was more sensitive to precipitation than to temperature while Kaduk and Heimann (1994) reported that the net carbon flux was also more sensitive to precipitation than to temperature variations. It is reasonable because of the study area is located in the tropical zone where the light intensity and temperature are unlikely to be the limiting factors for the net primary production. Therefore, Thong Pha Phum Forest has the rate of NPP equal to 10.34 tonne C/ ha/ yr.

From calculated NPP result it can say that if forest area is destroyed, within 1 year there are plant community succession and net increase in total biomass is accounted approximately 10.34 tonne C/ ha. Brown *et al.* (2001) reported that fine litterfall that composed of leaves, branches, fruits and flowers are major part of NPP losses. NPP losses in part of fine litterfall in tropical forests are calculated about 10 tonne C/ha/year (Kutintara, 1999), so NPP increment in forest is less than NPP losses in term of fine litterfall. Thus, calculated net NPP increment that minus from NPP losses at Thong Pha Phum Forest is about only 0.34 tonne C/ ha/year. It can conclude that NPP increment should be considered in term of biomass or tree carbon sequestration. NPP increment or aboveground biomass increment from this study has different potential in each forest that tropical rain forest is the greatest than dry evergreen forest and mixed deciduous forest respectively. The NPP increment or aboveground biomass increment potential depend on tree density in each size class and species composition.

Table 18 A comparison of NPP (g/ m^2/ year) in Thong Pha Phum National Forest, the West of Thailand, Khao Chong forest, the South of Thailand and Ban Koum, the Northeast of Thailand.

Variable	NPP (tonne C/ ha/ yr)	Source
Annual mean temperature (26.6 ± 0.4 ^{0} C) Annual mean precipitation (1,761 ± 296.8 mm)	12.96 10.34	This study
Annual mean temperature (27.2 ^{0} C) Annual mean precipitation (2,696 mm)	13.1 12.5	Kira *et al.* (1967)
Annual mean temperature (27.1 ^{0} C) Annual mean precipitation (2,070 mm)	13.1 11.5	Gajaseni (2000)

A previous study in Thailand by Kira *et al.* (1967) and Gajaseni (2000) estimated NPP from the Miami model is shown in Table 18. Esser *et al.* (1997) recorded the NPP field studies from all over the world including the study site by Kira *et al.* (1967) in Khao Chong, Southern Thailand measured the maximum above ground NPP was 12.5 tonne C/ ha/ year. The Khao Chong forest is characterized as a tropical rain forest with annual temperature at 27.2 degree Celsius and annual precipitation at 2,696 mm. As the study by Gajaseni (2000) at Amphoe Khong Chiam, the Northeast of Thailand between the proposed Ban Koum Project and the Pak Mun Dam measured the maximum above ground NPP was 11.56 tonne C/ ha/ year with annual temperature at 27.1 ± 0.9 degree Celsius and annual precipitation at 2,069 ± 360 mm. While the present study at Thong Pha Phum National Forest is 10.34 tonne C/ ha/ year with annual temperature at 26.6 ± 0.4 degree Celsius and annual precipitation at 1,761 ± 296.8 mm.

The NPP of tropical rain forest at Khao Chong by Kira *et al.* (1967) and the NPP of Ban Koum Project and the Pak Mun Dam by Gajaseni (2000), estimated by the Miami model from annual precipitation, at 12.5 and 11.56 tonne C/ ha/ year respectively is higher than the estimated NPP for the present study at 10.34 tonne C/ ha/ year. This difference is reasonable because Khao Chong and Ban Koum project area receives a higher annual precipitation at 2,696 and 2,070 mm than Thong Pha

Phum National Forest at 1,761 mm. The forest type is like as tropical rain forest between Khao Chong and Thong Pha Phum National Forest but Khao Chong classified as old – growth tropical rain forest with high biomass density than Thong Pha Phum National Forest. While the forest type at Ban Koum mostly dry dipterocarp forest with low biomass density but the estimated NPP is higher than the present study becauae annual precipitation at Ban Koum is higher than Thong Pha Phum National Forest. This comparison supports the view that annual precipitation may be the limiting factor for NPP in these tropical terrestrial ecosystems.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

There is still an incomplete understanding of the factors controlling carbon exchange between forest ecosystems and the atmosphere. The current rise in atmospheric CO_2 concentration is thought mitigated in part by carbon sequestration within forest ecosystems, where carbon can be stored in vegetation or soils. The ultimate objective of UNFCCC is the stabilization of the greenhouse gas concentration in the atmosphere at the level that would prevent dangerous anthropogenic interference with the climate system. One way to solve this problem is bring CO_2 from the atmosphere temporarily would be into biomass, in which the carbon stock changes from a lower amount to a higher one, which can take place such as by enlarging the forest area or increasing the biomass stock per hectare. This study has described and characterized biodiversity as species composition and species diversity and also focus on aboveground biomass study with non-destructive method by using allometric regression equation.

5.1 Study area

The study area is dominated by tropical rain forest, dry evergreen forest and mixed deciduous forest. This study-classified community based on identified the dominant species according to the IVI because species composition and richness can reflect the interrelationships between species and physical conditions. In addition, species can reflect the evolutionary history of ecosystems and the quality of biodiversity performance according to ecosystem health, ecosystem resilience and ecosystem stability.

The results from this study show that the number of tree species occurring on the sample area with DBH more than 4.5 cm in tropical rain forest at Ton Mai Yak station and Ban Passadu Khlang station, dry evergreen forest at KP 27, and mixed deciduous forest at Pong Phu Ron station are 59, 57, 74 and 53 species respectively.

While tree density at Ton Mai Yak station, Ban Passadu Khlang station, KP 27 station, and Pong Phu Ron station are 745±142.9, 399, 560±68.8, and 544±98.3 No./ha respectively. It is clearly shown that the highest tree density is found in tropical rain forest at Ton Mai Yak station while the lowest at Ban Passadu Khlang station that identified as tropical rain forest, due to the lots of sapling and palm.

The result of IVI and correspondence analysis indicates that showed that Dipterocarpacae are dominant in both tropical rain forest and dry evergreen forest for example *Dipterocarpus turbinatus* C.F. Garetn. (Yang Daeng), *Dipterocarpus costatus* C.F. Garetn. (Yang Pai), and *Dipterocarpus alatus* Roxb. (Yang Na). While, the species as *Parashorea stellata* (Khai Khiao) is indicator in only tropical rain forest (Ton Mai Yak and Ban Passadu Khlang station), which has high important value index. In addition, Khai Khiao is usually occurred in tropical rain forest in the South of Thailand (Kutintara, 1999) that corresponded to the result of this study.

The species diversity represented by a value of H′ which the value in Ton Mai Yak station, Ban Passadu Khlang station, KP 27 station and Pong Phu Ron station as 3.52, 3.48, 3.62 and 3.09 respectively. The index is maximal at 3.62 in the KP 27 station and minimal at 3.09 in Pong Phu Ron station. The fact is clearly demonstrated that the highest species diversity is found in the tropical rain forest and the lowest species diversity is from the mixed deciduous forest because there are rich in resource such as diverse of habitat types and a large extent on food available in tropical rain forest more than in other forest types. However, the result from this study shows that dry evergreen forest at KP 27 station has a higher in species diversity values than tropical rain forest. It may be concluded that the site study of tropical rain forest at Ton Mai Yak station performs relatively poorer in the distribution pattern of species than that of the dry evergreen forest.

Today, there is a specific concern for the destruction of tropical forests and the consequences of destruction to local, regional, and global environments. One of these concerns is the lack of management or control over certain land uses once they are achieved. For example, under traditional practices, most stages of forest development had used and were managed for those uses. More recently there have been excellent accounts showing that much of the conversions of mature forests caused by political, economic and social forces (Brown and Lugo, 1990). Regardless of cause, the current situation in the tropics requires appropriate management for conservation and preservation in the sustainable manner.

5.2 Aboveground biomass and carbon sequestration

In the summary, the estimation of aboveground biomass is based on data sets that consider only live trees, and do not consider litter or standing dead trees. An additional the equations that used in this study, are appropriate available for each forest type; however, one must have caution in applying them to any specific region because of not only high environmental variability but also high diversity of tree species among different locality.

The statistical analysis of one – way ANOVA, shows that the aboveground biomass accumulation among forest types is significantly different. Average aboveground biomass in Ton Mai Yak and Ban Passadu Khlang station (tropical rain forest), KP 27 station (dry evergreen forest) and Pong Phu Ron station (mixed deciduous forest) are 275.46±96.15, 141.61, 140.58±14.76 and 96.28±33.44 tonne/ ha respectively. Aboveground biomass changed from plot to plot in forest area due to different stage of forest growth cycle, habitat variation, and tree density. The stem weight, especially tree biomass of bigger trees, is the largest component of a forest biomass (Ogawa *et al.*, 1965).

In the estimation of carbon sequestration of three forest types were calculated, the carbon is stored at Ton Mai Yak station as 137.73±48 and followed by Ban Passadu Khlang station, KP 27 station and Pong Phu Ron station are 70.81, 70.29±7.38 and 48.14±16.72 tonne C/ ha respectively. Data on carbon sequestration in the different forest types show that the highest carbon is stored in the biomass of tropical rain forest at Ton Mai Yak station. Ton Mai Yak station has double of carbon sequestered when compared to Ban Passadu Khlang, KP 27 station and Pong Phu Ron station. Because tree sizes at Ton Mai Yak station are quite large when compared to other stations so calculated carbon sequestration are highest in this station. It does not mean that other forest types are not important, because the mainly groups of small tree sizes at ≥ 4.5 – 20 cm will grow to bigger size by the near future. They will have greater potential for future sequestration if the forests are under appropriate management without human disturbance.

The main conclusion that carbon sequestration potential in different forest types correlates to DBH size class. In both tropical rain forest and dry evergreen forest, the main tree size classes that have a great potential in carbon sequestering are small and medium tree size at >20 – 40 and >40 – 60 cm. While, the main tree size classes that have the highest potential in carbon sequestering in mixed deciduous forest are medium tree size at >40 – 60 cm. In addition, carbon sequestration potential does not only correlate to tree size but also species compositions. The relationship among species compositions, DBH size class, and carbon sequestration potential in three forest types shows the same pattern. It is possible to conclude that the tropical rain forest has the highest potential of carbon sequestration and following by the dry evergreen forest and the mixed deciduous forest respectively.

The smallest tree size has the lowest carbon sequestration but it has potential to increase in medium tree size. To summarize the carbon sequestration potential, the smallest trees at ≥4.5-20 cm are not the highest carbon sequestration potential but they are relevant mainly in terms of their future potential to grow up. And species compositions in forests bring to a different in carbon sequestration potential in each step of their growth. These trees will be able to increase biomass and store more carbon, if these forests naturally grow without any serious disturbances. With high carbon sequestration potential in Thong Pha Phum National Forest, the Ministry of Natural Resources and Environment must urgently considers to strictly protect and conserve these kinds of forest for sequestering carbon from atmospheric carbon dioxide, which can increase carbon sink into the natural forest. Thailand can contribute to reduce the problem of greenhouse effects regarding global warming and climate changes.

To compare the result with other forest zones, tropical forests tend to carry their biomass in the standing crop relatively more than temperate forests. Therefore, tropical forest inventories, which ignore dead matter, will be a small loss of proportion to total aboveground biomass than similar inventories in the temperate zone. According to carbon sequestration potential, it is clear that tropical forests have more e ffective i n c arbon sequestering than temperate forest due to net productivity differences (Johnson and Sharpe, 1983; cited in Brown *et al.,* 1989). Then tropical forest can play a major role in carbon dioxide reduction as carbon – sink. Carbon is considered as a representative of ecosystem services for the ecosystem evaluation, because of its fundamental biological importance and its relevance to the issue of climate change. It can also be expressed in monetary terms to encourage economists, decision-makers, and policy-makers to take ecosystem value into their consideration of sustainable development.

5.3 Net primary productivity

The world' s forests are a prominent factor in the study of climate change, not only in terms of total net emissions but also in terms of global carbon storage capacity. The available data on net primary production in tropical forests are extremely limited, and even best estimates for estimates for this biome can only be thought of as rough approximations within wide bounds. It is difficult to measure NPP directly in the field because of many constrains, for example consumption, decomposition, mortality, they undergo during the measurement interval. In recent years, the foresters are developed the method for estimate primary production at the global scale by using model. Nevertheless, this study evaluates NPP by using the Miami model (Leith, 1975).

The calculated NPP by Miami model based on annual mean temperature and annual mean precipitation are 12.96 and 10.34 tonne C/ ha/ yr respectively. The result indicates that the best estimate of NPP is calculated from the annual mean precipitation rather than annual mean temperature. It is reasonable because of the study area is located in the tropical zone where the light intensity and temperature are unlikely to be the limiting factors for the net primary production. Therefore, Thong Pha Phum Forest has the rate of NPP equal to 10.34 tonne C/ ha/ yr.

Both biomass and NPP may represent important means by which to assess the relative ecological significance of organisms within a community. Biomass provides an index of the physical size of an organism in terms of its dry mass, and thereby correlates for carbon and other nutrient resource sequestered by each species. The production of biomass reflects the use of available energy. It is essential that models like Miami model that presented in this study should be developed in closed cooperation with meteorologists, hydrologists, and soil scientists to solve climate change problems in global scale. NPP will be useful for the future estimation to the rate of carbon sequestration of this area in the future.

5.4 Recommendation

Forests are an important component of the global carbon cycle. They both influence and are influenced by climate change, and their management or destruction will have a significant impact on the course of global warming in the twenty-first century (FAO, 2001). From this study, it is found that carbon sequestrations potential of forest is depended on species, tree density and tree sizes, so it will be useful for management application such as carbon sequestration in natural forest or apply to agroecosystems.

The result from this study indicate that carbon sequestration rates for each species in tonne of carbon per hectare are different and most of dominant species such as Ta Baek, Yang Daeng and Khai Khiao have a better carbon sequestrations potential than other species. In addition tree sizes at > 20 - 40 and > 40 – 60 cm have a better carbon sequestrations potential than other size classes of trees. The sequestrations potential for agroforestry is even more variable, depending on the planting density and production objectives of the system. So, it can apply agroforestry for management carbon sequestration by considered tree species and tree size that have the highest potential for carbon sequestering. Forest management can contribute towards emission reductions and to carbon sequestrations that mean the results from this study can bring to increase the productivity of forest ecosystems or in sivilcultural activities, such as timely thinning can increase forest carbon stocks in the near future.

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APPENDICES

Appendix 1 Total species are found in each area size by nested plot technique at tropical rain forest

No.	Local name	Area (m^2)				
		15 x15	35 x 35	50x50	80 x 80	100 x 100
1	Kradang Nga	X	X	X	X	X
2	Kra Thum Noen		X	X	X	X
3	Kra Bao Yai				X	X
4	Khai Khiao		X	X	X	X
5	Khem Pa		X	X	X	X
6	Kho Laen		X	X	X	X
7	Champa Pa	X	X	X	X	X
8	Champi Pa				X	X
9	Chik Khao		X	X	X	X
10	Chomphu Pa		X	X	X	X
11	Chingchi		X	X	X	X
12	Ta Khian Kaeo		X	X	X	X
13	Ta Khian Thong		X	X	X	X
14	Ta Baek Daeng		X	X	X	X
15	Tang			X	X	X
16	Ta Suea			X	X	X
17	Tao Luang			X	X	X
18	Sai			X	X	X
19	Po Hu Chang			X	X	X
20	Phra Chao Ha Phra Ong		X	X	X	X
21	Phlap Phla	X	X	X	X	X
22	Mafai				X	X
23	Mayom Pa		X	X	X	X
24	Mahat			X	X	X
25	Yom Hom		X	X	X	X
26	Yang Daeng			X	X	X
27	Lueat Khwai		X	X	X	X
28	Som Phong	X	X	X	X	X
29	Wa		X	X	X	X
30	Op Choei			X	X	X

Appendix 1 Total species are found in each area size by nested plot technique at tropical rain forest (continued)

No.	Local name	Area (m^2)				
		15 x15	35 x 35	50x50	80 x 80	100 x 100
31	Unknown1	X	X	X	X	X
32	Unknown2	X	X	X	X	X
33	Unknown3	X	X	X	X	X
34	Unknown4		X	X	X	X
35	Unknown5		X	X	X	X
36	Unknown6		X	X	X	X
37	Unknown7		X	X	X	X
38	Unknown8		X	X	X	X
39	Unknown9		X	X	X	X
40	Unknown10			X	X	X
41	Unknown11			X	X	X
Total species		7	28	38	41	41
Additional species (%)			39.3	26.3	7.3	0

Appendix 1 Total species are found in each area size by nested plot technique at dry evergreen forest (continued)

No.	Local name	Area (m^2)				
		15 x15	35 x 35	50x50	80 x 80	100 x 100
1	Kra Thum Nam		X	X	X	X
2	Ko			X	X	X
3	Kum Nam	X	X	X	X	X
4	Khanun Pa			X	X	X
5	Khamin Dam		X	X	X	X
6	Khae Hang Khang				X	X
7	Champi Pa			X	X	X
8	Chik		X	X	X	X
9	Chomphu Nam	X	X	X	X	X
10	Cha Muang				X	X
11	Daeng Nam	X	X	X	X	X
12	Ta khian Hin	X	X	X	X	X
13	Ta Baek			X	X	X
14	Ta Suea		X	X	X	X
15	Tio		X	X	X	X
16	Po Man			X	X	X
17	Po Hu Chang		X	X	X	X
18	Phrik Phran			X	X	X
19	Phlong		X	X	X	X
20	Phlap Phla				X	X
21	Mahat			X	X	X
22	Maduea		X	X	X	X
23	Manao Phi	X	X	X	X	X
24	Mafai	X	X	X	X	X
25	Mamao	X	X	X	X	X
26	Mai Khi Non			X	X	X
27	Yang Daeng	X	X	X	X	X
28	Lamyai Pa	X	X	X	X	X
29	Som Phong		X	X	X	X
30	Sadao	X	X	X	X	X

Appendix 1 Total species are found in each area size by nested plot technique at dry evergreen forest (continued)

No.	Local name	Area (m^2)				
		15 x15	35 x 35	50x50	80 x 80	100 x 100
31	Sattaban					X
32	Wa		X	X	X	X
33	Unknown1	X	X	X	X	X
34	Unknown2		X	X	X	X
35	Unknown3		X	X	X	X
36	Unknown4		X	X	X	X
37	Unknown5		X	X	X	X
Total species		11	25	33	36	37
Additional species (%)			56	24.2	8.33	2.7

Appendix 1 Total species are found in each area size by nested plot technique at mixed deciduous forest (continued)

No.	Local name	Area (m²)				
		15 x15	25 x 25	35x35	50 x 50	65 x 65
1	Kruai Pa			X	X	X
2	Kradon		X	X	X	X
3	Kra thum Noen	X	X	X	X	X
4	Kra Phi Chan	X	X	X	X	X
5	Kra Phi Khao Khwai			X	X	X
6	Kha Nang			X	X	X
7	Khun		X	X	X	X
8	Khae Bit		X	X	X	X
9	Khae Foi		X	X	X	X
10	Khae Hang Khang			X	X	X
11	Daeng			X	X	X
12	Ta Khro		X	X	X	X
13	Ta Baek Daeng	X	X	X	X	X
14	Taptao Ton		X	X	X	X
15	Teng Nam			X	X	X
16	Thong Lang			X	X	X
17	Po Daeng		X	X	X	X
18	Plao	X	X	X	X	X
19	Pheka	X	X	X	X	X
20	Ma Klam Ton				X	X
21	Ma Kham Pom			X	X	X
22	Ma Khai				X	X
23	Maduk			X	X	X
24	Mamao				X	X
25	Mok Man	X	X	X	X	X
26	Samo Phi Phek		X	X	X	X
27	Sakae Na	X	X	X	X	X

Appendix 1 Total species are found in each area size by nested plot technique at mixed deciduous forest (continued)

No.	Local name	Area (m^2)				
		15 x15	25 x 25	35x35	50 x 50	65 x 65
28	Sadao			X	X	X
29	Salao	X	X	X	X	X
30	Nam Ma Khet	X	X	X	X	X
31	Mak Lek Mak Noi					X
Total species		9	17	27	30	31
Additional species (%)			47.1	37	10	3.2

Appendix 2 Species compositions within Ton mai yak station.

Local name	Family	Scientific name
Kradang Nga	ANNONACEAE	*Cananga odorata* (Lam) Hook. f. & Thomson
Kra Thon	MELIACEAE	*Sandoricum koetjape* (Burm.f.) Merr.
Kra Thum Noen	RUBIACEAE	*Mytragyna sp.*
Kra Bao Yai	FLACOURTIACEAE	*Hydnocarpus sp.*
Khanun Pa	MORACEAE	*Artocarpus lanceifolius Roxb.*
Khai Khiao	DIPTEROCARPACEAE	*Parashorea stellata* Kurz
Khem Pa	RUBIACEAE	*Pavetta wallichiana* Steud.
Kho Laen	SAPINACEAE	*Nephelium hypoleucum* Kurz
Ngo Pa	SAPINDACEAE	*Nephelium lappaceum* Linn.
Champa Pa	MAGNOLIACEAE	*Michelia champaca L.*
Champi Pa	MAGNOLIACEAE	*Michelia baillonii* (Pierre) Finet & Gagnep.
Chik Khao	LECYTHIDACEAE	*Barringtonia pendula* (Griff.) Kurz
Chomphu Pa	MYRTACEAE	*Syzygium aqueum* (Burm.f.) Alston
Cha Muang	GUTTIFERAE	*Garcinia cowa* Roxb.ex DC.
Chingchi	CAPPARIDACEAE	*Capparis spp.*
Ta Khro	SAPINACEAE	*Schleichera sp.*
Ta Khian Kaeo	DIPTEROCARPACEAE	*Hopea sangal* Korth.
Ta Khian Thong	DIPTEROCARPACEAE	*Hopea odorata* Roxb.
Ta Baek Daeng	LYTHRACEAE	*Lagerstroemia spp.*
Tang	ASCLEPIADACEAE	*Hoya pachyclada* Kerr
Ta Suea	MELIACEAE	*Aphanamixis sp.*
Tao Rang	PALMAE	*Caryota sp.*
Tao Luang	EUPHORBIACEAE	*Macaranga gigantea* (Rchb.f. & Zoll.) Mull. Arg.

Appendix 2 Species compositions within Ton mai yak station (continued).

Local name	Family	Scientific name
Sai	MORACEAE	*Ficus sp.*
Po Man	BORAGINACEAE	*Cordia mhaya* Kerr
Po Hu Chang	STERCULIACEAE	*Pterospermum sp.*
Plao	EUPHORBIACEAE	*Croton spp.*
Phueng	MORACEAE	*Ficus albipila* (Miq.) King
Phra Chao Ha Phra Ong	ANACARDIACEAE	*Dracontomelon dao* (Blanco) Merr. & Rolfe
Phlong	MELASTOMATACEAE	*Memecylon sp.*
Phlap Phla	TILIACEAE	*Microcos tomentosa*
Manao Phi	RUTACEAE	*Atalantia monophylla* (DC.) Correa
Ma Fo	EUPHORBIACEAE	*Trewia nudiflora* L.
Mafai	EUPHORBIACEAE	*Baccaurea ramiflora* Lour.
Mayom Pa	SIMAROUBACEAE	*Ailanthus triphysa* (Dennst.) Alston
Mahat	MORACEAE	*Artocarpus sp.*
Yom Hom	MELIACEAE	*Toona ciliata* M. Roem.
Yang Daeng	DIPTEROCARPACEAE	*Dipterocarpus turbinatus* C. F. Garetn.
Lamyai Pa	SAPINDACEAE	*Paranephelium sp.*
Lin Chi	SAPINDACEAE	*Litchi sp.*
Lueat Khwai	MYRISTICACEAE	*Knema sp.*
Lueat Nok	TILIACEAE	*Pentace sp.*
Som Phong	DATISCACEAE	*Tetrameles nudiflora* R. Br.
San	DILLENIACEAE	*Dillenia spp.*
Saraphi Pa	THEACEAE	*Anneslea fragrans* Wall.
Salao	LYTHRACEAE	*Lagerstroemia sp.*

Appendix 2 Species compositions within Ton mai yak station (continued).

Local name	Family	Scientific name
Wa	MYRTACEAE	*Syzygium sp.*
Op Choei	LAURACEAE	*Cinnamomum iners* Bl.
UnKnown1	-	-
UnKnown2	-	-
UnKnown3	-	-
UnKnown4	-	-
UnKnown5	-	-
Unknown6	-	-
UnKnown7	-	-
UnKnown8	-	-
Unknown9	-	-
Unknown10	-	-

Appendix 2 Species compositions within Ban passadu khlang station (continued).

Local name	Family	Scientific name
Kradang Nga	ANNONACEAE	*Cananga odorata* (Lam) Hook. f. & Thomson
Kra Thon	MELIACEAE	*Sandoricum koetjape* (Burm.f.) Merr.
Kra Bao Yai	FLACOURTIACEAE	*Hydnocarpus sp.*
Kom Khom	SIMAROUBACEAE	*Picrasma javanica*
Khai Khiao	DIPTEROCARPACEAE	*Parahorea stellata* Kurz
Khan Ham Suea	ARALIACEAE	*Aralia sp.*
Khae Hang Khang	BIGNONIACEAE	*Markhamia sp.*
Chakkachan	PAPILIONACEAE	*Millettia xylocarpa*
Chik Khao	LECYTHIDACEAE	*Barringtonia pendula* (Griff.) Kurz
Chettamun	ERYTHROXYLACEAE	*Erythroxylum cuneatum* (Miq) Kurz
Chomphu Nam	MYRTACEAE	*Syzygium diospyrifolium* (Wall. Ex Duthie) S.N. Mitra
Chang Rong Hai	PALMAE	*Borassodendron machadonis* (Ridl.) Becc.
Ta Khram	BURSERACEAE	*Garuga pinnata* Roxb.
Ta Khian Thong	DIPTEROCARPACEAE	*Hopea odorata* Roxb.
Ta Baek	LYTHRACEAE	*Lagerstroemia spp.*
Ta Suea	MELIACEAE	*Aphanamixis sp.*
Tin Nok	LABIATAE	*Vitex sp.*
Tao Rang	PALMAE	*Caryota sp.*
Sai	MORACEAE	*Ficus sp.*
Nom Khwai	ANNONACEAE	*Melodorum sp.*
Po I Keng	STERCULIACEAE	*Pterocymbium tinctorium* (Blanco) Merr.
Phi Suea	ALANGIACEAE	*Alangium sp.*
Phlap Phla	TILIACEAE	*Microcos tomentosa*
Maduea	MORACEAE	*Ficus spp.*
Yang Pai	DIPTEROCARPACEAE	*Dipterocarpus costatus* C. F. Gaertn.
Yang Wat	DIPTEROCARPACEAE	*Dipterocarpus chartaceus* Symington
Lueat Khwai Bai Yai	MYRISTICACEAE	*Knema furfuracea*
Sok	CAESALPINIACEAE	*Saraca spp.*

Appendix 2 Species compositions within Ban passadu khlang station (continued).

Local name	Family	Scientific name
Nam Khi Raet	MIMOSACEAE	*Acacia megaladena* Desv.
Nam Ma Khet	RUBIACEAE	*Canthium parvifolium* Roxb.
Lang Kap	PALMAE	*Arenga westerhoutii* Griff.
Wa	MYRTACEAE	*Syzygium sp.*
Mueat	PROTEACEAE	*Helicia sp.*
Op Choei	LAURACEAE	*Cinnamomum iners* Bl.
Unknown1	ANNONACEAE	-
Unknown2	RUBIACEAE	-
Unknown3	SAPINDACEAE	-
Unknown4	-	-
Unknown5	-	-
Unknown6	-	-
Unknown7	-	-
Unknown8	-	-
Unknown9	-	-
Unknown10	-	-
Unknown11	-	-
Unknown12	-	-
Unknown13	-	-
Unknown14	-	-
Unknown15	-	-
Unknown16	-	-
Unknown17	-	-
Unknown18	-	-
Unknown19	-	-
Unknown20	-	-
Unknown21	-	-

Appendix 2 Species compositions within KP 27 station (continued).

Local name	Family	Scientific name
Kradang Nga	ANNONACEAE	*Cananga odorata* (Lam) Hook. f. & Thomson
Kra Thon	MELIACEAE	*Sandoricum koetjape* (Burm.f.) Merr.
Kra Thum Nam	RUBIACEAE	*Nauclea orientalis*
Kra Phi Chan	PAPILIONACEAE	*Millettia sp.*
Ko	FAGACEAE	*Lithocarpus sp.*
Kum Nam	CAPPARIDACEAE	*Crateva magna* (Lour.) DC.
Khanun Pa	MORACEAE	*Artocarpus lanceifolius Roxb.*
Khamin Dam	ZINGIBERACEAE	*Curcuma sp.*
Kha Nang	FLACOURTIACEAE	*Homalium tomentosum* (Vent.) Benth.
Kheng	TILIACEAE	*Brownlowia sp.*
Khun	CAESALPINIACEAE	*Cassia fistula*
Khae Pa	BIGNONIACEAE	*Dolichandrone sp.*
Khae Hang Khang	BIGNONIACEAE	*Markhamia sp.*
Champa Pa	MAGNOLIACEAE	*Michelia champaca L.*
Champi Pa	MAGNOLIACEAE	*Michelia baillonii* (Pierre) Finet & Gagnep.
Chik	ELAEOCARPACEAE	*Elaeocarpus sp.*
Chomphu Nam	MYRTACEAE	*Syzygium diospyrifolium* (Wall. Ex Duthie) S.N. Mitra
Cha Muang	GUTTIFERAE	*Garcinia cowa* Roxb.ex DC.
So	VERBENACEAE	*Gmelina arborea* Roxb.
Daeng Nam	MELIACEAE	*Aglaia cucullata* (Roxb.)
Ta Khian Hin	DIPTEROCARPACEAE	*Hopea ferrea* Laness.
Takhrai Ton	LAURACEAE	*Litsea sp.*
Ta Baek	LYTHRACEAE	*Lagerstroemia spp.*
Ta Suea	MELIACEAE	*Aphanamixis sp.*

Appendix 2 Species compositions within KP 27 station (continued).

Local name	Family	Scientific name
Tio	GUTTIFERAE	*Cratoxylum sp.*
Thong Lang	PAPILIONACEAE	*Erythrina subumbrans* (Hassk.) Merr.
Nom Ngua	ANNONACEAE	*Goniothalamus sp.*
Pra Du Pa	PAPILIONACEAE	*Pterocarpus macrocarpus* Kurz
Po Man	BORAGINACEAE	*Cordia mhaya* Kerr
Po Hu Chang	STERCULIACEAE	*Pterospermum sp.*
Plao	EUPHORBIACEAE	*Croton spp.*
Phrik Phran	APOCYNACEAE	*Tabernaemontana bufalina* Lour.
Phlong	MELASTOMATACEAE	*Memecylon sp.*
Phlap Phla	TILIACEAE	*Microcos tomentosa*
Pheka	BIGNONIACEAE	*Oroxyium indicum* (L.) Kurz
Makok Pa	ANACARDIACEAE	*Spondias bipinnata* Airy Shaw & Forman
Maduk	CELASTRACEAE	*Siphonodon sp.*
Maduea	MORACEAE	*Ficus spp.*
Manao Phi	RUTACEAE	*Atalantia monophylla* (DC.) Correa
Ma Fo	EUPHORBIACEAE	*Trewia nudiflora* L.
Mafai	EUPHORBIACEAE	*Baccaurea ramiflora* Lour.
Mamuang Pa	ANACARDIACEAE	*Mangifera caloneuara* Kurz
Mamao	EUPHORBIACEAE	*Antidesma spp.*
Mayom Pa	SIMAROUBACEAE	*Ailanthus triphysa* (Dennst.) Alston
Mahat	MORACEAE	*Artocarpus sp.*
Mok Man	APOCYNACEAE	*Wrightia sp.*
Mai Khi Non	SAPINACEAE	*Zollingeria dongnaiensis* Pierre
Yang Daeng	DIPTEROCARPACEAE	*Dipterocarpus turbinatus* C. F. Garetn.
Yang Na	DIPTEROCARPACEAE	*Dipterocarpus alatus* Roxb. ex G. Don

Appendix 2 Species compositions within KP 27 station (continued).

Local name	Family	Scientific name
Lamyai Pa	SAPINDACEAE	*Paranephelium sp.*
Som Poi	MIMOSACEAE	*Acacia sp.*
Som Phong	DATISCACEAE	*Tetrameles nudiflora* R. Br.
Samo Phi Phek	COMBRETACEAE	*Terminalia bellerica* (Gaertn) Roxb.
Sakae Na	COMBRETACEAE	*Combretum quadrangulare* Kurz
Sadao	MELIACEAE	*Azadirachta spp.*
Sak	VERBENACEAE	*Tectona grandis Linn. f.*
Sattaban	APOCYNACEAE	*Dyear scholaris* R. Br.
Sake	MORACEAE	*Artocarpus altilis* (Parkinson) Fosberg
San	DILLENIACEAE	*Dillenia spp.*
Salao	LYTHRACEAE	*Lagerstroemia sp.*
Nam Kun Ta	SIMAROUBACEAE	*Harrisonia perforata*
Nam Khi Raet	MIMOSACEAE	*Acacia megaladena* Desv.
Ma Mun	ELAEOCARPACEAE	*Elaeocarpus sp.*
Wa	MYRTACEAE	*Syzygium sp.*
Oi Chang	RHAMNACEAE	*Ziziphus rugosa* Lam.
Inthanin	LYTHRACEAE	*Lagerstroemia sp.*
Unknown1	-	-
UnKnown2	-	-
Unknown3	-	-
Unknown4	-	-
Unknown5	-	-
Unknown6	-	-

Appendix 2 Species compositions within Pong phu ron station (continued).

Local name	Family	Scientific name
Kruai Pa	FLACOURTIACEAE	*Casearia grewiifolia* Vent.
Kradon	LECYTHIDACEAE	*Careya arborea* Roxb.
Kra Thum Noen	RUBIACEAE	*Mytragyna sp.*
Kra Phi Chan	PAPILIONACEAE	*Millettia sp.*
Kra Phi Khao Khwai	PAPILIONACEAE	*Millettia sp.*
Ket Dam	PAPILIONACEAE	*Dalbergia cultrata* Graham ex Benth.
Ket Daeng	PAPILIONACEAE	*Dalbergia oliveri* Gamble
Kha Nang	FLACOURTIACEAE	*Homalium tomentosum* (Vent.) Benth.
Khun	CAESALPINIACEAE	*Cassia fistula*
Khae Bit	BIGNONIACEAE	*Fernandao sp.*
Khae Foi	CAESALPINIACEAE	*Bauhinia purpurea*
Khae Hang Khang	BIGNONIACEAE	*Markhamia sp.*
Ngio Pa	BOMBACACEAE	*Bombax sp.*
Chong Kho	CAESALPINIACEAE	*Bauhinia purpurea*
So	VERBENACEAE	*Gmelina arborea* Roxb.
Daeng	MIMOSACEAE	*Xylia xylocarpa* (Roxb.)
Ta Khro	SAPINACEAE	*Schleichera sp.*
Ta Khian Nu	COMBRETACEAE	*Anogeissus acuminata* (Roxb. Ex DC.) Guill. & Perr
Ta Baek Daeng	LYTHRACEAE	*Lagerstroemia spp.*
Taptao Ton	EBENACEAE	*Diospyros ehretioides* Wall. Ex G. Don
Teng Nam	EUPHORBIACEAE	*Bridelia retusa* (L.) A. Juss.
Thong Lang	PAPILIONACEAE	*Erythrina subumbrans* (Hassk.) Merr.
Po Daeng	STERCULIACEAE	*Sterculia sp.*
Plao	EUPHORBIACEAE	*Croton spp.*
Phlap Phla	TILIACEAE	*Microcos tomentosa*
Pheka	BIGNONIACEAE	*Oroxyium indicum* (L.) Kurz

Appendix 2 Species compositions within Pong phu ron station (continued)

Local name	Family	Scientific name
Ma Klam Ton	MIMOSACEAE	*Adenanthera sp.*
Makok Pa	ANACARDIACEAE	*Spondias bipinnata* Airy Shaw & Forman
Ma Kham Pom	EUPHORBIACEAE	*Phyllanthus emblica* L.
Ma Khai	EUPHORBIACEAE	*Mallotus spp.*
Maduk	CELASTRACEAE	*Siphonodon sp.*
Ma Fo	EUPHORBIACEAE	*Trewia nudiflora* L.
Mafai	EUPHORBIACEAE	*Baccaurea ramiflora* Lour.
Mamao	EUPHORBIACEAE	*Antidesma spp.*
Manam	RUBIACEAE	*Vangueria spinosa*
Mamao Chang	EUPHORBIACEAE	*Antidesma bunius*
Mok Man	APOCYNACEAE	*Wrightia sp.*
Mai Khi Non	SAPINACEAE	*Zollingeria dongnaiensis* Pierre
Yang On	ANNONACEAE	*Polyalthia viridis* Craib
Lamphu Pa	SONNERATIACEAE	*Duabanga grandiflora* (Roxb.ex DC.) Walp.
Samo Phi Phek	COMBRETACEAE	*Terminalia bellerica* (Gaertn) Roxb.
Sakae Na	COMBRETACEAE	*Combretum quadrangulare* Kurz
Sadao	MELIACEAE	*Azadirachta spp.*
Sato	MIMOSACEAE	*Parkia speciosa* Hassk.
Sattaban	APOCYNACEAE	*Dyear scholaris* R. Br.
Salao	LYTHRACEAE	*Lagerstroemia sp.*
Samae San	CAESALPINIACEAE	*Cassia garrettiana* Craib
Nam Kun Ta	SIMAROUBACEAE	*Harrisonia perforata*
Nam Chai Daeng	CAESALPINIACEAE	*Pterolobium macropterum* Kurz
Nam Ma Khet	RUBIACEAE	*Canthium parvifolium* Roxb.
Mak Lek Mak Noi	LABIATAE	*Vitex canescens* Kurz
Wa	MYRTACEAE	*Syzygium sp.*
Inthanin	LYTHRACEAE	*Lagerstroemia sp.*

Appendix 3 Important value index of species at Ton Mai Yak station.

Local name	Relative abundance	Relative frequency	Relative dominance	Important value index
Kradang Nga	5.5734	2.5210	1.5880	9.6825
Kra Thon	0.4287	1.6807	0.0919	2.2013
Kra Thum Noen	1.0718	2.5210	0.2150	3.8078
Kra Bao Yai	0.1072	0.8403	0.1651	1.1126
Khanun Pa	3.3226	1.6807	1.8473	6.8506
Khamin Dam	5.2519	2.5210	15.0821	22.8550
Khem Pa	0.7503	1.6807	0.1779	2.6088
Kho Laen	1.8221	1.6807	1.5815	5.0843
Ngo Pa	0.2144	1.6807	0.4480	2.3430
Champa Pa	1.0718	2.5210	1.0803	4.6731
Champi Pa	0.1072	0.8403	0.0376	0.9851
Chik Khao	1.3934	1.6807	1.4998	4.5739
Chomphu Pa	2.3580	1.6807	0.3428	4.3814
Cha Muang	0.9646	1.6807	0.0820	2.7273
Chingchi	0.8574	1.6807	0.6202	3.1584
Ta Khro	0.2144	0.8403	0.0033	1.0580
Ta Khian Kaeo	5.2519	2.5210	2.3641	10.1370
Ta Khian Thong	0.6431	1.6807	0.1628	2.4866
Ta Baek Daeng	1.5005	2.5210	3.9198	7.9414
Tang	0.2144	0.8403	0.0176	1.0723
Ta Suea	3.4298	2.5210	0.7936	6.7444
Tum Hu Kai Daeng	1.0718	0.8403	0.4066	2.3188
Tao Rang	0.1072	0.8403	0.0482	0.9957
Tao Luang	0.6431	0.8403	0.1673	1.6507

Appendix 3 Important value index of species at Ton Mai Yak station (continued).

Local name	Relative abundance	Relative frequency	Relative dominance	Important value index
Sai	0.3215	1.6807	6.6809	8.6832
Po Man	0.1072	0.8403	0.1207	1.0682
Po Hu Chang	2.5723	1.6807	1.9721	6.2251
Plao	0.6431	1.6807	0.0195	2.3433
Phueng	0.2144	0.8403	2.1379	3.1926
Phra Chao Ha Phra Ong	5.8950	2.5210	9.2068	17.6228
Phlong	3.9657	1.6807	0.3930	6.0394
Phlap Phla	2.2508	2.5210	0.5764	5.3482
Manao Phi	1.2862	1.6807	0.1074	3.0742
Ma Fo	0.2144	1.6807	0.3004	2.1954
Mafai	5.2519	2.5210	2.3856	10.1585
Mayom Pa	0.9646	2.5210	0.5316	4.0173
Mahat	4.0729	2.5210	1.2305	7.8244
Yom Hom	2.7867	2.5210	4.9163	10.2240
Yang Daeng	11.3612	2.5210	12.0857	25.9679
Lamyai Pa	0.5359	1.6807	0.0308	2.2474
Lin Chi	0.1072	0.8403	0.0061	0.9536
Lueat Khwai	2.7867	2.5210	2.5798	7.8876
Lueat Nok	0.2144	0.8403	0.3795	1.4342
Som Phong	3.4298	2.5210	9.0779	15.0287
San	0.8574	1.6807	1.5875	4.1257
Saraphi Pa	0.1072	0.8403	0.0303	0.9779
Salao	1.0718	1.6807	4.6261	7.3786

Appendix 3 Important value index of species at Ton Mai Yak station (continued).

Local name	Relative abundance	Relative frequency	Relative dominance	Important value index
Wa	3.9657	2.5210	4.7735	11.2602
Op Choei	0.4287	1.6807	0.4494	2.5588
UnKnown1	0.5359	0.8403	0.0174	1.3937
UnKnown2	0.7503	0.8403	0.0187	1.6093
UnKnown3	0.4287	0.8403	0.0252	1.2943
UnKnown4	0.3215	1.6807	0.0086	2.0108
UnKnown5	0.9646	1.6807	0.0207	2.6660
Unknown6	0.3215	1.6807	0.0045	2.0067
UnKnown7	0.3215	0.8403	0.0127	1.1745
UnKnown8	0.4287	1.6807	0.0172	2.1266
Unknown9	0.6431	1.6807	0.0702	2.3939
Unknown10	1.5005	1.6807	0.8559	4.0371

Appendix 3 Important value index of species at Ban Passadu Khlang station (continued).

Local name	Relative abundance	Relative frequency	Relative dominance	Important value index
Kradang Nga	0.3922	1.7241	0.0200	2.1363
Kra Thon	0.3922	1.7241	0.0562	2.1725
Kra Bao Yai	7.0588	1.7241	4.2509	13.0338
Kom Khom	4.3137	1.7241	2.7581	8.7960
Khai Khiao	10.1961	1.7241	15.0754	26.9956
Khan Ham Suea	0.3922	1.7241	0.0283	2.1446
Khae Hang Khang	3.1373	1.7241	2.9722	7.8336
Chakkachan	3.5294	1.7241	6.4217	11.6753
Chik Khao	1.5686	1.7241	0.3322	3.6250
Chettamun	1.1765	1.7241	0.3150	3.2156
Chomphu Nam	1.1765	1.7241	0.8342	3.7348
Chang Rong Hai	8.6275	1.7241	2.7660	13.1176
Ta Khram	1.9608	1.7241	1.5332	5.2182
Ta Khian Thong	0.3922	1.7241	6.9642	9.0805
Ta Baek	0.7843	1.7241	0.7684	3.2769
Ta Suea	7.4510	1.7241	6.0016	15.1767
Tin Nok	1.5686	1.7241	3.4446	6.7374
Tao Rang	0.7843	1.7241	1.1854	3.6939
Sai	0.3922	1.7241	11.4051	13.5214
Nom Khwai	0.3922	1.7241	0.4327	2.5490
Po I Keng	3.9216	1.7241	2.5583	8.2040
Phi Suea	0.3922	1.7241	0.0696	2.1859
Phlap Phla	0.7843	1.7241	0.9230	3.4314
Maduea	0.7843	1.7241	0.0845	2.5930

Appendix 3 Important value index of species at Ban Passadu Khlang station (continued).

Local name	Relative abundance	Relative frequency	Relative dominance	Important value index
Yang Pai	3.5294	3.4483	6.2472	13.2249
Yang Wat	3.9216	1.7241	2.7182	8.3639
Lueat Khwai Bai Yai	5.8824	1.7241	4.2046	11.8111
Sok	0.7843	1.7241	0.4300	2.9384
Nam Khi Raet	0.3922	1.7241	0.0867	2.2030
Nam Ma Khet	0.3922	1.7241	0.0581	2.1744
Lang Kap	0.3922	1.7241	0.4227	2.5390
Wa	0.3922	1.7241	0.0984	2.2147
Mueat	0.3922	1.7241	0.5061	2.6224
Op Choei	0.7843	1.7241	0.6777	3.1862
Unknown1	0.3922	1.7241	0.1706	2.2869
Unknown2	0.3922	1.7241	0.0823	2.1986
Unknown3	0.3922	1.7241	4.2971	6.4134
Unknown4	0.3922	1.7241	0.4531	2.5694
Unknown5	0.3922	1.7241	0.0984	2.2147
Unknown6	0.3922	1.7241	0.1644	2.2807
Unknown7	0.7843	1.7241	0.5016	3.0101
Unknown8	1.1765	1.7241	0.2830	3.1836
Unknown9	0.7843	1.7241	0.6888	3.1973
Unknown10	1.1765	1.7241	0.5231	3.4238
Unknown11	1.5686	1.7241	0.2262	3.5190
Unknown12	0.7843	1.7241	0.1370	2.6454

Appendix 3 Important value index of species at Ban Passadu Khlang station (continued).

Local name	Relative abundance	Relative frequency	Relative dominance	Important value index
Unknown13	1.1765	1.7241	0.3547	3.2553
Unknown14	3.9216	1.7241	2.5524	8.1981
Unknown15	0.3922	1.7241	0.0396	2.1558
Unknown16	0.3922	1.7241	0.0258	2.1421
Unknown17	0.3922	1.7241	0.4739	2.5902
Unknown18	1.9608	1.7241	0.4236	4.1086
Unknown19	0.3922	1.7241	0.3514	2.4677
Unknown20	0.7843	1.7241	0.6639	3.1724
Unknown21	1.1765	1.7241	0.4242	3.3248

Appendix 3 Important value index of species at KP 27 station (continued).

Local name	Relative abundance	Relative frequency	Relative dominance	Important value index
Kradang Nga	1.5536	1.2048	0.4256	3.1840
Kra Thon	0.4088	1.8072	0.1148	2.3309
Kra Thum Nam	3.2706	2.4096	1.3102	6.9905
Kra Phi Chan	0.0818	0.6024	0.0080	0.6922
Ko	0.2453	0.6024	0.4181	1.2658
Kum Nam	0.1635	0.6024	0.2681	1.0341
Khanun Pa	2.6983	2.4096	1.0747	6.1826
Khamin Dam	0.4906	1.2048	0.5579	2.2534
Kha Nang	0.0818	0.6024	0.0712	0.7554
Kheng	0.0818	0.6024	0.0080	0.6922
Khun	0.0818	0.6024	0.0034	0.6876
Khae Pa	1.5536	1.8072	0.3216	3.6824
Khae Hang Khang	0.0818	0.6024	0.0054	0.6896
Champa Pa	0.1635	0.6024	0.4008	1.1667
Champi Pa	0.0818	0.6024	0.0555	0.7397
Chik	4.4971	2.4096	1.7957	8.7025
Chomphu Nam	3.1889	2.4096	1.6877	7.2862
Cha Muang	1.0630	1.8072	0.6411	3.5113
So	0.1635	0.6024	0.0494	0.8154
Daeng Nam	3.1071	2.4096	0.8676	6.3844
Ta Khian Hin	1.8806	2.4096	3.4777	7.7680
Takhrai Ton	0.0818	0.6024	0.0055	0.6897
Ta Baek	2.1259	2.4096	6.6841	11.2196
Ta Suea	5.6419	2.4096	2.0334	10.0849

Appendix 3 Important value index of species at KP 27 station (continued).

Local name	Relative abundance	Relative frequency	Relative dominance	Important value index
Tio	0.3271	0.6024	0.1586	1.0881
Thong Lang	0.4906	1.2048	0.4088	2.1042
Nom Ngua	0.0818	0.6024	0.0061	0.6902
Pra Du Pa	2.6983	1.8072	0.9905	5.4961
Po Man	1.9624	2.4096	4.4314	8.8034
Po Hu Chang	0.0818	0.6024	0.0410	0.7252
Plao	0.8994	1.2048	0.0998	2.2041
Phrik Phran	0.1635	1.2048	0.0106	1.3790
Phlong	4.5789	2.4096	2.1291	9.1177
Phlap Phla	0.8177	1.8072	0.3436	2.9685
Pheka	3.5159	1.8072	0.5379	5.8610
Makok Pa	1.7989	1.8072	0.8586	4.4647
Ma Kluea	0.2453	0.6024	0.0703	0.9180
Maduk	0.1635	1.2048	0.0799	1.4483
Maduea	3.7612	2.4096	1.1117	7.2825
Manao Phi	3.5977	2.4096	1.2773	7.2847
Ma Fo	2.2077	1.8072	1.3012	5.3161
Mafai	4.0065	2.4096	2.5662	8.9824
Mamuang Pa	0.1635	0.6024	0.1338	0.8998
Mamao	0.1635	1.2048	0.0092	1.3776
Mayom Pa	0.3271	0.6024	0.1248	1.0543
Mahat	2.1259	2.4096	0.6322	5.1678
Mok Man	0.0818	0.6024	0.0064	0.6906
Mai Khi Non	1.9624	2.4096	1.3356	5.7077
Yang Daeng	5.7236	2.4096	18.8516	26.9849
Yang Na	4.0883	1.2048	17.0619	22.3550

Appendix 3 Important value index of species at KP 27 station (continued).

Local name	Relative abundance	Relative frequency	Relative dominance	Important value index
Lamyai Pa	7.8496	2.4096	2.8515	13.1107
Som Poi	0.0818	0.6024	0.0073	0.6915
Som Phong	0.9812	1.8072	7.3886	10.1770
Samo Phi Phek	0.0818	0.6024	0.4384	1.1225
Sakae Na	1.7171	1.8072	0.1440	3.6683
Sadao	3.9248	2.4096	1.6320	7.9665
Sak	0.0818	0.6024	0.1096	0.7938
Sattaban	0.4906	1.2048	1.4659	3.1613
Sake	0.0818	0.6024	0.0342	0.7184
San	0.8177	1.8072	0.2098	2.8347
Salao	0.7359	1.2048	0.5343	2.4751
Nam Kun Ta	0.0818	0.6024	0.0165	0.7007
Nam Khi Raet	0.0818	0.6024	0.0073	0.6915
Ma Mun	0.0818	0.6024	0.3102	0.9944
Wa	1.3900	2.4096	6.9759	10.7756
Oi Chang	0.0818	0.6024	0.1020	0.7862
Inthanin	0.3271	1.2048	0.0239	1.5558
Unknown1	0.3271	0.6024	0.0270	0.9564
UnKnown2	0.3271	0.6024	0.0735	1.0030
Unknown3	0.3271	0.6024	0.0454	0.9749
Unknown4	0.1635	0.6024	0.0083	0.7743
Unknown5	0.4906	1.2048	0.1059	1.8014
Unknown6	0.6541	1.8072	0.6243	3.0857

Appendix 3 Important value index of species at Pong Phu Ron station (continued).

Local name	Relative abundance	Relative frequency	Relative dominance	Important value index
Kruai Pa	1.7621	1.4815	0.7205	3.9641
Kradon	0.8811	2.2222	0.1136	3.2169
Kra Thum Noen	15.1248	3.7037	3.0029	21.8314
Kra Phi Chan	8.9574	2.9630	2.7734	14.6938
Kra Phi Khao Khwai	0.2937	0.7407	0.0478	1.0822
Ket Dam	0.1468	0.7407	0.0163	0.9039
Ket Daeng	0.4405	1.4815	0.2634	2.1854
Kha Nang	8.2232	3.7037	1.8318	13.7587
Khun	2.4963	2.2222	0.3575	5.0761
Khae Bit	0.2937	1.4815	0.1911	1.9663
Khae Foi	0.1468	0.7407	0.0185	0.9060
Khae Hang Khang	2.9369	2.9630	0.3164	6.2162
Ngio Pa	0.1468	0.7407	0.0393	0.9269
Chong Kho	0.2937	1.4815	0.2134	1.9885
So	0.1468	0.7407	0.0390	0.9266
Daeng	4.1116	3.7037	0.9744	8.7897
Ta Khro	8.5169	3.7037	2.4876	14.7082
Ta Khian Nu	0.2937	0.7407	0.0216	1.0561
Ta Baek Daeng	5.7269	3.7037	32.7797	42.2103
Taptao Ton	2.0558	3.7037	4.0026	9.7621
Teng Nam	0.4405	1.4815	0.0429	1.9649
Thong Lang	0.5874	2.2222	0.2770	3.0865
Po Daeng	0.5874	2.9630	1.2491	4.7994
Plao	2.7900	3.7037	4.9463	11.4400
Phlap Phla	0.2937	0.7407	0.5006	1.5350
Pheka	7.7827	3.7037	1.1361	12.6224

Appendix 3 Important value index of species at Pong Phu Ron station (continued).

Local name	Relative abundance	Relative frequency	Relative dominance	Important value index
Ma Klam Ton	0.1468	0.7407	0.0390	0.9266
Makok Pa	0.1468	0.7407	1.0071	1.8947
Ma Kham Pom	0.7342	2.9630	0.1890	3.8862
Ma Khai	0.1468	0.7407	0.0175	0.9050
Maduk	0.1468	0.7407	0.0082	0.8958
Ma Fo	1.6153	2.2222	1.6128	5.4502
Mafai	0.7342	2.9630	1.8282	5.5254
Mamao	1.3216	2.9630	0.1315	4.4161
Manam	0.1468	0.7407	0.0112	0.8988
Mamao Chang	0.1468	0.7407	0.0051	0.8927
Mok Man	3.9648	3.7037	1.3520	9.0205
Mai Khi Non	0.1468	0.7407	0.0146	0.9022
Yang On	0.1468	0.7407	0.4058	1.2934
Lamphu Pa	0.1468	0.7407	3.7821	4.6697
Samo Phi Phek	2.0558	2.9630	7.6927	12.7115
Sakae Na	0.5874	2.2222	0.0802	2.8898
Sadao	0.1468	0.7407	0.0388	0.9264
Sato	0.1468	0.7407	0.0159	0.9034
Sattaban	0.1468	0.7407	0.0140	0.9016
Salao	2.9369	3.7037	11.3105	17.9511
Samae San	1.1747	1.4815	0.1670	2.8232
Nam Kun Ta	0.4405	0.7407	0.0838	1.2651
Nam Chai Daeng	0.1468	0.7407	0.0501	0.9377
Nam Ma Khet	6.1674	3.7037	3.9718	13.8429
Mak Lek Mak Noi	0.4405	1.4815	5.8589	7.7809
Wa	0.2937	0.7407	1.3117	2.3461
Inthanin	0.1468	0.7407	0.6376	1.5251

Appendix 4 Total aboveground biomass of each species for three plots at Ton mai yak station

Local name	stem biomass (Kg)	branch biomass (Kg)	leaf biomass (Kg)	total biomass (tonne / ha)
Kradang Nga	4852.0814	1433.3737	141.4952	3.3474
Kra Thon	431.0699	36.0815	13.9603	0.2506
Kra Thum Noen	285.5507	43.6884	13.2560	0.1784
Kra Bao Yai	1305.5958	434.7197	22.6878	0.9182
Khanun Pa	7487.7206	689.3828	155.3218	4.3398
Khai Khiao	79668.1928	22715.8289	1042.9365	53.8682
Khem Pa	330.2906	93.7096	11.8496	0.2270
Kho Laen	9652.2424	1173.2643	153.8103	5.7184
Ngo Pa	1570.3014	433.0255	29.9614	1.0590
Champa Pa	1296.5852	305.2811	37.5547	0.8539
Champi Pa	189.7420	55.9369	5.5721	0.1309
Chik Khao	766.9076	217.3795	27.7734	0.5271
Chomphu Pa	934.7080	263.3890	35.1160	0.6423
Cha Muang	248.3257	63.4329	10.4923	0.1678
Chingchi	1525.2331	470.9294	38.0715	1.0595
Ta Khro	4.7136	0.4529	0.4529	0.0029
Ta Khian Kaeo	4131.9015	911.4214	113.8736	2.6860
Ta Khian Thong	651.9815	189.6859	20.5870	0.4491
Ta Baek Daeng	16961.9196	5208.9792	253.8220	11.6795
Tang	50.2950	13.0549	2.5575	0.0343
Ta Suea	2261.2825	552.1214	76.5917	1.5052
Tao Rang	277.6911	7.3523	7.3523	0.1523
Tao Luang	722.2815	211.3275	22.6204	0.4980

Appendix 4 Total aboveground biomass of each species for three plots at Ton mai yak station (continued)

Local name	stem biomass (Kg)	branch biomass (Kg)	leaf biomass (Kg)	total biomass (tonne / ha)
Sai	36991.8062	9827.6977	346.4169	24.5656
Po Man	321.2948	97.9208	8.1758	0.2226
Po Hu Chang	5832.0718	1855.9327	129.3105	4.0715
Plao	44.8472	9.0608	2.7893	0.0295
Phueng	10736.9148	4080.3033	106.1740	7.7726
Phra Chao Ha Phra Ong	46778.6383	15230.8576	743.3700	32.6838
Phlong	1267.0622	286.8457	51.0256	0.8359
Phlap Phla	1495.3396	369.6522	50.2130	0.9975
Manao Phi	245.0395	43.1668	12.5233	0.1566
Ma Fo	1120.0427	176.1752	24.4905	0.6879
Mafai	8174.8551	2445.8340	182.7307	5.6268
Mayom Pa	1600.6547	351.8982	40.3368	1.0380
Mahat	3611.1623	753.5776	111.0901	2.3312
Yom Hom	15709.4922	4580.8434	246.0391	10.6960
Yang Daeng	53811.5591	15769.0959	906.8410	36.7122
Lamyai Pa	91.4254	11.3887	4.5210	0.0559
Lin Chi	15.7361	0.9097	0.9097	0.0091
Lueat Khwai	8904.5807	1627.2897	176.2589	5.5772
Lueat Nok	1161.6532	374.2068	23.7307	0.8123
Som Phong	24861.6204	5470.1115	440.8016	16.0274
San	7030.5455	301.9510	127.5943	3.8855
Saraphi Pa	51.9049	14.0998	2.1687	0.0355
Salao	28773.2773	449.9298	363.7459	15.4099
Wa	17253.9567	3660.9820	337.9052	11.0692
Op Choei	1920.0171	635.4839	35.8073	1.3496

Appendix 4 Total aboveground biomass of each species for three plots at Ton mai yak station (continued)

Local name	stem biomass (Kg)	branch biomass (Kg)	leaf biomass (Kg)	total biomass (tonne / ha)
Unknown1	35.9134	8.7682	2.4288	0.0245
Unknown2	33.1172	7.8290	2.5589	0.0227
Unknown3	72.9284	19.2050	3.6264	0.0499
Unknown4	15.7977	3.7650	1.1780	0.0108
Unknown5	34.0559	7.9275	2.8080	0.0233
Unknown6	1313.1624	409.5573	32.3349	0.9141
Unknown7	29.0435	7.2458	1.7882	0.0198
Unknown8	42.2748	10.7520	2.4385	0.0289
Unknown9	327.4014	22.9058	10.4829	0.1879
Unknown10	1782.0259	532.4991	51.0535	1.2321

Appendix 4 Total aboveground biomass of each species for three plots at Ban passadu khlang station (continued)

Local name	stem biomass (Kg)	branch biomass (Kg)	leaf biomass (Kg)	total biomass (tonne / tree)
Kradang Nga	1.5627	0.3403	0.1693	0.0032
Kra Thon	8.5243	2.0661	0.5822	0.0175
Kra Bao Yai	2348.1084	741.9559	55.6767	4.9152
Kom Khom	1181.4909	346.2958	36.5290	2.4442
Khai Khiao	10984.3778	3722.3016	192.6578	23.2802
Khan Ham Suea	2.7704	0.6255	0.2569	0.0057
Khae Hang Khang	1469.1588	444.1424	40.0977	3.0522
Chakkachan	4239.6856	1362.6619	87.9871	8.8911
Chik Khao	71.3391	18.4550	3.7605	0.1462
Chettamun	101.2462	28.2728	3.8958	0.2085
Chomphu Nam	404.0762	121.9291	11.1521	0.8393
Chang Rong Hai	1077.8247	316.3236	34.9058	2.2329
Ta Khram	637.3613	184.4680	20.4292	1.3160
Ta Khian Thong	6900.2564	2552.1100	76.2347	14.8884
Ta Baek	354.0845	104.4910	10.4249	0.7328
Ta Suea	3655.9839	1179.7606	78.8717	7.6791
Tin Nok	2942.4151	1025.1466	43.2423	6.2669
Tao Rang	650.4822	198.4509	16.4851	1.3522
Sai	11591.1906	4429.7480	111.2080	25.2065
Nom Khwai	206.2920	61.1378	5.9218	0.4271
Po I Keng	1341.2097	412.9234	34.2737	2.7944
Phi Suea	12.0624	2.9884	0.7496	0.0247
Phlap Phla	453.8706	135.3750	12.6809	0.9405

Appendix 4 Total aboveground biomass of each species for three plots at Ban passadu khlang station (continued)

Local name	stem biomass (Kg)	branch biomass (Kg)	leaf biomass (Kg)	total biomass (tonne / tree)
Maduea	11.6458	2.7940	0.8445	0.0239
Yang Pai	4837.1773	1655.8860	78.4634	10.2680
Yang Wat	1590.7169	479.2337	35.5199	3.2898
Lueat Khwai Bai Yai	2225.5982	690.8735	55.7967	4.6442
Sok	183.5359	53.6535	5.6964	0.3795
Nam Khi Raet	17.1830	4.3532	0.9698	0.0352
Nam Ma Khet	8.9798	2.1836	0.6047	0.0184
Wa	21.0251	5.3948	1.1233	0.0430
Mueat	259.0507	77.8850	6.9896	0.5374
Op Choei	314.6176	93.4393	9.1300	0.6519
Capidaceae	349.0960	106.3597	9.0574	0.7258
Unknown1	128.9389	35.3355	5.2610	0.2649
Unknown2	58.5653	15.4841	2.8385	0.1201
Unknown3	34.1296	8.8033	1.8556	0.0700
Unknown4	15.7881	3.9785	0.9119	0.0323
Unknown5	4054.1903	1449.9795	51.7632	8.6811
Unknown6	220.6388	65.6677	6.2189	0.4571
Unknown7	21.0251	5.3948	1.1233	0.0430
Unknown8	47.4070	12.8045	2.0302	0.0973
Unknown9	203.7974	59.0174	6.6024	0.4210
Unknown10	75.3256	20.3330	3.3566	0.1547
Unknown11	352.6412	106.9862	9.3580	0.7328
Unknown12	183.8037	51.6756	6.7071	0.3784

Appendix 4 Total aboveground biomass of each species for three plots at Ban passadu khlang station (continued)

Local name	stem biomass (Kg)	branch biomass (Kg)	leaf biomass (Kg)	total biomass (tonne / tree)
Unknown13	1253.2166	380.4674	33.9994	2.6058
Unknown14	4.7984	1.1216	0.3832	0.0098
Unknown15	2.3762	0.5313	0.2297	0.0049
Unknown16	50.2606	13.6255	2.1185	0.1031
Unknown17	31.3947	8.2619	1.5040	0.0643
Unknown18	199.3344	58.9480	5.7757	0.4126
Unknown19	235.5650	70.4004	6.5224	0.4883
Unknown20	86.6581	22.1622	4.7552	0.1775
Unknown21	151.6618	44.0830	4.7336	0.3132

Appendix 4 Total aboveground biomass of each species for three plots at KP 27 station (continued)

Local name	stem biomass (Kg)	branch biomass (Kg)	leaf biomass (Kg)	total biomass (tonne / tree)
Kradang Nga	506.8198	135.2264	23.6930	0.2601
Kra Thon	145.2792	39.3163	6.8281	0.0748
Kra Thum Nam	2237.8563	663.0548	79.1490	1.1641
Kra Phi Chan	5.9054	1.3986	0.4457	0.0030
Ko	840.3134	254.0302	29.3594	0.4389
Kum Nam	543.9388	165.2085	18.7904	0.2844
Khanun Pa	1784.5245	512.6460	66.3203	0.9232
Khamin Dam	1133.8556	347.6603	37.6325	0.5934
Kha Nang	115.2979	32.9384	3.8773	0.0594
Kheng	5.9054	1.3986	0.5205	0.0031
Khun	1.8017	0.3959	0.1878	0.0009
Khae Pa	397.5777	104.7313	22.5799	0.2050
Khae Hang Khang	3.4268	0.7842	0.3441	0.0018
Champa Pa	1001.2953	323.9823	20.1431	0.5256
Champi Pa	82.7393	23.1472	3.8765	0.0429
Chik	3305.8065	1005.3284	115.0771	1.7290
Chomphu Nam	3842.1581	1225.7447	99.3361	2.0185
Cha Muang	1063.4313	308.8960	43.5586	0.5531
So	64.1905	17.4651	2.7253	0.0330
Daeng Nam	2767.9967	861.2502	84.7542	1.4508
Ta Khian Hin	9199.1409	3045.4645	237.2550	4.8757
Takhrai Ton	6.4699	1.4754	0.6583	0.0034
Ta Baek	20525.3717	7179.6533	377.1465	10.9696
Ta Suea	3006.9660	847.0368	130.5171	1.5565
Tio	243.9143	69.4113	11.0144	0.1267

Appendix 4 Total aboveground biomass of each species for three plots at KP 27 station (continued)

Local name	stem biomass (Kg)	branch biomass (Kg)	leaf biomass (Kg)	total biomass (tonne / tree)
Thong Lang	863.6874	269.3552	21.2476	0.4509
Nom Ngua	8.0188	1.8532	0.6724	0.0041
Pra Du Pa	3329.8685	1056.0325	89.8012	1.7483
Po Man	12232.0841	4089.4890	260.6633	6.4774
Po Hu Chang	55.0624	15.0134	2.8439	0.0285
Plao	88.1994	21.5525	6.2529	0.0453
Phrik Phran	6.9247	1.6000	0.6762	0.0036
Phlong	3744.9641	1121.5120	126.6110	1.9504
Phlap Phla	545.8430	156.2877	18.7919	0.2816
Pheka	599.5136	154.3178	34.7679	0.3080
Makok Pa	1781.6158	554.3700	47.0130	0.9309
Maduk	106.5718	29.0182	5.0468	0.0549
Maduea	1867.3479	543.9789	70.7727	0.9696
Manao Phi	1988.7042	555.3200	96.9610	1.0316
Ma Fo	2520.5807	762.9255	84.9175	1.3158
Mafai	5003.7685	1511.6102	161.8409	2.6083
Mamuang Pa	252.3933	75.3562	7.1431	0.1308
Mamao	5.4957	1.2403	0.5816	0.0029
Mayom Pa	221.3532	60.5845	9.1353	0.1137
Mahat	880.0736	245.4803	39.5665	0.4551
Mok Man	4.2936	0.9966	0.3534	0.0022
Mai Khi Non	2626.2425	785.5853	91.9329	1.3687
Yang Daeng	52797.6647	17900.9486	1035.0704	28.0210
Yang Na	52989.4078	18672.9151	991.0800	28.3802

Appendix 4 Total aboveground biomass of each species for three plots at KP 27 station (continued)

Local name	stem biomass (Kg)	branch biomass (Kg)	leaf biomass (Kg)	total biomass (tonne / tree)
Lamyai Pa	5021.5873	1502.2769	187.3854	2.6216
Som Poi	11.8647	2.8120	1.0433	0.0061
Som Phong	27429.5809	10420.0517	287.5683	14.8973
Samo Phi Phek	1207.1223	399.9469	21.4289	0.6361
Sakae Na	146.7935	35.6575	11.1198	0.0756
Sadao	2875.8224	835.1243	108.9806	1.4922
Sak	204.1388	60.4596	5.8768	0.1057
Sattaban	4101.9952	1379.7757	71.5047	2.1692
Sake	43.1085	11.5739	1.8945	0.0221
San	261.6013	70.8903	13.2600	0.1351
Salao	1062.4933	321.5092	32.5140	0.5533
Nam Kun Ta	15.9682	4.0267	0.9194	0.0082
Nam Khi Raet	5.2217	1.2271	0.4075	0.0027
Ma Mun	782.0628	252.1132	21.4012	0.4123
Wa	21966.7937	7655.3188	424.2994	11.7369
Oi Chang	185.7112	54.6745	7.1699	0.0967
Inthanin	35.9646	8.6072	2.6246	0.0184
Unknown1	18.9066	4.4357	1.7352	0.0098
UnKnown2	90.2835	24.2025	5.0402	0.0467
Unknown3	39.3909	9.7053	3.0071	0.0204
Unknown4	4.7691	1.0673	0.5213	0.0025
Unknown5	148.8985	38.8659	8.1538	0.0765
Unknown6	1462.4909	467.4420	34.7622	0.7675

Appendix 4 Total aboveground biomass of each species for three plots at Pong phu ron station (continued)

Local name	stem biomass (Kg)	branch biomass (Kg)	leaf biomass (Kg)	total biomass (tonne / tree)
Kruai Pa	383.5229	69.9279	15.0534	0.3748
Kradon	95.2335	14.1481	3.8750	0.0906
Kra Thum Noen	1794.9110	345.1172	62.7888	1.7623
Kra Phi Chan	1720.4755	347.7334	56.9274	1.7001
Kra Phi Khao Khwai	18.6471	2.8778	0.7576	0.0178
Ket Dam	5.1892	0.7485	0.2109	0.0049
Ket Daeng	152.6247	28.0888	6.0258	0.1494
Kha Nang	875.8198	146.6419	35.2642	0.8462
Khun	131.9701	20.1478	5.3644	0.1260
Khae Bit	127.8129	23.4734	4.9430	0.1250
Khae Foi	6.2056	0.8932	0.2519	0.0059
Khae Hang Khang	109.7451	16.0364	4.4565	0.1042
Ngio Pa	16.2471	2.6305	0.6630	0.0156
Chong Kho	123.8663	23.6351	4.8010	0.1218
So	16.1153	2.6070	0.6577	0.0155
Daeng	552.3006	93.3326	22.1127	0.5342
Ta Khro	1809.6443	408.5681	44.3488	1.8100
Ta Khian Nu	9.5635	1.3149	0.3872	0.0090
Ta Baek Daeng	34402.5656	9056.7558	501.7979	35.1689
Taptao Ton	3268.6061	744.9090	92.2789	3.2846
Teng Nam	20.8157	3.0064	0.8447	0.0197
Thong Lang	287.5167	51.8930	11.2671	0.2805
Po Daeng	1027.4471	234.2297	29.0652	1.0326
Plao	4528.9186	1090.5662	97.4712	4.5736
Phlap Phla	398.1462	88.8459	12.1700	0.3993
Pheka	419.1645	64.7696	17.0283	0.4008

Appendix 4 Total aboveground biomass of each species for three plots at Pong phu ron station (continued)

Local name	stem biomass (Kg)	branch biomass (Kg)	leaf biomass (Kg)	total biomass (tonne / tree)
Ma Klam Ton	33.6271	5.3328	1.3676	0.0323
Makok Pa	944.8377	230.7976	20.4847	0.9569
Ma Kham Pom	92.1924	16.4294	3.6619	0.0898
Ma Khai	5.7681	0.8244	0.2341	0.0055
Maduk	2.1248	0.2756	0.0855	0.0020
Ma Fo	1064.1975	217.6552	37.7900	1.0557
Mafai	1572.9070	367.4095	39.6582	1.5840
Mamao	50.2338	7.3941	2.0416	0.0477
Manam	7.6720	1.0750	0.3111	0.0072
Mamao Chang	5.1053	0.6977	0.2065	0.0048
Mok Man	839.2387	164.5849	27.9610	0.8254
Mai Khi Non	4.4926	0.6386	0.1824	0.0043
Yang On	312.5329	68.2553	10.1490	0.3127
Lamphu Pa	4457.3647	1273.9371	33.4611	4.6118
Samo Phi Phek	9424.6604	2396.0521	144.3516	9.5721
Sakae Na	28.9095	4.3627	1.1747	0.0276
Sadao	18.4624	2.8592	0.7501	0.0177
Sato	4.9931	0.7174	0.2029	0.0047
Sattaban	7.8408	1.0998	0.3180	0.0074
Salao	11481.2321	2930.8859	184.4384	11.6772
Samae San	62.0237	9.6886	2.5241	0.0594
Nam Kun Ta	35.0210	5.7739	1.4221	0.0338
Nam Chai Daeng	22.2189	3.7132	0.9052	0.0215
Nam Ma Khet	2770.9041	555.1816	99.3739	2.7404
Mak Lek Mak Noi	7357.6121	2078.1017	45.3662	7.5849
Wa	1322.0760	325.7625	26.6595	1.3396
Inthanin	543.6839	125.5816	14.9618	0.5474