การย่อยสลายเศษซากใบไม้โดยปลวกในป่าเต็งรัง ตำบลไหล่น่าน อำเภอเวียงสา จังหวัดน่าน

นางสาวปัทมาศ ยะแสง

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
สาขาวิชาสัตววิทยา ภาควิชาชีววิทยา
คณะวิทยาศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2556

LEAF LITTER DECOMPOSITION BY TERMITES IN DRY DIPTEROCARP FOREST AT LAINAN SUBDISTRICT, WIANG SA DISTRICT, NAN PROVINCE

Miss Patthamas Yasang

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Zoology
Department of Biology
Faculty of Science
Chulalongkorn University
Academic Year 2013

Thesis Title	LEAF LITTER DECOMPOSITION BY TERMITES IN DRY DIPTEROCARP FOREST AT LAINAN SUBDISTRICT, WIANG SA DISTRICT, NAN PROVINCE
By	Miss Patthamas Yasang
Field of Study	Zoology
Thesis Advisor	Chatchawan Chaisuekul, Ph.D.
Thesis Co-Advisor	Nipada Ruankaew Disyatat, Ph.D.

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

....Dean of the Faculty of Science

(Professor Supot Hannongbua, Dr.rer.nat.)

THESIS COMMITTEE

....Chairman

(Noppadon Kitana, Ph.D.)

....Thesis Advisor

(Chatchawan Chaisuekul, Ph.D.)

....Thesis Co-Advisor

(Nipada Ruankaew Disyatat, Ph.D.)

....Examiner

(Assistant Professor Art-ong Pradatsundarasar, Ph.D.)

....External Examiner

(Assistant Professor Vacharobon Thirakhupt, Ph.D.)

ปัทมาศ ยะแสง : การย่อยสลายเศษซากใบไม้โดยปลวกในป่าเต็งรัง ตำบลไหล่น่าน อำเภอเวียงสา จังหวัดน่าน. (LEAF LITTER DECOMPOSITION BY TERMITES IN DRY DIPTEROCARP FOREST AT LAINAN SUBDISTRICT, WIANG SA DISTRICT, NAN PROVINCE) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: อ. ดร.ชัชวาล ใจซื่อกุล, อ.ที่ปรึกษาวิทยานิพนธ์ร่วม: อ. ดร.นิพาดา เรือนแก้ว ดิษยทัต, 118 หน้า.

การศึกษาผลผลิตเศษซากใบไม้ และการย่อยสลายเศษซากใบไม้โดยปลวก ในป่าเต็งรัง ตำบลไหล่น่าน อำเภอเวียงสา จังหวัดน่าน ในเดือน พฤศจิกายน 2555-ธันวาคม 2556 โดยทำการติดตั้งเครื่องมือดักเก็บเศษซากใบไม้และถุงเก็บเศษซากใบไม้ขนาดรูตาข่าย 0.5 มิลลิเมตร (ปลวกผ่านไม่ได้) และถุงขนาดรูตาข่าย 2.0 มิลลิเมตร (ปลวกผ่านได้) ในแปลงศึกษาขนาด 40x40 ตารางเมตร ซึ่งมีพลวงเป็นไม้เด่น มวลชีวภาพเหนือพื้นดินของ 4 แปลงศึกษามีค่าเฉลี่ย 81.4±13.5 ตัน/เฮกตาร์ โดยค่ามวลชีวภาพของต้นไม้ที่เพิ่มขึ้นใน 1 ปี คิดเป็นร้อยละ 4.2 มวลชีวภาพใบไม้จากเครื่องมือดักเก็บซากใบไม้มีค่า 7.9±0.9 ตัน/เฮกตาร์/ปี ทั้ง 4 แปลงมีค่ามวลชีวภาพใบไม้สูงสุดในช่วงเดือนมีนาคม 2556 และการศึกษาถุงเก็บเศษซากใบไม้ ระยะเวลา 13 เดือนพบว่า ถุงขนาดรูตาข่าย 0.5 และ 2.0 มิลลิเมตร มีการลดลงของค่าเฉลี่ยมวลเศษซากใบไม้ในถุงจาก 40 กรัม เหลือ 15.53±0.85 กรัม และ 11.89±0.65 กรัม ตามลำดับ โดยถุงขนาดรูตาข่าย 2.0 มิลลิเมตร มีการลดลงของมวลใบไม้สูงกว่าถุงเก็บเศษซากใบไม้ขนาดรูตาข่าย 0.5 มิลลิเมตร อย่างมีนัยสำคัญ (F=4.85, df=1, 96, p=0.03) ค่าคงที่ของอัตราการย่อยสลายซากใบไม้ Olson’s decomposition constant (k) ตั้งแต่เดือนพฤศจิกายน 2555-ธันวาคม 2556 ในถุงเก็บเศษซากใบไม้ขนาดรูตาข่าย 0.5 มิลลิเมตร มีค่าเท่ากับ 0.87 และในถุงขนาดรูตาข่าย 2.0 มิลลิเมตร มีค่าเท่ากับ 1.12 พบสิ่งมีชีวิตในดิน (Soil fauna) เช่น แมลงหางดีด ตัวอ่อนด้วง และ ไร ในถุงเก็บเศษซากใบไม้ขนาดรูตาข่าย 0.5 มิลลิเมตรมากกว่าถุงขนาดรูตาข่าย2.0 มิลลิเมตร ทั้งนี้ขนาดรูตาข่ายของถุงเก็บเศษซากใบไม้, อุณหภูมิอากาศ, ปลวกที่พบในถุงเก็บเศษซากใบไม้, ค่าความชื้นสัมพัทธ์, และตัวอ่อนด้วง มีความสัมพันธ์เชิงบวกต่อการลดลงของมวลเศษซากใบไม้ (F=5.556, df=11, 261, p<0.001) ในขณะที่ ค่าปริมาณน้ำฝน, เหาหนังสือ, แมลงหางดีด, ไร, อุณหภูมิดิน และค่าความเป็นกรด-เบสของดิน มีความสัมพันธ์เชิงลบต่อการลดลงของมวลเศษซากใบไม้ จากการศึกษาครั้งนี้ใบไม้ในถุงเก็บเศษซากใบไม้ถูกย่อยสลายไปร้อยละ 70 ซึ่งใบไม้ที่เหลือจะถูกสะสมไว้ และอาจเป็นเชื้อเพลิงสำหรับการเกิดไฟป่า สรุปผลการศึกษาแสดงให้เห็นว่าปลวกมีบทบาทในการเป็นปัจจัยทางชีวภาพที่สำคัญในการย่อยสลายเศษซากใบไม้ในพื้นที่ป่าเต็งรัง ทั้งนี้ อุณหภูมิอากาศ และค่าความชื้นสัมพัทธ์ อาจมีผลกระทบโดยตรงกับการย่อยสลายเศษซากใบไม้ในป่าเต็งรัง และยังส่งผลต่อกิจกรรมของปลวกในการเพิ่มการย่อยสลายเศษซากใบไม้ในป่าเต็งรังอีกด้วย

ภาควิชา ชีววิทยา	ลายมือชื่อนิสิต ....
สาขาวิชา สัตววิทยา	ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก ....
ปีการศึกษา 2556	ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์ร่วม ....

5472025323 : MAJOR ZOOLOGY
KEYWORDS: TERMITE / LEAF LITTER DECOMPOSITION / DRY DIPTEROCARP FOREST / SOIL FAUNA

PATTHAMAS YASANG: LEAF LITTER DECOMPOSITION BY TERMITES IN DRY DIPTEROCARP FOREST AT LAINAN SUBDISTRICT, WIANG SA DISTRICT, NAN PROVINCE. ADVISOR: CHATCHAWAN CHAISUEKUL, Ph.D., CO-ADVISOR: NIPADA RUANKAEW DISYATAT, Ph.D., 118 pp.

The litter productivity and the litter decomposition by termites were investigated in the dry dipterocarp forest at Lainan Subdistrict, Wiang Sa District, Nan Province from November 2012-December 2013. Litter traps and litter bags with two mesh sizes, 0.5 mm (non-accessible by termites) and 2.0 mm (accessible by termites), were installed in four 40x40 m^2 plots dominated by *Dipterocarpus tuberculatus* Roxb. Aboveground biomass averaged at 81.4±13.5 tons/ha with 4.2% increase per year. The average of leaf litter production was 7.9±0.9 tons/ha/yr with the highest leaf litter production measured in March 2013. Average litter mass in 0.5 and 2.0 mm litter bags was significantly reduced from 40 g to 15.53±0.85 and 11.89±0.65 g in 13 months, respectively. The litter mass loss in 2.0 mm litter bags was significantly higher than in 0.5 mm litter bags (F=4.85, df=1, 96, p=0.03). Leaf litter decomposition rate calculated as Olson's decomposition constant (k) from November 2012-December 2013 were 0.87 for 0.5 mm bags and 1.12 for 2.0 mm bags, respectively. Soil fauna, such as springtails, beetle larvae, and mites were found in significantly higher abundance in 0.5 mm litter bags than 2.0 mm litter bags. Mesh size, air temperature, termites, humidity, and beetle larvae had positive effect on the litter mass loss (F=5.556, df=11, 261, p<0.001) while rainfall, bark lice, springtails, mites, soil temperature, and soil pH had negative effect on the litter mass loss. Only 70% of leaf litter was decomposed over 13 months, so the remaining leaf litter could be accumulated as fuel for bushfire. In conclusion, the results suggested that termite is an important biological factor in leaf litter decomposition in dry dipterocarp forest. In addition, air temperature and humidity may directly affect leaf litter decomposition as well as influencing the activities of termites in leaf litter decomposition in dry dipterocarp forest.

Department:	Biology	Student's Signature ....
Field of Study:	Zoology	Advisor's Signature ....
Academic Year:	2013	Co-Advisor's Signature ....

ACKNOWLEDGEMENTS

I would like to express my sincere thanks to my advisor Dr. Chatchawan Chaisuekul for providing guidance and suggestion for me from the initial to the final stage of my research. I would also like to thank my co-advisor Dr. Nipada Ruankaew Disyatat, for suggestions and kind support on this research. I gratefully acknowledge the valuable discussions and comments of the chairman, Dr. Noppadon Kitana and the examiner, Assistant Professor Dr. Art-ong Pradatsundarasar and Assistant Professor Dr.Vacharobon Thirakhupt. I appreciate the assistance of Assistant Professor. Dr. Duangkhae Sitthichareonchai for termite identification.

This thesis would not succeed without the kind support by Assistant Professor Dr. Wichase Khonsue, Dr. Pongchai Dumrongrojwatthana, Aj. Marut Fuangarworn, and all members of Chulalongkorn University Forest and Research Station, Nan Province. Moreover, I would like to thank Ms. Chanyapatch Saenthetthanyawat, Mr. Kittipum Chansri, Mr. Khattapan Jantawongsri, and Ms. Kamolchanok Boriboon for field assistance, supports, and friendship throughout my academic time.

This thesis was supported by the Plant Genetic Conservation Project Under the Royal Initiative of Her Royal Highness Princess Maha Chakri Sirindhorn-Chulalongkorn University (CU-RSPG) grant, Sponsorship of Graduate Student Research Under CU Academic Network in the Region (CU-ANR-56-03) and The 90th anniversary of Chulalongkorn University fund (Ratchadaphiseksomphot Endowment Fund).

My deep gratitude goes to my family, for their belief in me and all their love and support. I am also greatly thankful to all my friends for the great time, experiences, and morale support.

CONTENTS

Page

Page

LIST OF TABLES

Page

LIST OF FIGURES

Page

CHAPTER I

INTRODUCTION

1.1 Rationale

Termites are eusocial insects classified in the order Isoptera (chomEngel, Grimaldi, and Krishna, 2009). Termites are distributed among 12 families (Engel et al., 2009): Cratomastotermitidae, Mastotemitidae, Hodotermitidae, Archotermopsidae, Stolotermitidae, Termopsidae, Serritermitidae, Kalotermitidae, Archeorhinotermitidae, Stylotermitidae, Rhinotermitidae and Termitidae. Termites live in colonies composed of 3 castes: reproductive, soldier and worker castes. Termites are detritivore and work with other soil fauna, for example, earthworms, beetles, and springtails in the decomposition process (Lavelle et al., 1992). Earthworms and termites are soil macrofauna (Abbott, 1989). They are responsible for the degradation by changing the organic material into inorganic material for nutrient cycling with the assistance of microflora and microfauna, such as bacteria and protozoa, respectively. Lower termites have anaerobic flagellate protozoa and bacteria in hindgut (Brauman et al., 1992). These flagellates feed and degrade the wood particles comminuted by the termite (Brune and Friedrich, 2000). Essentially termites break large pieces of organic matter into smaller ones (Witkamp, 1966). By feeding on the wide range of food from fresh leaf litter to humus, termites can affect the entire dynamics of soil carbon (Odum, 1983). Moreover, the ability to change organic material into inorganic material by termites represents half of the biomass synthesized by plant such that its decomposition is prone to impact global carbon cycling (Dickinson, 2012).

Carbon storage in above ground biomass of tropical forests is commonly measured for various purposes (Jepsen, 2006). The important production by forests in the tropical zone is the litterfall on forest floor because litterfall is the main pathway of nutrient cycles and litter accumulation becomes soil organic matter through the decomposition processes and through fire (Melillo, Aber, and Muratore, 1982; Warin Boonriam, 2010).

Decomposition processes help return nutrients to trees and increase the capability of trees to stock carbon through biomass accumulation. Leaf litter decomposition contributes a large portion of nutrients necessary for a forest ecosystem. Leaves are broken down into organic materials that enrich the soil for plant growth. Leaf litter decomposition in tropical forest is very complex. Tropical forests have a tight nutrient cycle, where most of the vegetative biomass occurs aboveground in the green stems and leaves of plants, and little occurs belowground (Mason, 1977). As tropical plants shed their leaves or die, the leaf litter decomposes rapidly and the nutrients are rapidly reabsorbed back into the living vegetation (Takeda, 1995).

Dry dipterocarp forest is a major type of tropical deciduous forest and it covers a large area of northern Thailand. The dominant tree species are mainly *Shorea obtuse*, *S. siamensis*, *Dipterocarpus obtusifolius*, *D. tuberculatus* and *D. intricatus* (Smitinand, 1969). Dry dipterocarp forest is commonly found in dry areas of sandy soil. In the dry season, many dipterocarps drop their leaves to reduce transpiration (Swift et al., 1979). A previous showed that litter decomposition rate of dry dipterocarp forest was higher than that of the plantations (Yamashita and Takeda, 1998). In addition, the use of the chemical chlorpyrifos decreased termite population and subsequently decreased litter decomposition rate (De Silva et al., 2010).

Therefore, the study of litter decomposition by termites in dry dipterocarp forest is a significant study to obtain information useful for management of forest ecosystems. However, there have been only a few studies about the role of termites in litter decomposition in dry dipterocarp forests. There are widely distributed dry dipterocarp forests at Nan Province (Meesuk, 2011). At the present, dry dipterocarp forest areas are decreased and changed to be construction areas, plantations, and orchards which may affect the role of termite and other soil fauna on the decomposition and therefore nutrient cycling in dry dipterocarp forest ecosystem.

1.2 Objectives

The aims of this study are: 1) to study aboveground tree biomass and litter production in dry dipterocarp forest at Lainan Subdistrict, Wiang Sa District, Nan

Province; 2) to study litter decomposition rate in dry dipterocarp forest at Lainan Subdistrict, Wiang Sa District, Nan Province; 3) to study some biological factors influencing decomposition, such as termites and other soil fauna; and 4) to study some physical factors influencing decomposition, such as relative humidity, air temperature, soil temperature, soil pH, and rainfall.

1.3 Scopes of the Study

The scope of this study involves measurements of the factors influencing litter decomposition, such as biological and physical factors, and therefore, to apply the knowledge of ecological function to conservation and restoration of the dry dipterocarp forest (Figure 1).

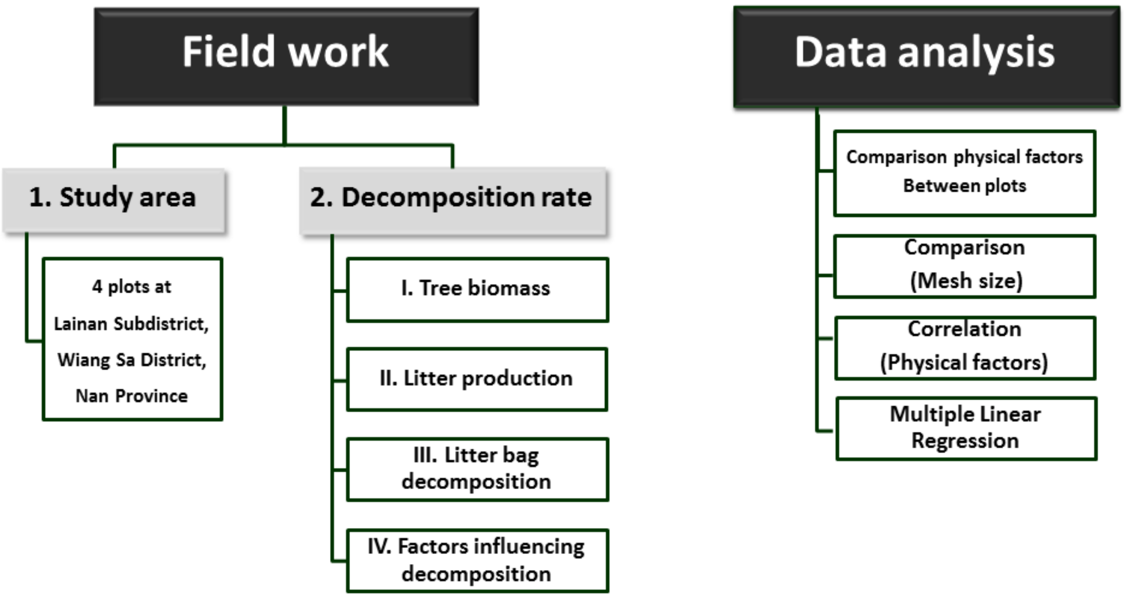

Figure 1 Scopes of the study

The study was conducted in four 40 x 40 m^2 plots located at Lainan Subdistrict, Wiang Sa District, Nan Province from November 2012-December 2013. To study aboveground tree biomass, the diameter at breast height (DBH) of each tree with 4.5 cm or larger DBH was measured and used to calculate aboveground tree biomass by allometric equations. To study litter production, 8 litter traps per plot was used to collect litter monthly. Litter decomposition was studied using litter bags of two mesh sizes (0.5 mm and 2.0 mm). Mesofauna and macrofauna was extracted using Berlese-Tullgren funnel to study the soil communities responsible for the litter decomposition. Physical factors potentially influencing litter decomposition, such as relative humidity, air temperature, soil temperature, soil pH, and rainfall were measured.

CHAPTER II

LITERATURE REVIEW

Litterfall is the main pathway of nutrient cycles in tropical forest ecosystems. Leaf litter accumulates and transforms into soil organic matter through decomposition processes. Litter decomposition is influenced by physical factors and biological factors, which affect the nutrient cycles at various steps (Figure 2). Disturbances such as fires and land use changes may also have impacts on the rates of decomposition through changes in related physical and biological factors.

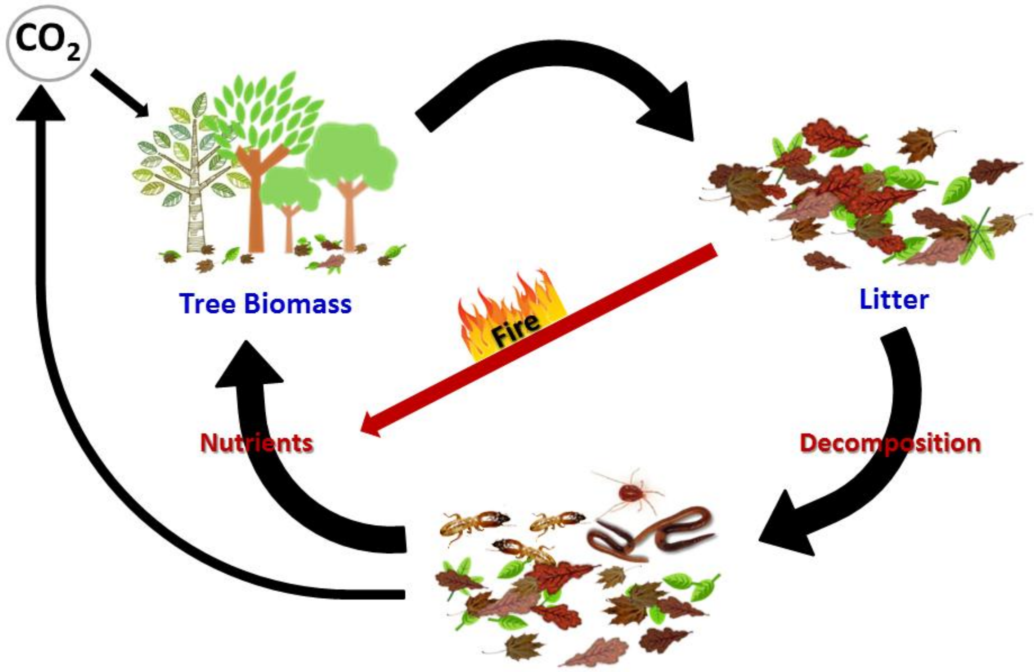

Figure 2 Nutrient cycling of litter in tropical forest

2.1 Litter decomposition

Carbon storage

Tropical forests play a key role in the global carbon flux and stocks (Dixon et al., 1994; Kimmins, 2004). Carbon accumulation in the forest ecosystems is stored as biomass, including of aboveground and belowground biomass (Senpaseuth Phouveth, 2009). Aboveground biomass is defined as all living biomass above the soil surface including stems, stumps, bark, branches, seeds and foliage while belowground biomass is defined as all living biomass of live roots (Change, 2006; FAO, 2006). Fine roots of less than 2 mm diameter are sometimes excluded because these often cannot be practically distinguished from soil organic matter or litter (Change, 2006; FAO, 2006).

Carbon is stored in forests predominantly as live biomass. Various plant structures are there transformed to leaf litter, dead roots and dead wood on the soil surface (Odum, 1983). Carbon stock assessment in dipterocarp forest in the Philippines showed that some of carbon was mineralized as CO_2 in the atmosphere by decomposition processes. Additionally, after selective logging in a dipterocarp forest, the original carbon density in aboveground biomass was reduced by 50%. Subsequently, the forest recovered up to 70% of the original carbon just before the next cutting cycle began (Lasco et al., 2006).

The accurate estimation of biomass in tropical forests is important for many applications, from the commercial exploitation of timber to the global carbon cycle assessment. Allometric equations can be used to estimate the biomass and carbon stock of forests without actual cut down and weigh all trees. These equations were developed on the basis that sparse measurements from destructive sampling are related to more easily collected biophysical properties of trees, such as diameter at breast height (DBH) (Basuki et al., 2009).

The accurate estimation of biomass in tropical forests is important for many applications, from the commercial exploitation of timber to the global carbon cycle assessment. Allometric equations can be used to estimate the biomass and carbon

stock of forests without actual cut down and weigh all trees. These equations were developed on the basis that sparse measurements from destructive sampling are related to more easily collected biophysical properties of trees, such as diameter at breast height (DBH) (Basuki et al., 2009). Separate equations have been developed for the Dipterocarpus, Hopea, Palaquium and Shorea genera, and an equation of a mix of these genera represents commercial species. Allometric equations have been developed for tropical forest dry dipterocarp forests by Ogawa and colleagues (1965) and have been applied in assorted studies in the tropics.

Terakunpisut, Gajaseni, and Ruankawe (2007) estimated aboveground carbon sequestration in the different forest ecosystems in Thong Pha Phum National Forest, Thailand. Aboveground biomass was estimated using allometric equations. The total aboveground biomass in tropical rain forest was higher than dry evergreen forest and mixed deciduous forest at 137.73± 48.07, 70.29± 7.38 and 48.14± 16.72 tons/ha, respectively.

Decomposition process

Decomposition of organic matter is one of the key in processes tropical forest ecosystems (Odum, 1983). Decomposition is the natural process during which dead organic materials are broken down. Decomposers are responsible for the degradation by changing the organic material into inorganic material for nutrient cycling in forest ecosystem (Lavelle and Spain, 2001; Melillo et al., 1982).

Decomposition of organic matter plays a vital role in the carbon storage and nutrient cycling of tropical forest ecosystems. The important production by forests in the tropical zone is the litterfall. Litterfall is the main pathway of nutrient cycles, and litter accumulation becomes soil organic matter through the decomposition processes that also releases carbon and other nutrients back to the environment (Melillo et al., 1982; Warin Boonriam, 2010). Therefore, litterfall represents an essential link in the organic production decomposition cycle and thus is a fundamental decomposition process in the forest (Meentemeyer, Box, and Thompson, 1982).

Leaf litter decomposition is the combined result of physical and chemical processes occurring inside and outside of living soil fauna and animals. Decomposition consists of 3 steps; namely, the breakdown process beginning with the leaching of dissolved nutrients from the leaves, soil fauna fragmentation, and microbial decomposition (Barajas-Guzmán and Alvarez-Sánchez, 2003; Mathuriau and Chauvet, 2002; Webb et al., 1983; Witkamp, 1966).

Initially, soluble materials were transferred away from decomposing organic matter into the environment through water leaching. These soluble materials are either absorbed by organisms, react with the mineral phase of soil or sediments, or are lost from the system in solution (Webb et al., 1983). Then, fragmentation by soil fauna breaks large pieces of organic matter into smaller ones that creates fresh surfaces for microbial colonization. Soil fauna also mix the decomposing organic matter into the soil and return organic matter to the soil or sediments as fecal pellets, and provide a more favorable environment for soil microbes (i.e., bacteria and fungi) than the original consumed material (Mathuriau and Chauvet, 2002; Witkamp, 1966).

Finally, chemical alteration is performed by bacteria and fungi. Dead plant organic matter is decomposed by the activity of soil microbes, although some chemical reactions also occur spontaneously in the soil without microbial mediation. Decomposition degrades litter into an unrecognizable form, it becomes soil organic matter. Fungi and bacteria further degrade the easily metabolized components leaving behind humus, which is composed of chemically complex organic matter that resists decomposition (Barajas-Guzmán and Alvarez-Sánchez, 2003; Witkamp, 1966).

Factors influencing decomposition

Litter decomposition is influenced by various biological factors and physical factors (Figure 3), which affect the decomposition rate and efficiency.

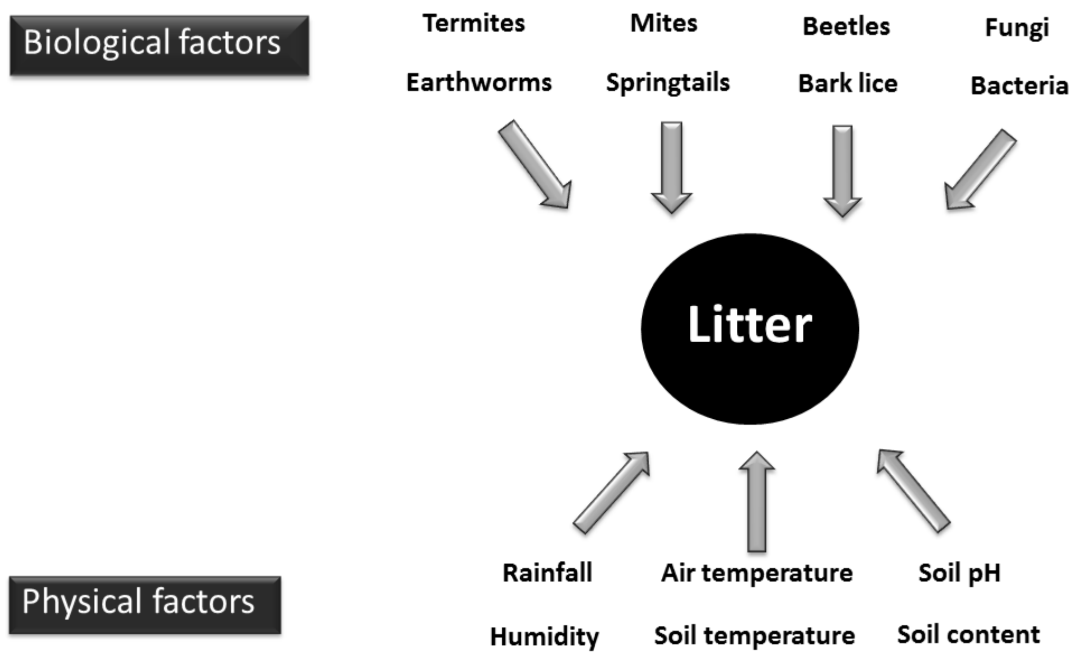

Figure 3 Factors influencing litter decomposition

1. Physical factors

Physical factors affecting decomposition include air temperature, soil temperature, Soil pH, humidity, rainfall, and soil content, for instance. Each individual factor is discussed below:

Air temperature: The rate of decomposition is more rapid in the temperature range of 25°C to 30°C. At temperatures below or above this range, the rate of decomposition is significantly decreased (Chompunut Songkhow, 2007). Appreciable organic matter decomposition occurs at 25°C and further fluctuation in the soil temperature has little effect on decomposition. Low outside temperatures during the winter months slow the decomposition process, while warmer temperatures high rate of decomposition (Swift et al., 1979).

Aeration: Good aeration is necessary for proper activity of the microorganisms involved in the decomposition of organic matter. Under anaerobic conditions, fungi and actinomycetes are mostly suppressed and only a few bacteria *(Clostridium)* take part in anaerobic decomposition (Feller and Beare, 1997).

Moisture: Adequate soil moisture about at 60 to 80 % of the water-holding capacity of the soil is necessary for the proper decomposition of organic matter. Too much moisture leads to insufficient aeration which results in the reduced activity of microorganisms and consequently inhibits the rate of decomposition (Swift et al., 1979).

Humidity: Relative humidity is likely to influence the amount of available water in the substrate to micro-organisms and this in turn will influence the activity of the decomposers (Swift et al., 1979). Decomposing leaves were exposed to a range of relative humidity between 0 and 100% in which they equilibrated at moisture contents ranging from 4.6 to 35.6% (Nagy and Macauley, 1982).

Soil pH: Soil pH affects directly the type, density and the activity of fungi, bacteria and actinomycetes involved in decomposition and, therefore, rate of decomposition of organic matter. The rate of decomposition is higher in neutral soils than that of acidic soils (Feller and Beare, 1997). Therefore, the rate of organic matter decomposition can be accelerated in the acid soils with treatment of lime.

2. Biological factors

Biological factors influencing decomposition process include soil fauna, for example, termites, earthworms, beetles, and springtails (Lavelle et al., 1992). Soil fauna can be classified by size into microfauna, mesofauna and macrofauna (Figure 4) (Lavelle, 1996; Swift et al., 1979).

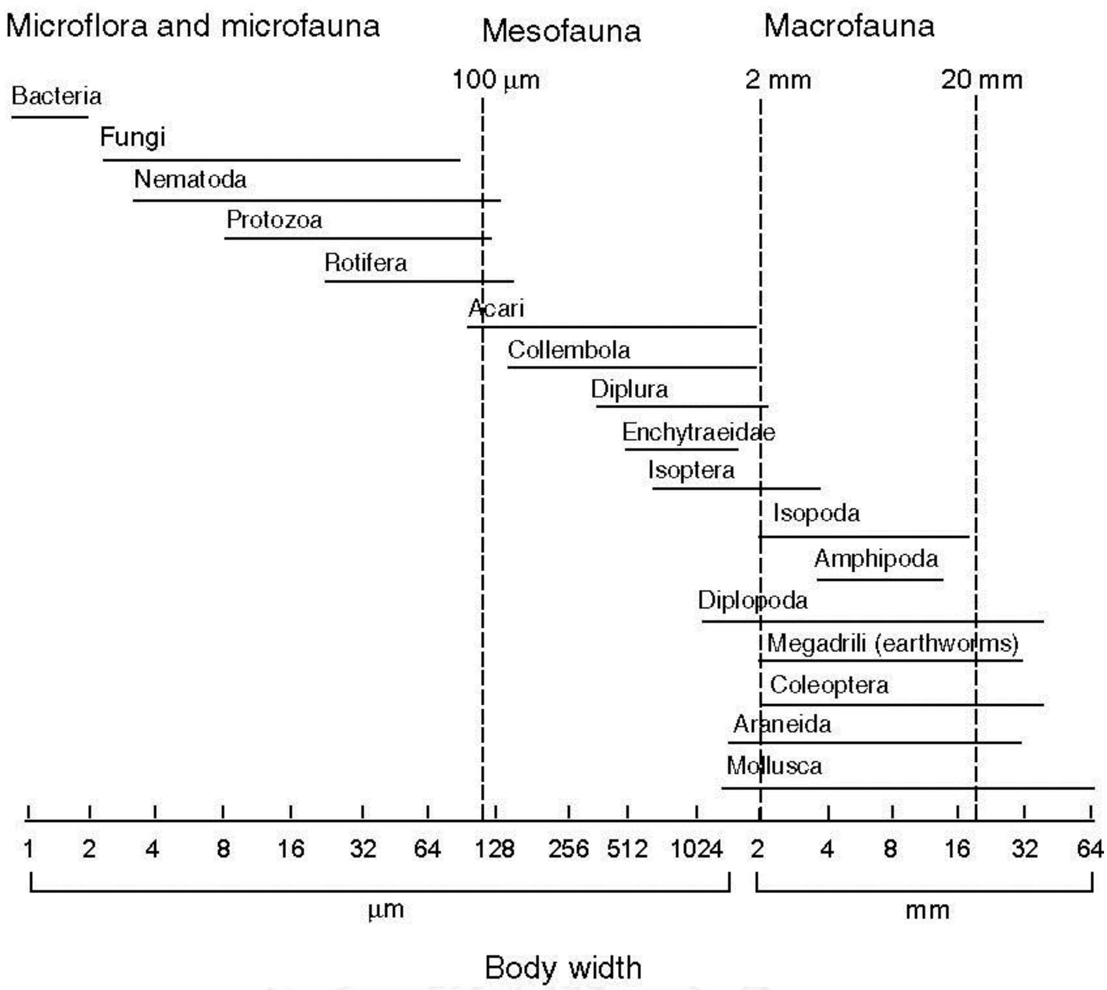

Figure 4 Types and size of soil fauna; microfauna, mesofauna, and macrofauna (Redrawn from Swift, Heal, and Anderson (1979))

Microfauna (<0.2 mm) are organisms smaller than 0.2 mm average body size and consist of protozoa and smaller nematodes. Microorganisms, or microflora, as a whole have the capacity to digest any substrate in the soil, and these refer to bacteria and fungi (Lavelle, 1996).

Mesofauna (<2mm) are soil invertebrates with a body diameter under 2 mm. Important soil mesofauna are Enchytraeidae, Pseudoscorpionida, Acari, Symphyla, Pauropoda, Collembola, Protura, Diplura, Psocoptera and Hymenoptera (Eisenbeis, 2006).

Macrofauna (>2mm) with a body diameter larger than 2 mm, are diverse, abundant and multifunctional elements of most soils. These include earthworms, large insects (termites) and arachnids, and the soil-dwelling vertebrates (Lavelle, 1984).

Soil fauna can be studied using litter bag collection. Höfer et al. (2001) found that different size classes of the fauna were involved in litter decomposition. This was demonstrated by use of litter bags of two different mesh sizes (1 cm and 250 µm). Decomposition rates in the large-mesh litter bags (1 cm) were strongly determined by the macrofauna particularly in primary forests, where large earthworms, termites and ants dominated the soil fauna. In the 250 µm mesh litter bags, where macrofauna was excluded, decomposition rates were significantly lower.

Bradford et al. (2002) used different mesh sizes of litter bag to control exposure of litter to different faunal size classes. The mesh size of litter bag were: micromesh (100 µm), permitting entry of microfauna only; mesomesh (2 mm), permitting entry of microfauna and mesofauna; and macromesh (4.7 mm), permitting entry of microfauna, mesofuana and macrofauna. Decomposition in micromesh litter bags was significantly decreased by the indirect effects of mesofauna and macrofauna, which did not enter through the 100 µm mesh of the litter bags. In macrofauna communities, increased mesh size significantly increased decomposition through mesh. See and Koon (1985) used litter bags of two different mesh sizes. Medium-mesh bags were constructed from aluminium screening material with a 2.0 mm mesh while fine-mesh bags were constructed from stainless steel sieving material with an approximately 0.5 mm mesh. The bags were used to study decomposition of seraya leaves and pine needles in a hill dipterocarp forest (HDF) and in a pine plantation (PP). At both sites, seraya leaves decomposed at a faster rate than pine needles and the 2.0 mm mesh bag showed a higher decomposition rate than the 0.5 mm mesh bag. Soil microarthopods were suspected to play a more important role in seraya leaf litter decomposition in the hill dipterocarp forest than in the pine plantation.

Litter decomposition has been studied for decades. The decomposition rate constant (k) was calculated using a first-order exponential decay function (Olson, 1963; Wider and Lang, 1982). Several litter decomposition studies used the Olson's decomposition rate constant (Olson's k). Takeda (1995) used Olson's k to study decomposition of needle litter using a litter bag method in a natural forest of *Chamaecyparis obtusa* for 5 years. Takeda (1995) found that the decomposition rate decreased with the advance of the decomposition processes consisting of three phases. In the leaching phase (0-3 months), soil fauna had no significant role in the decomposition processes. However, during the immobilization phase (3-15 months), soil fauna contributed to the immobilization processes through their grazing activities, and there were significant differences in litter mass loss between the control and defaunated plots. In the mobilization phase (15-60 months), saprovorous soil fauna, such as collembolans and acari contributed to the mobilization processes by feeding on decomposing litter.

In addition, Yamashita and Takeda (1998) studied litter decomposition rate of plantation forest and dry dipterocarp forest in Malaysia, using litter bags of different mesh sizes (0.5 and 2.0 mm) to compare the rate of litter decomposition by soil fauna with different sizes. Their result showed that dry dipterocarp forest showed a higher decomposition rate than the rubber plantation. And the decomposition rate constant (Olson's k) of the size 2.0 mm litter bag (k=2.15) was higher than the 0.5 mm litter bag (k=0.76).

Decomposition rate constants in various forest types in the tropics are shown in Table 1. The decomposition rate constant (k) of the evergreen forest and deciduous forest in India was the 0.1-0.5 range while the decomposition rate of moist deciduous forest in India was in 0.74-2.0 range. The decomposition rate of dry dipterocarp was from 0.7-2.2 in Thailand and Malaysia.

Table 1 Decomposition rate constant (k) in various forest types in the tropics

Forest type	*k* (year $^{-1}$)	Source
Evergreen forests (India)	0.181-0.363	(Sundarapandian and Swamy, 1999)
Deciduous forest (India)	0.136-0.403	(Sundarapandian and Swamy, 1999)
Moist deciduous forest (India)	0.74-2.0	(Sankaran, 1993)
Dry dipterocarp forest (Malaysia)	0.76-2.15	(Yamashita and Takeda, 1998)
Dry evergreen forest and dry dipterocarp forest (Thailand)	0.74-1.62	(Warin Boonriam, 2010)

2.2 Termite

Termite taxonomy

Termites are eusocial insects classified in the order Isoptera. Currently, approximately 2,600 species of termites are distributed among 12 families and 280 genera (Engel et al., 2009).

Termite classification (modified after (Engel et al., 2009).

Family Cratomastotermitidae (Engel et al., 2009)

Family Mastotermitidae (Desneux, 1904) a

Family Termopsidae (Holmgren, 1911)

Family Hodotermitidae Desneux, 1904b (Desneux and Wytsman, 1904) b

Family Archotermopsidae (Engel et al., 2009)

Family Stolotermitidae (Holmgren, 1910)

Family Kalotermitidae (Froggatt, 1897)

Family Archeorhinotermitidae (Krishna and Grimaldi, 2003)

Family Stylotermitidae (Holmgren, Holmgren, and Fletcher, 1917)

Family Rhinotermitidae (Froggatt, 1897)

Family Serritermitidae (Holmgren, 1910)

Family Termitidae (Latreille, 1802)

In Thailand, the genera *Coptotermes*, *Microcerotermes*, *Macrotermes*, *Hypotermes* and *Odontotermes* have been found in rural and urban areas. Up to 92 species of termite have been recorded from Thailand (Sornnuwat, Vongkaluang, and Takematsu, 2004). Previous studies show that the termite commonly observed are in the families Rhinotermitidae, Termitidae. The most common infestation in the urban area was caused by *Coptotermes gestroi* (Lee, Vongkaluang, and Lenz, 2007; Sornnuwat et al., 1996) (Table2).

Table 2 Termite pest species found in infested houses in Thailand (n = 200) (Sornnuwat et al., 1996)

Species	Urban	Rural
Coptotermes gestroi	90	22
Coptotermes kalshoveni	3	0
Coptotermes premrasmii	1	1
Coptotermes travians [*havilandi*]	4	0
Schedorhinotermes medioobscurus	2	1
Globitermes sulphureus	0	7
Macrotermes gilvus	0	4
Microtermes pakistanicus	0	2
Microtermes anandi	0	2
Microcerotermes crassus	0	42
Odontotermes proformosanus	0	8
Odontotermes longignathus	0	6

Termites are eusocial insects living in colonies composed of 3 castes; reproductive, soldier and worker castes. Reproduction is normally confined to a single pair of individuals, the king and the queen. Workers forage for food and build the mounds. Soldiers defend the colonies against predators (Lavelle et al., 1992). A typical termite life cycle is shown in Figure 5.

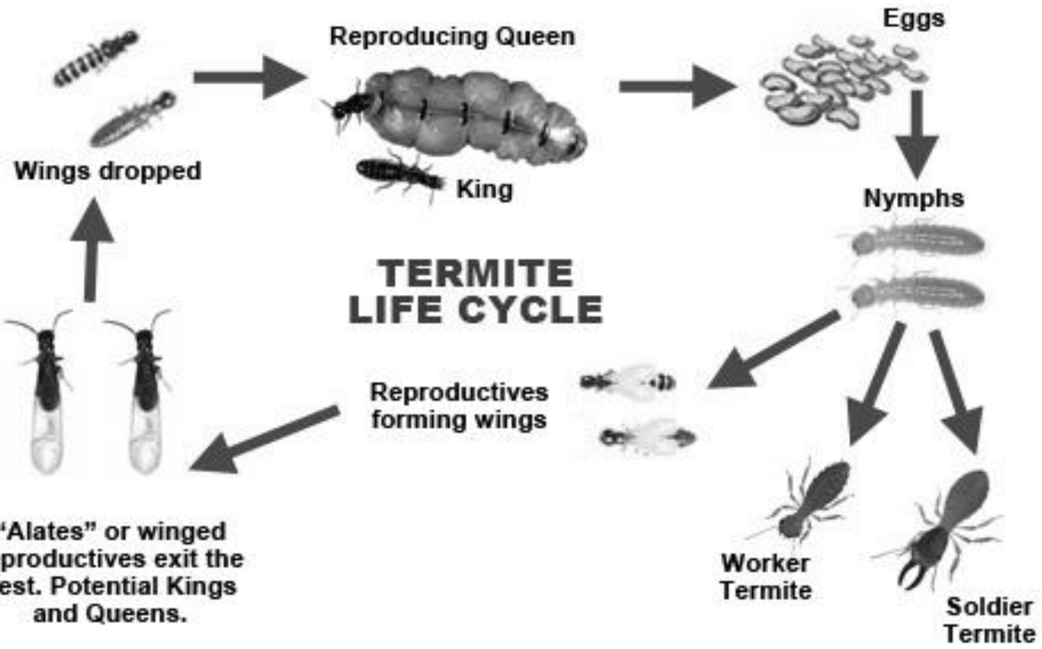

Figure 5 Life cycle of termite (Life after bugs, 2013)

Types of termite: feeding types

Among xylophagous insects, termites are the most efficient decomposers of cellulose (Noble et al., 2009). Almost all species feed on dead plant material (Bignell, 2000). Termite species can be classified into 4 feeding groups, according to the gradient they feed on (Donovan, Eggleton, and Bignell, 2001). These groups are:

Group I or Wood and grass feeders Lower termites (i.e. non-Termitidae) feeding on dead wood and grass.

Group II or Litter feeders Termitidae with a range of feeding habits including dead wood, grass, leaf litter, micro-epiphytes, fungus comb and conidia.

Group III or Soil-wood feeders Termitidae feeding in the organic rich upper layers of the soil, presumably feeding on the soil-wood interface.

Group IV or Soil feeders Termitidae, which are called true soil-feeders, ingesting apparently mineral soil to feed on organic matter usually found highly dispersed therein.

Soil feeders are small, soft-bodied organisms living and foraging in the soil matrix. Litter and intermediate feeders are normally larger organisms with highly sclerotized bodies, and frequently feed in the open (De Souza and Brown, 1994). Moreover, resources for wood and litter feeders depend on the quantity of fallen trees and the surrounding plants killed.

Types of termite: habitat types

Termites are commonly classified by habitat into three groups (Sornnuwat, 1996) as follows:

1) Drywood termites: species living entirely within drywood and do not need to access to an external moisture source and soil

2) Dampwood termites: species living in old tree stumps, rotting logs and pieces of buried timbers, and can also invade into sound wood in buildings

3) Subterranean termites: species building shelter tubes and nest in the soil or on the sides of trees or building constructions and rely principally on soil for moisture

Subterranean termites are the most destructive pest of wooden constructions in Thailand. Over 90% of the overall losses are caused by subterranean termites in the whole country. Baiting methods have been adopted to estimate the field population of subterranean termites and to monitor their foraging territory (Sornnuwat, 1996).

Monitoring termites

Termite colonies have a fixed location, and both workers and soldiers are usually present throughout the year. Therefore, workers and soldiers of termites can be sampled directly comparing to other insects which are solitary and mobile. A sampling method should be the methods that can characterize and quantify accurately the structure of the local termite assemblage at different sites (Jones and Eggleton, 2000).

Three commonly used methods are:

1. Belt transect (Davies, 1997; Eggleton et al., 1997; Jones and Eggleton, 2000): A belt transect (2 x 100 m) is laid in each forest. Each transect is divided into 20 (2 x 5 m) sections and in each section one man hour is spent searching for termites. Within each section the following microhabitats are searched; surface soil (12 samples, each about 12 x 12 cm, to 10 cm depth), leaf litter and humus on the forest floor (at the base of trees, between buttress roots etc.), inside dead logs, tree stumps, branches, twigs, subterranean nests, mounds, and runways on trees up to a height of 2 m aboveground and arboreal nests up to 2 m height.

2. Standardized search protocol (Coaton and Sheasby, 1972): The standardized sampling protocol is based on a belt transect of 100 m length by 2 m width, divided into 20 contiguous sections of 5 x 2 m, the plots were searched for termites. One hour was spent searching each plot. All possible termite microhabitats are examined, including the bark on trees, visible termite mound structures, fallen logs, soil portions and others. All specimens collected are preserved in vials containing alcohol for later identification.

3. Baiting (Ferrar, 1982; La Fage, Nutting, and Haverty, 1973): Subterranean termite are sampled using baiting systems. Most bait systems are much smaller than natural food resources and normally do not include wood. Instead, either paper, cardboard or cellulose powder is offered (French, Ahmed, and Ewart, 1995; Su, 1994). In a previous study in arid Namibian rangelands (African), three types of baits were placed in a regular spacing in each of the 1 ha study plots: 1) toilet paper rolls, 2) cattle dung, and 3) soft pine-wood tongue depressors. The results showed that the baiting method detected 69% of the taxa, and the soil-excavating transect and the visual search method 63% each. Some taxa were detected with one method only, and could be absent seasonally (Zeidler, Hanrahan, and Scholes, 2004).

Evans (2005) sampled termites in the Brindabell Mountains of the Australian Capital Territory. He examined the effect of bait size and composition (paper only or paper plus wood) on termite presence and on untreated bait paper removal rates over four months. The results showed that the most effective bait were large, folded paper-plus-wood baits with inspections at two months.

Decomposition by termites

Almost all termites feed on dead organic matter, breaking it down in a complete way. Effects of termites in decomposition processes were quantitatively elucidated in a dry evergreen forest, Northeast Thailand, in terms of C mineralization and N fixation (Yamada, Wawatwitaya, and Inoue, 2005). In many tropical habitats, termites also contribute to the consumption and mineralization of a significant litter portion by processing large quantities of plant material (Bignell, 2000; Freymann, De Visser, and Olff, 2010; Yamada et al., 2005).

A previous study showed that the use of the chemical chlorpyrifos during litter bag experiments decreased termite population and subsequently decreased litter decomposition rate (De Silva et al., 2010). In addition, the study in lowland dipterocarp forest in Sabah, Malaysia showed that converse distribution of macrofauna (earthworms and termites), the termites having the highest species richness and biomass in tropical rainforest, while earthworms have the highest species richness and biomass in both tropical rainforest and tropical savannas. And both macrofauna (termite and earthworm) are regarded as fulfilling functionally analogous roles in soil processes. Moreover, a full analysis of soil properties (e.g. soil pH, moisture, C and N) may describe the factors determining termite and earthworm distributions (Donovan et al., 2007).

2.3 Dry dipterocarp forest

Distribution of dry dipterocarp forest

The dry dipterocarp forest is a deciduous forest distributed naturally on mainland of Southeast Asia (Figure 6). Dry dipterocarp forest is a major type of tropical deciduous forest and it covers a large area of northern Thailand. A survey in 1982 found that dry dipterocarp forest of Thailand had an area of 48,930 km^2 or about 31.25% of the total country forest area. Its distribution is in the Northern, Northeastern, Central, and Eastern regions with 34,318, 13,819, 540, and 253 km^2, respectively. A characteristic of dry dipterocarp forest is its low tree density. It is mostly consisted of medium and small trees, and fewer understory species and vines (Surasak Ratree, 2003).

Dry dipterocarp forest is scattered in the area characterized by monsoon climate with a marked dry period usually more than four months per year, total annual rainfall of 900-1,200 mm and relative humidity of 60-80%. It usually favors sandy and laterite soils. Soil fertility is lower than in other forest types. (Bunyavejchewin, 1982; Wong, 1991). The dry dipterocarp or deciduous dipterocarp forests, covering an extensive area in the dry regions of the country from a peneplain (a land surface of considerable area and slight relief shaped by erosion) of 150-300 m elevation to slopes and ridges of up to 1300 m elevation (Smitinand, 1969). Tree species are diverse ,and the dominant tree species are mainly *Shorea obtusa*, *S. siamensis*, *Dipterocarpus obtusifolius*, *D. tuberculatus* and *D. intricatus* (Smitinand, 1977).

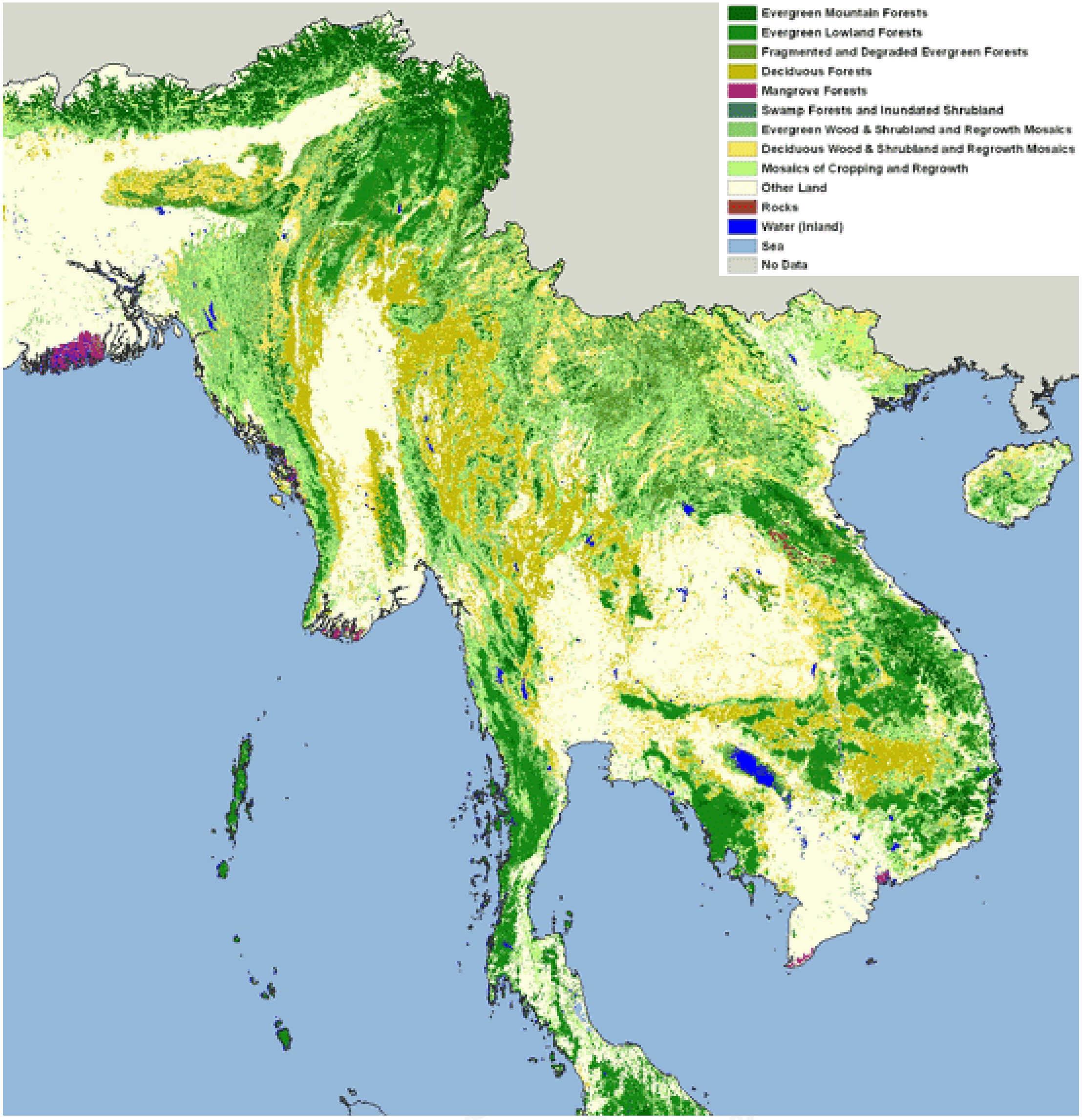

Figure 6 The forest map in Southeast Asia (Stibig, Achard, and Fritz, 2004)

Type of dry dipterocarp forest

Ogawa et al. (1965) divided dry dipterocarp forest into 3 community types as follows:

(1) *Shorea obtusa-S. siamensis* community type is the driest forest that distributes in a hillside. Mostly the soil originates from sandstone, granite, gneiss or basalt. It is usually found on laterite soil. *S. obtusa* and *S. siamensis* are the dominant species. Ground cover generally distributes with grass and *Cycas siamensis*. In more arid zones, there are *Zyzyphus* spp. and *Cratoxylon* spp.

(2) *Dipterocarpus tuberculatus-D. obtusifolius* community type distributes in low land level, rather plain and at 700 m level. It usually grows on sandy loam, deep soils without lateritic characteristics. *D. tuberculatus* and *D. obtusifolius* are dominant species. If general conditions are more moist, this forest will have higher tree species numbers.

(3) Mixed dry dipterocarp community type usually has more moisture and grows on sandy clay loam as in a valley. There is not dominant species in this forest. It is mixed with *D. tuberculatus*, *D. obtusifolius*, *S. obtusa* and *S. siamensis*.

In Thailand during the dry season from December to April, trees shed their leaves, and consequently, the leaf litter can accumulate quickly, and then serve as perfect fuel for forest fires which play an important role in the maintenance of this forest type (Chaiyo, Pizzo, and Garivait, 2013). Sometimes fires are deliberately set by local communities. Fires of tropical deciduous forests, including dry dipterocarp forest and mixed deciduous forest in Thailand are generally anthropogenic in origin. The reasons frequently recorded by forest fire control stations are 1) to facilitate the gathering of non-timber forest product, 2) to ease the access to forest for hunting and 3) to help land clearing for crop cultivation (Cermak, 2005). The fires occurring in dry dipterocarp forest are surface fire. The fuel this type of fire is biomass present on the ground surface of the forest; leaf litter, twig, grass, undergrowth, shrub, climber, and seedling. The leaf litter constitutes the major component of biomass fuel. Studies on fuel consumption indicated that about 95% of biomass fuels in dry dipterocarp forest are consumed by surface fires (Supparat Samran, 2005).

Today, human-induced fires are the more important of the two main categories of fire causes. Stott, Goldammer, and Werner (1990) reported that human-induced fires are started for a deliberate purpose, including path clearing and a drive in hunting. In the tropics, these deliberate fires can have many other applications, such as the production of thatching material (e.g., the large leaves developed by *Dipterocarpus tuberculatus*, a common dipterocarp forest tree), the extraction of wood-oil (from tree in the family Dipterocarpaceae) and of honey, the encouragement of edible shoots (e.g., *Milientha suavis*) or of fungi on the forest floor, and the stimulation of better growth in tendu leaves *Diospyros melanoxylon*, which are used for cigarette (bidi) wrappings in Maharashta, India.

Furthermore in dry season, leaves are broken down into organic materials that enrich the soil for plant growth. Leaf litter decomposition in tropical forest is very complex. Tropical forests have a tight nutrient cycle, where most of the vegetative biomass occurs aboveground in the green stems and leaves of plants, and little occurs below ground. As tropical plants shed their leaves or die, they decompose quickly and their nutrients are rapidly reabsorbed back into the living vegetation (Mason, 1977; Takeda, 1988).

Dry dipterocarp forests are widely distributed in Nan Province, Thailand (Meesuk, 2011). Nan Province has a tropical savanna climate (Koppen climate classification). Winters are quite dry and very warm. Temperatures rise until April, which is very hot with the average daily maximum at 36.5 °C (Table 3). The monsoon season runs from late April through October, with heavy rain and cooler temperatures (Wikimedia Foundation, 2014).

The average rainfall of 12 months is 1,263 mm/year. The highest precipitation was in August 2013, with 247.6 mm and highest average precipitation day of 22 days (Table 3). Over the course of a year, the temperature typically varied from 15°C to 36°C and is rarely below 13°C or above 37°C. The hottest day of the year was in April 2013, with an average high of 36.5°C and low of 22°C. The coldest day of the year was in December 2013, with an average low of 14.3°C and high of 29°C (Table 3). The relative humidity typically ranged from 40 to 99% over the course of the year; The air is driest around March 2013 at which time the relative humidity drops below 40% and it is most humid around December, exceeding 99% (Weatherspark, 2014)

Table 3 Climate data of Nan Province 2013 (Thai Meteorological Department, 2014)

	Month												
	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13	Year
Average high °C	29.8	32.7	35.3	36.5	34.6	32.9	31.9	31.7	32.2	32	30.6	29	32.43
Average low °C	13.4	15.1	18.3	22	23.6	24.1	23.8	23.7	23.3	21.8	18.6	14.3	20.17
Precipitation (mm)	8.1	14.1	27.5	103.1	175	155.6	207.2	247.6	205.3	94.5	19.1	5.9	1,263

CHAPTER III

METHODOLOGY

3.1 Structure of the study

The research is divided into 2 parts, namely the field data collection and the data analysis. The field study was conducted in four plots of dry dipterocarp forest. We measured aboveground tree biomass, litter production, litter bag decomposition, and factors influencing decomposition. Statistical analyses were used to compare and find relationships among the measurements (Figure 7).

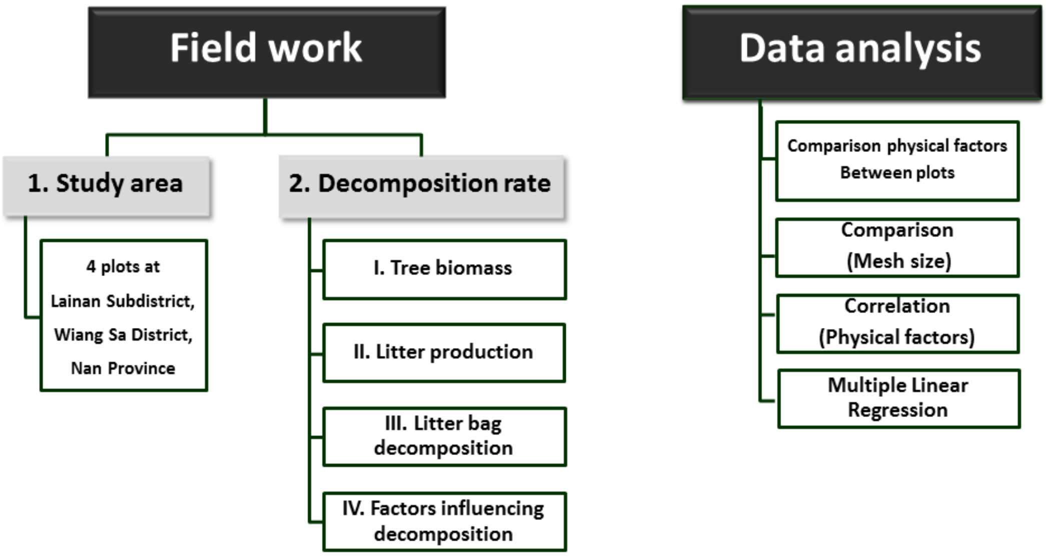

Figure 7 Structure of the study

3.2 Study Site Description

Study area

The study was conducted at the Chulalongkorn University Forest and Research Station (CFRS), Lainan Subdistrict, Wiang Sa District, Nan Province, Northern Thailand from November 2012 to December 2013 (Figure 8). The areas boundary was placed within the UTM zone 47Q: N2051960-2054260 and E0688400-0690360. The area was the low level forest, settled 800 m or higher above sea level. Forest types of the area are deciduous forest, mixed deciduous forest and dry dipterocarp forest (Pongchai Dumrongrojwatthana, 2004). Secondary dry dipterocarp forest is dominated by *Dipterocarpus tuberculatus* Roxb. The study site is in the tropical seasonal forest with the temperature typically varies from 15°C to 36°C and annual rainfall of 1,263 mm. Monthly rainfall is typically less than 40 mm during the dry season, from December to April 2013 (Thai Meteorological Department, 2014).

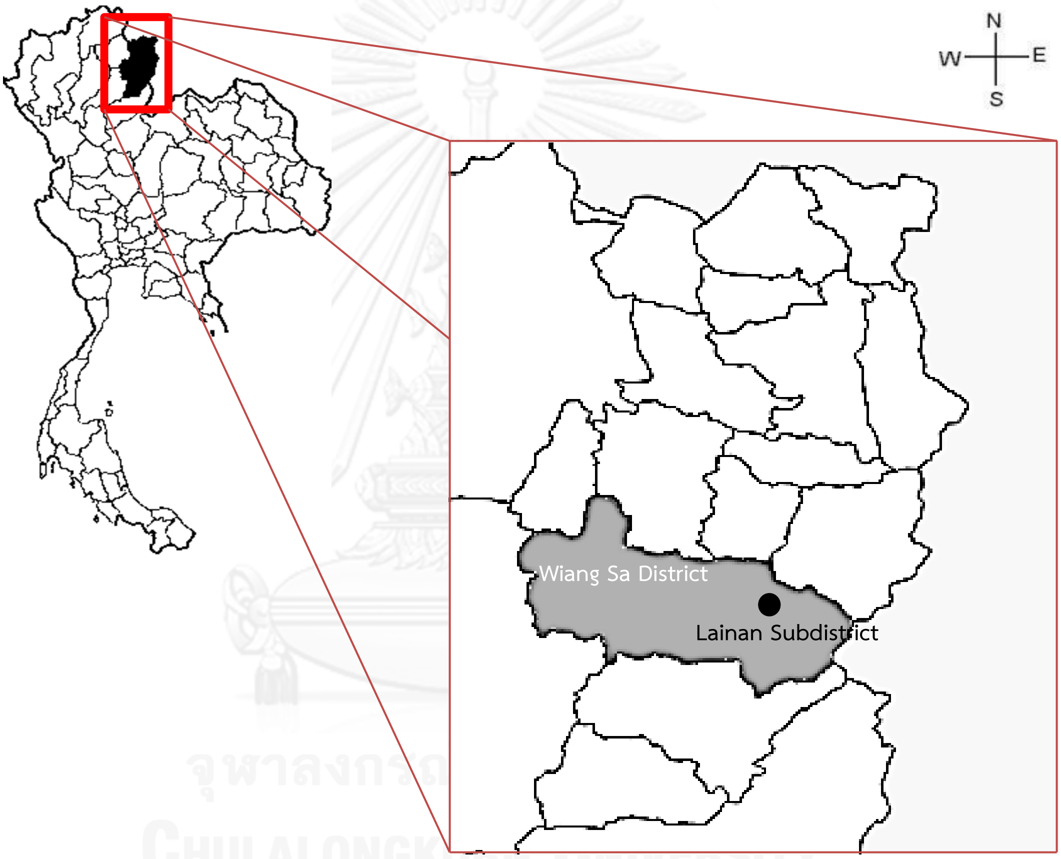

Figure 8 Map of Nan Province, Thailand and Lainan Subdistrict, Wiang Sa District, Nan Province.

3.3 Study site designation

Four 40 x 40 m^2 plots (A1-A4) were located in secondary dry dipterocarp forest, as shown in Figures 9 and 10. The overall forest vegetation was dominated by *D. tuberculatus* Roxb (22%). A1 and A2 plots were located in the fire control area while A3 and A4 plots were located in the fire-prone area. Each plot (40 x 40 m^2)

consisted of four 20 x 20 m^2 quadrats (sub-plots) namely; Q1, Q2, Q3, and Q4 (Figure 11).

Figure 9 Location of plots A1-A4 in dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province (Aerail photograph taken by the Department of Land Development in 2002)

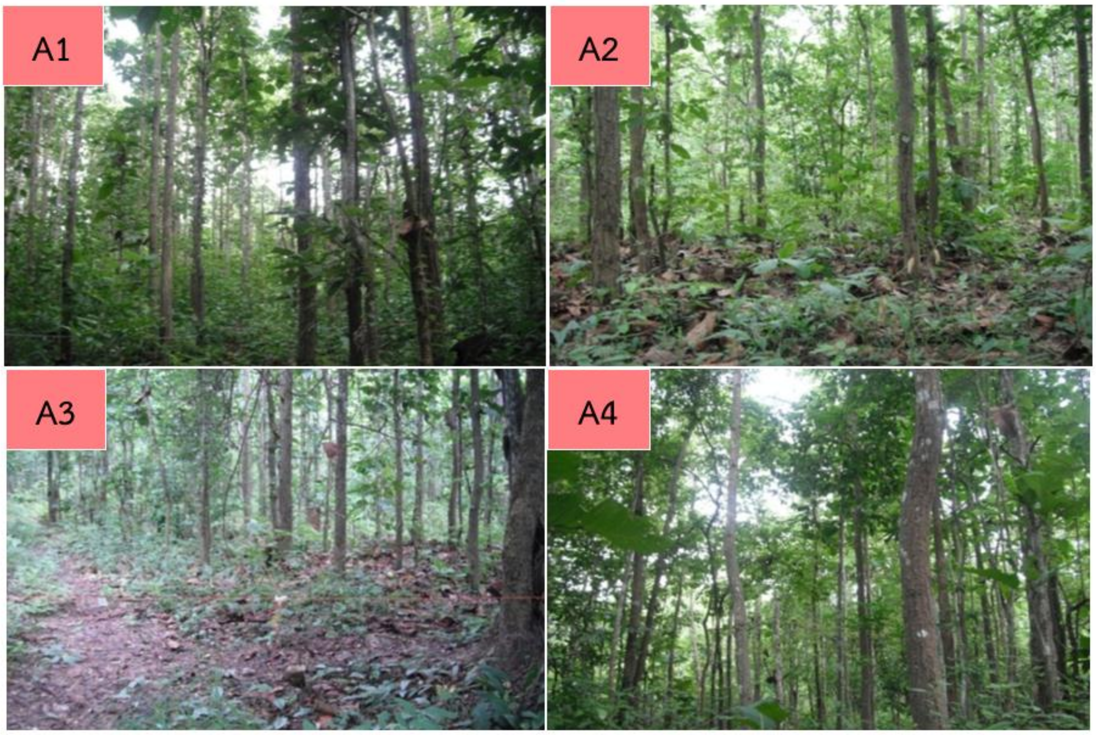

Figure 10 Experimental plots (A1-A4) in dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

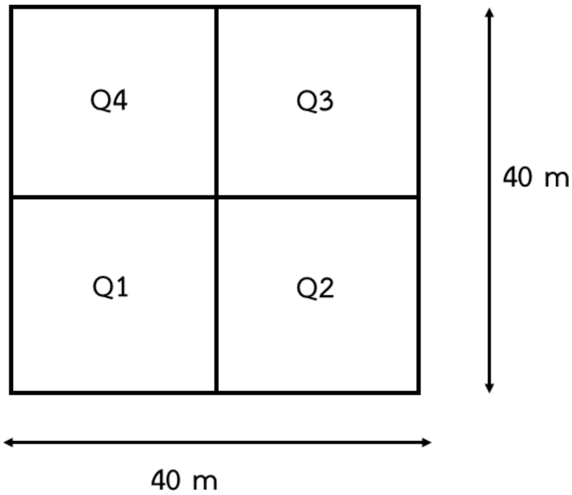

Figure 11 The 20x20 m^2 subplots (Q1-Q4) in each 40x40 m^2 plot

3.4 Aboveground tree **biomass**

The diameter at breast height (DBH) of each tree with 4.5 cm or larger DBH was used to calculate biomass by allometric equations (Ogawa et al., 1965). The biomass was measured at the beginning (November 2012) and was repeated at the end of the study (December 2013). The following allometric equations were used:

Stem mass (Ws) = $0.0396\ (D^2H)^{0.9326}$ kg

Branch mass (Wb) = $0.003487(D^2H)^{1.027}$ kg

Leaf mass (Wl) = 1/[(28.0/(Ws+Wb))+0.025] kg

Aboveground biomass (AGB) = Ws+Wb+Wl kg

Where: 1/H = 1 / (a*DBH^h) + 1 / Hmax

by Simplex Method Number of samples is 1991

a = 0.8427938

h = 0.9813652

H_{max} = 26.63541

3.5 Litter production

Mixed-species leaf litter was collected within each 40x40 m^2 plot. Two 1x1 m^2 litter traps were randomly placed into each 20x20 m^2 sub-plot (Figure 12) for a total of eight traps per plot. Trap were constructed with 2 mm plastic mesh and held 1 m above the ground. The litter was collected monthly from the traps, from November 2012-December 2013. The litter samples were oven-dried at 95±5°C for 2 hours or until no weight change (±0.001 g) was measured. The dried litter samples were weighed for the litter biomass.

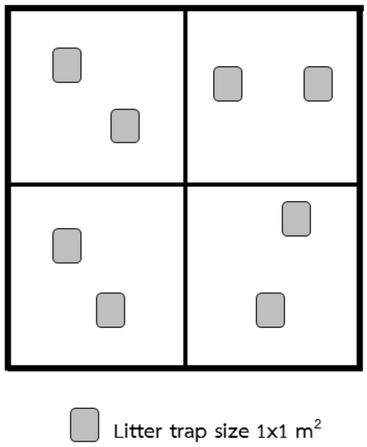

Figure 12 Location of litter traps in each plot in in dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

Figure 13 1x1 m^2 litter trap

3.6 Litter bag decomposition

Litter bag preparation

Mixed leaves of the same composition found in the litter traps were collected, and oven-dried at 95±5°C for 2 hours or until no weight change (±0.001 g) was measured. Then, 40 g of the dried litter were placed into each 20x20 cm^2 nylon bag with 0.5 or 2.0 mm mesh size in November 2012 (Figure 14). Three rows of 12 pairs of both mesh size bags were placed on the ground in the middle of each 40x40 m^2 plot and secured with 2 cm-mesh plastic net, for a total of 36 bags for each mesh size (Figure 15). Three bags of each mesh size were sampled from each plot monthly from November 2012 to December 2013. The litter from each bag was first hand sorted for macrofauna larger than 2 mm, then extracted for mesofauna and macrofauna using Berlese-Tullgren funnel (2 mm sieve) for 4 days. Afterward, the litter was oven-dried at 95±5°C for 2 hours or until no weight change (±0.001 g) was measured. The decomposition rate of litter was determined by measuring litter mass loss, between the initial of dry matter and the mass of dry matter after a given month incubation. Olson's decomposition constant (k) (Olson, 1963) was used to calculate the decomposition rate due to the logarithmic pattern of the litter mass loss. Leaf litter decomposition rate by Olson's decomposition constant (k) provided a formula for simple decay with no litter input.

Rate of mass loss in litter bags can be expressed as:

$$\frac{dL}{dt} = -kL$$

Where:

L = quantity of litter

t = time

k = decomposition rate constant

The above equation can be solved as following:

$$\frac{L_t}{L_o} = \exp(-kt)$$

Where:

L_0 = initial of dry matter

L_t = mass of dry matter after a given month incubation *t*

k = decomposition rate constant

Figure 14 Litter bags, 0.5 mm mesh size (top row) and 2.0 mm mesh size (bottom row)

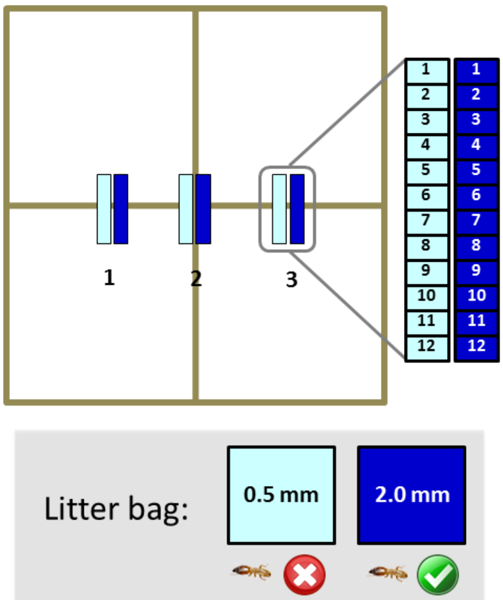

Figure 15 Location of litter bags on the ground in each plot of size 40x40 m^2 for a total of 36 bags for each mesh size (0.5 mm and 2.0 mm)

3.7 Factors influencing decomposition

3.7.1 Biological factors

Soil samples were collected for soil fauna detection monthly from November 2012-December 2013. Soil samples of 10x10x5 cm^3 volume were collected from four 20x20 m^2 subplots from each plot and the samples were pooled for each plot with about 200 g total weight. First, each soil sample was manually sorted for macrofauna larger than 2 mm, then the soil sample was extracted for mesofauna and macrofauna using Berlese-Tullgren funnel (2 mm sieve) for 4 days (Figure 16). Letters A to E signify the range of number of soil fauna. The median of each range represent the relative abundance of that particular soil fauna.

	Number of soil fauna (individauls)	Median
A	1-5	2.5
B	6-10	7.5
C	11-50	30
D	50-100	75
E	100 up	–

Moreover, termite relative abundance surrounding the litter bags was estimated monthly from November 2012-December 2013. Each baiting station consisting of eight PVC tubes (10 cm diameter and 20 cm depth) was systematically placed in the ground of each plot (Figure 17), with 10 g of straw paper bait in each tube (Figure 18). The termite infestation in each baiting station was observed monthly and the paper bait was replaced monthly.

Figure 16 Berlese-Tullgren funnel (2 mm sieve) to extract mesofauna and macrofauna in soil and litter bags

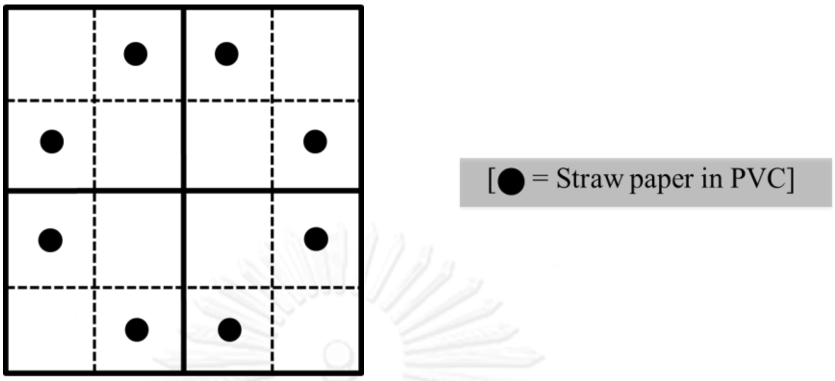

Figure 17 Location of eight termite baiting stations in each plot

Figure 18 Paper bait trap in termite baiting stations

3.7.2 Physical factors

Relative humidity and air temperature were measured using a thermo-hygrometer. Soil temperatures were measured using a thermometer placing 5 cm depth in the soil. Soil pH were measured by mixing soil samples with distilled water at 1:1 ratio by volume and tested with pH paper (Burt, 1992). Soil content was evaluated by measuring the thickness of layers precipitated for 24 hour from mixing 400 g of grounded soil with distilled water in 1,000 ml graduate cylinder (adapted from Jones and Benton (1999)). The physical factors were measured monthly in each plot.

3.8 Data analysis

Analysis of aboveground tree biomass, litter production, litter bag decomposition and soil fauna

Two-way ANOVA was used to analyze the effects of plot and month on aboveground tree biomass and litter production as well as to analyze the effects of plots and mesh size on litter decomposition and soil fauna relative abundance in litter bags. Pearson's correlation was used to examine the relationship between all factors. Multiple Linear Regression was used to analyze the relationship between factors that affect to litter decomposition. All analyses were performed with Sigmaplots v11.1.0 (Systat Software, 2008)

CHAPTER IV

RESULTS

4.1 Aboveground tree biomass

At the beginning of the study, there were 443, 291, 459, and 225 trees of more than 4.5 cm DBH in A1-A4 plots, respectively. 463, 304, 464, and 231 trees of more than 4.5 cm DBH were observed in A1-A4 plots, respectively, at the end of the study (Table 4). Aboveground biomass at the beginning of the study period of A1-A4 plots were 1.14×10^5, 0.81×10^5, 0.61×10^5, and 0.57×10^5 kg/ha, respectively. At the end of study, the aboveground biomass of the 4 plots were 1.19×10^5, 0.83×10^5, 0.65×10^5, and 0.58×10^5 kg/ha, respectively. Aboveground biomass was highest in plot A1 and lowest in plot A4 (Figure 19). The aboveground tree biomass was significantly different among plots (F=9.23, df=3, 2609, p<0.001) (Appendix A, Table A-1). Average annual aboveground tree biomass increased 4.2% in all 4 plots (Table 5). The frequency of tree class size in all plots A1-A4 show that 10 cm DBH trees was most common in all plots, and plot A3 contained the highest relative frequency of 10 cm DBH trees among all plots (Figure 20) (Appendix A, Table A-2).

Table 4 Number of trees (individuals) in plots A1-A4 (Nov 2012-Dec 2013) at dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

Plot	Number of trees (individuals)	
	November 2012	December 2013
A1	443	463
A2	291	304
A3	459	464
A4	225	231
Total	1418	1462

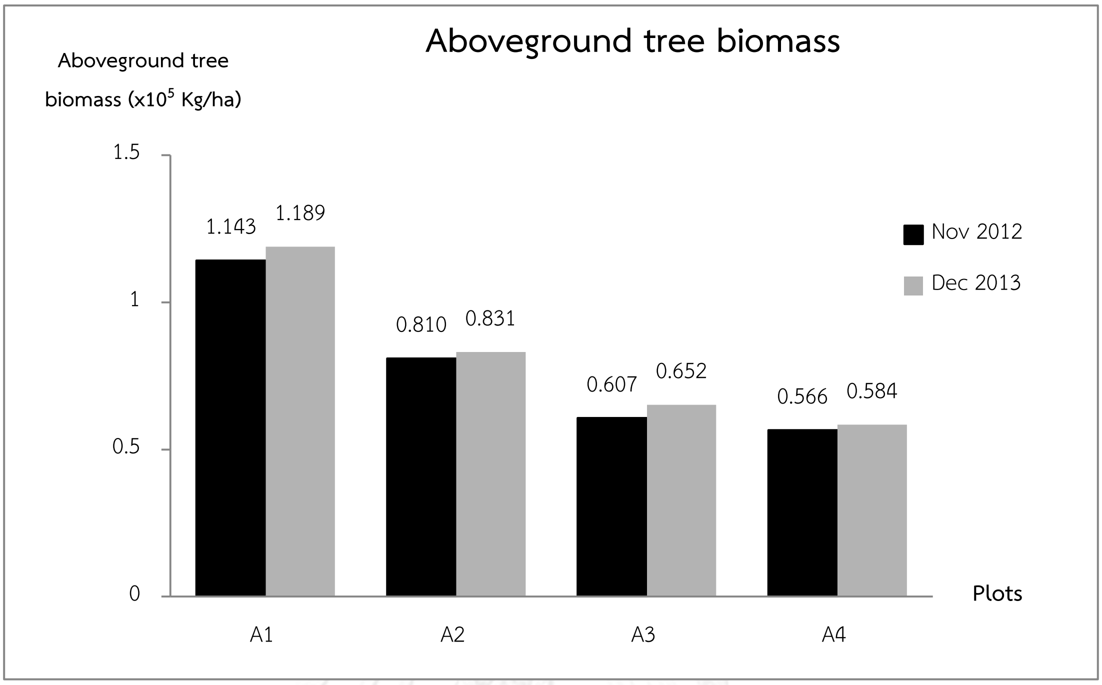

Figure 19 Aboveground biomass in plots A1-A4 (November 2012 and December 2013) at dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

Table 5 The aboveground tree biomass at the beginning of the study (November 2012) and at the end of the study (December 2013) and average annual biomass increase in plots A1-A4 at dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

Plot	Aboveground tree biomass (tons/ha)		Annual biomass increase (%)
	November 2012	December 2013	
A1	114.3	118.9	4.1
A2	81.0	83.1	2.6
A3	60.7	65.2	7.5
A4	56.6	58.4	3.2
Average	78.1	81.4	4.2

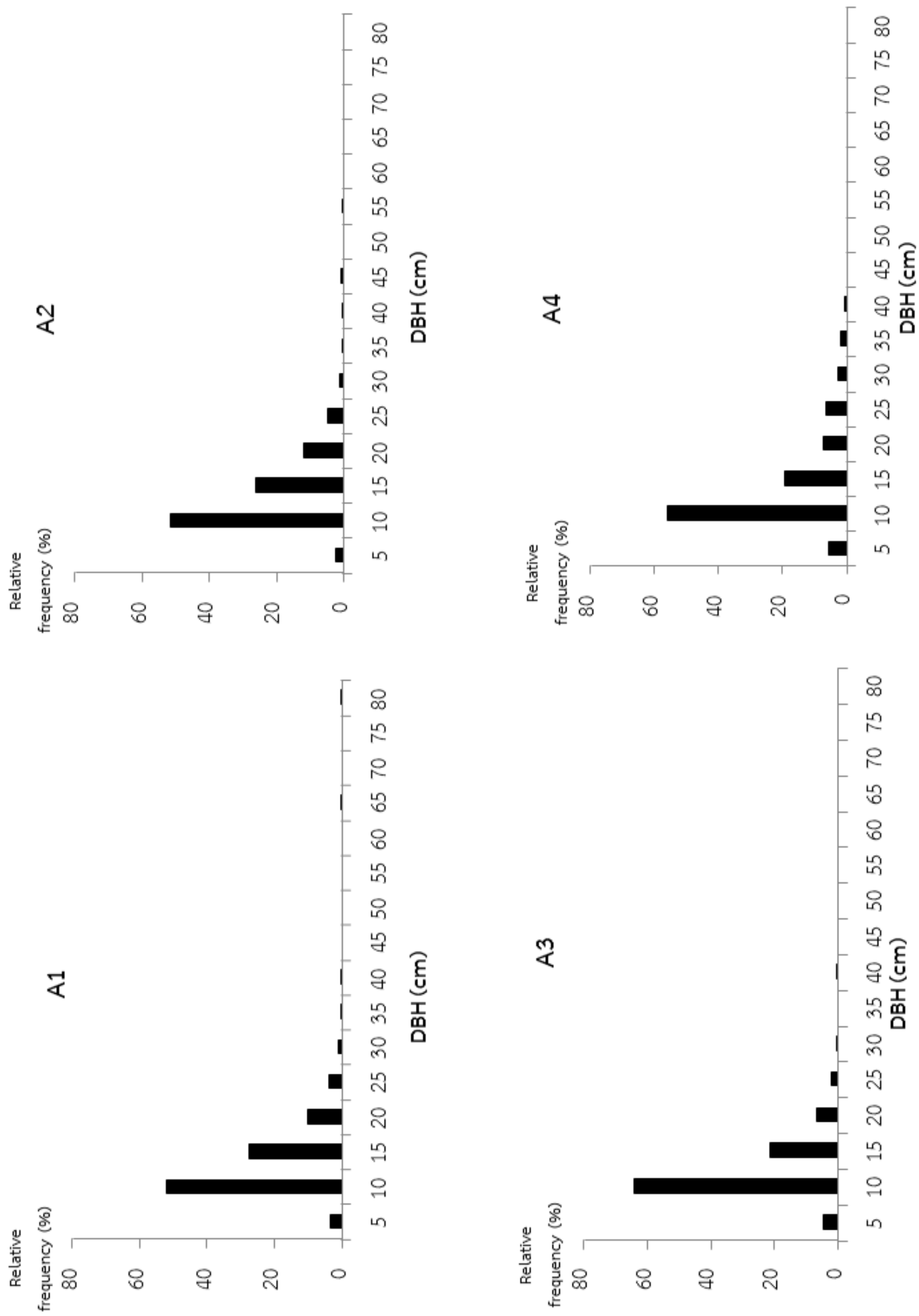

Figure 20 Frequency of tree class size in plots A1-A4 at dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

4.2 Litter production (Litter biomass)

Overall, annual litter production in plot A2 was highest, followed by A1, A3, and A4, respectively (Table 6). However, there was no significant difference of litter production between plot (*F*=3.152, df=3, 36 *p*=0.073) (Appendix A, Table A-3). The highest leaf litter production was in March 2013 while the lowest leaf litter production was in July 2013 for all four plots (Figure 21). Leaf litter production was high in late dry season (January-March 2013) and low production in wet season (April-September 2013) (Figure 21). The average of leaf litter production was 7.9±0.9 tons/ha/yr (Table 6). Aboveground tree biomass and litter production were positively correlated (R^2=0.57) (Figure 22)

Table 6 Aboveground tree biomass and litter production in plots A1-A4

Area	Aboveground tree biomass (tons/ha)	Litter production (tons/ha/yr)
A1	118.9	9.1
A2	83.1	9.7
A3	65.2	6.3
A4	58.4	6.3
Average	81.4	7.9

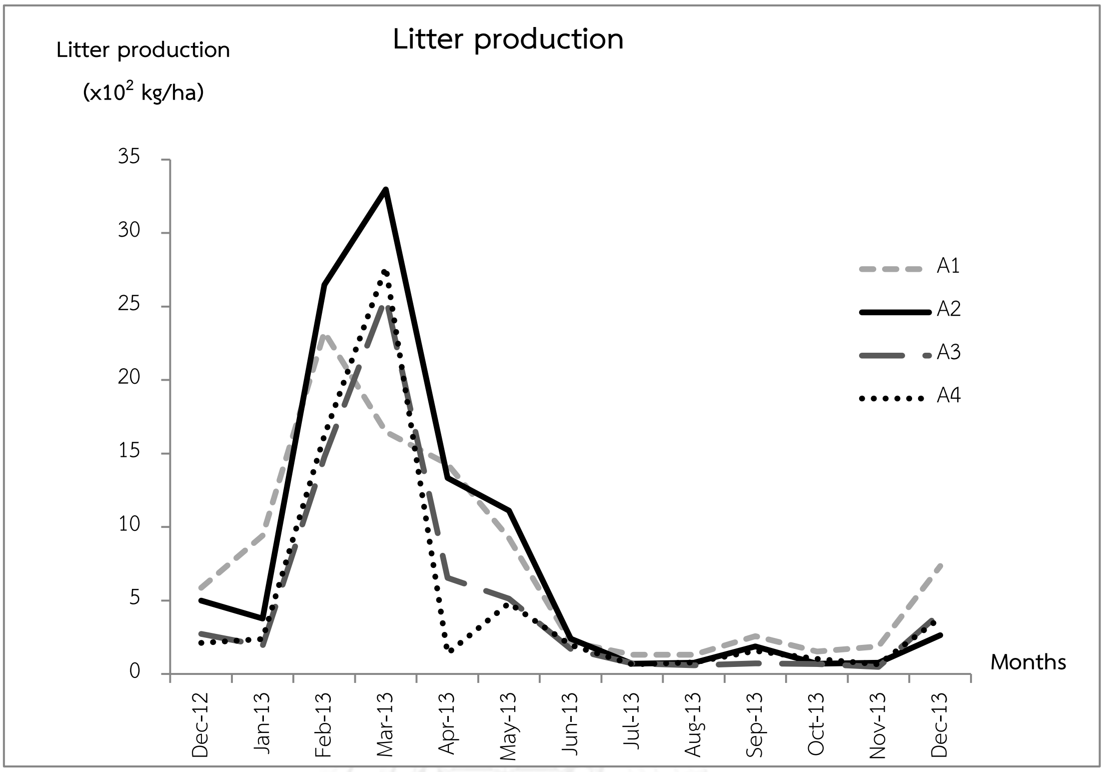

Figure 21 Litter production collected in litter traps in plots A1-A4 (December 2012-December 2013) at dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

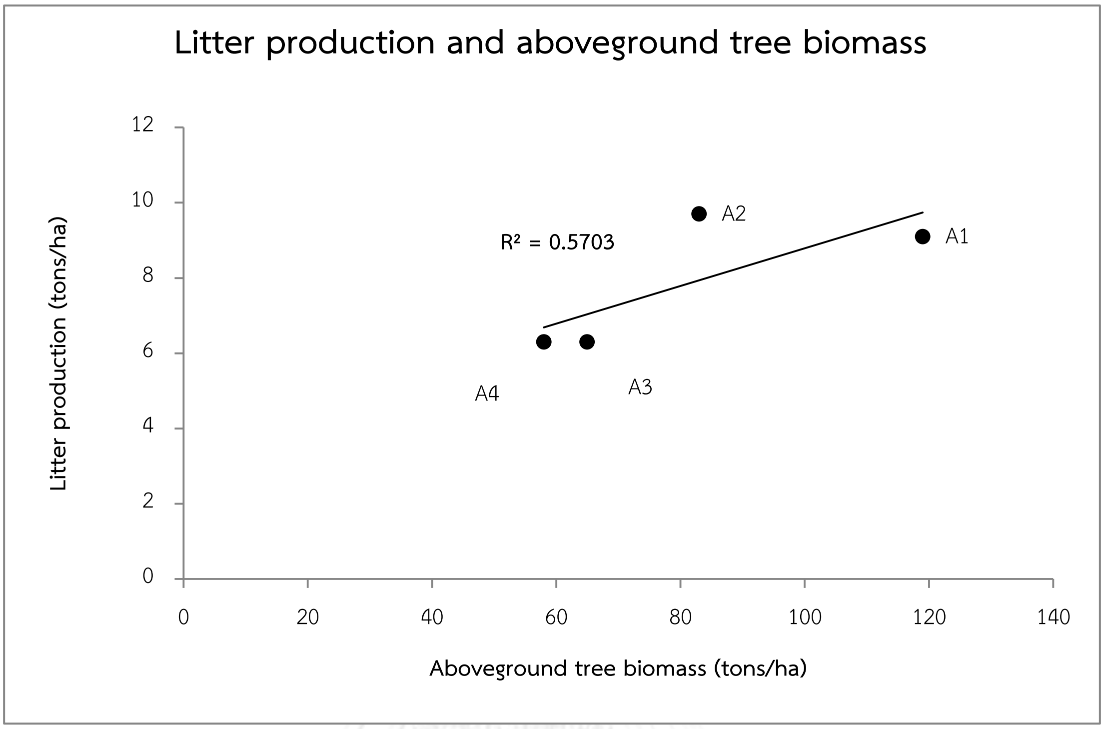

Figure 22 Average aboveground tree biomass and litter production in plots A1-A4 (December 2012-December 2013) at dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

4.3 Litter decomposition

Monthly litter mass loss was small at the beginning of the 13-month study, only up to 5 g per bag in the first 3 months (December 2012-February 2013). The monthly mass loss increased cumulatively, resulting in the remaining litter, from the initial 40 g, of 11.89±0.65 g in 2.0 mm-mesh bags and 15.53±0.85 g in 0.5 mm-mesh bags in December 2013 (Table 7 and Figure 23). The litter biomass decreased was logarithmical: R^2= 0.79 for 0.5mm and R^2= 0.86 for 2.0 mm (Figure 24). The litter mass loss in plot A4 was highest, followed by A2, A3, and A1, respectively (Figure 25).

Three phases of decomposition process, the initial phase (0-3 months), the middle phase (4-9 months), and the last phase (10-13 months) can be observed over the study period based on the rate of mass loss (Figure 23). There was no significant difference between the remaining in 0.5 mm mesh litter bags and 2.0 mm mesh litter bags at the initial phase (F=0.48, df=1, 24 p=0.49) and the middle phase (F=0.91, df=1, 40 p=0.35). However, the litter mass loss of the 2.0 mm mesh litter bags was significantly higher than 0.5 mm mesh litter bags at the last phase (F=7.64, df=1, 24 p=0.01).

Average litter mass loss at the end of the 13-month period (December 2012-December 2013) of the 2.0 mm litter bags was higher than that of 0.5 mm bags (F=4.85, df=1, 96, p=0.03). Soil fauna were found in the litter bags throughout the 12 month study period (January-December 2013). Termites were found in the litter bags of both mesh sizes, so we separated the 0.5 mm litter bags infested with termites (15 bags with the presence of holes bigger than 2 mm presumably caused by termite invasion) from the non-infested 0.5 mm bags (129 bags) in calculation. No significant difference was found in litter mass loss among plots in the 0.5 mm mesh litter bags (F=1.40, df=3, 36, p=0.26), but the litter mass loss in the 2.0 mm mesh litter bags was different between plots (F=6.36, df=3, 36, p=0.001) (Figure 25) (Appendix B, Tables B-1, B-1, B-3).

Table 7 Average remaining litter biomass in litter bags, 0.5 and 2.0 mm mesh sizes, placed in all 4 plots (December 2012-December 2013) in dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

Mesh size	Months													
	Nov-12	Dec-12	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13
0.5 mm	40	38.09	35.59	35.55	35.31	36.62	34.94	34.10	33.90	32.61	28.20	21.78	21.14	15.54
2.0 mm	40	36.14	35.34	35.24	32.93	34.70	33.71	33.12	30.05	26.01	24.80	15.80	15.60	11.89

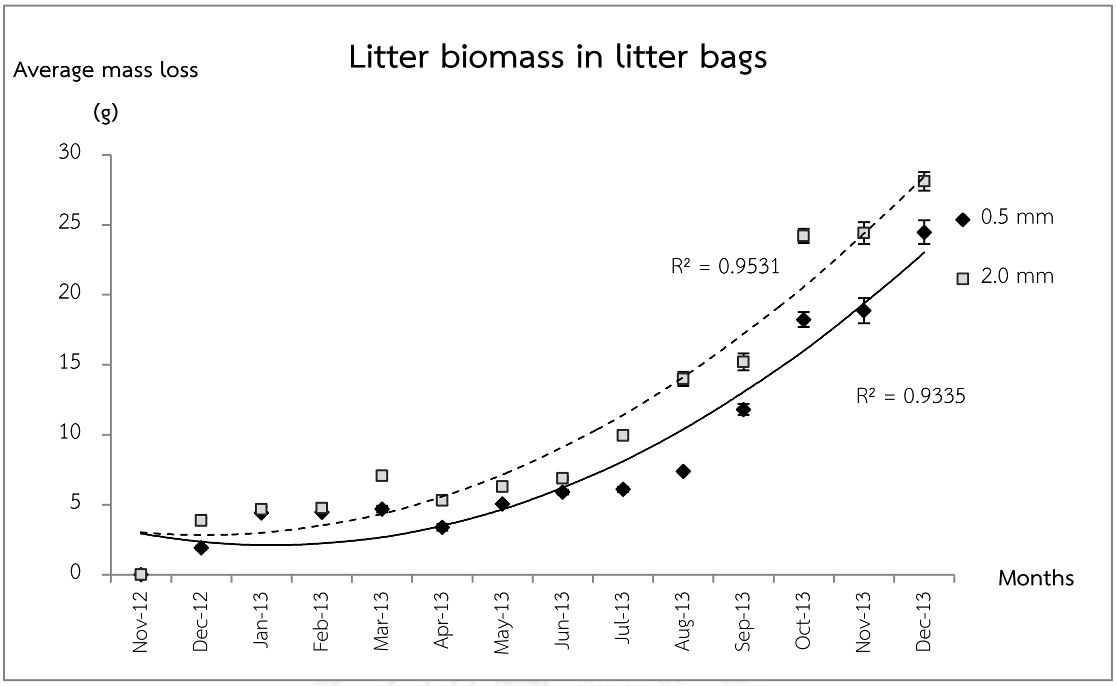

Figure 23 Litter biomass in litter bags, 0.5 and 2.0 mm mesh sizes, placed in all 4 plots (November 2012-December 2013) in dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

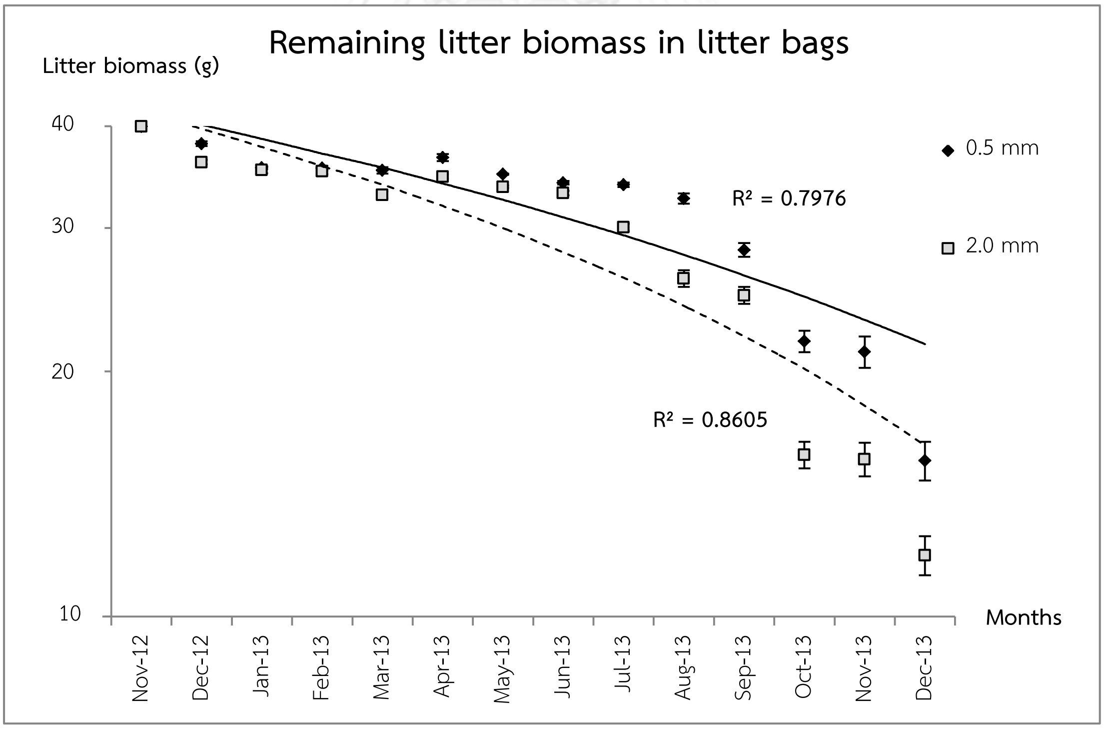

Figure 24 Litter biomass remaining in litter bags (in log scale), 0.5 and 2.0 mm mesh sizes, placed in all 4 plots (November 2012-December 2013) in dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

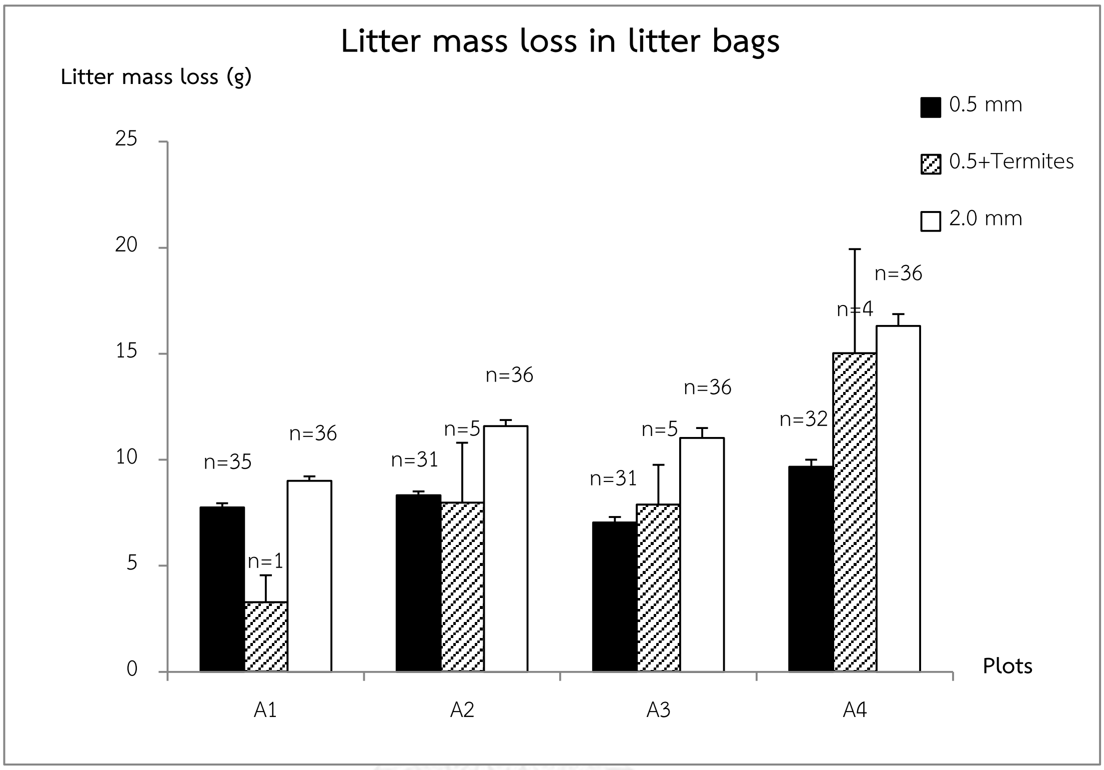

Figure 25 Litter mass loss (mean±SE) in non-infested 0.5 mm, termite-infested 0.5 mm, and 2.0 mm litter bags by plots (A1-A4) from January-December 2013 at dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

Leaf litter decomposition rate (Olson's k) from December 2012-December 2013 (Table 8) were 0.87 for 0.5 mm bags and 1.12 for 2.0 mm bags which are comparable to the studies in tropical forests in Malaysia (Yamashita and Takeda, 1998) and India (Kumar et al., 2012) (Table 9). The decomposition constant of this study is lower than the other studies probably due to different physical factors, for example, rainfall and humidity. Moreover, the mass loss of leaf litter was positively correlated to humidity (Pearson's correlation=0.21, df=287, p<0.001).

Table 8 Olson's decomposition constant (k) from 0.5 mm mesh litter bags and 2.0 mm mesh litter bags

Mesh size	Months												
	Dec-12	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13
0.5 mm	0.05	0.11	0.11	0.12	0.08	0.12	0.15	0.15	0.19	0.32	0.56	0.59	0.87
2.0 mm	0.09	0.11	0.12	0.18	0.13	0.16	0.17	0.26	0.40	0.44	0.86	0.87	1.12

Table 9 Comparison of Olson's decomposition constant (k)

	This study	Assam, India (Kumar, Tapwal, and Baruah, 2012)	Peninsular Malaysia (Yamashita and Takeda, 1998)
k (0.5 mm bags)	0.87	-	0.76
k (2.0 mm bags)	1.12	2.45	2.15

4.4 Factors influencing decomposition

A variety of soil fauna were found in the litter bags, such as springtails (Collembola), beetle larvae (Coleopteran), bark lice (Psocoptera), mites (Acari), ants (Hymenoptera), lepidopteran larvae, spiders, pseudoscorpions, cockroaches, (Blattidae), Thrips (Thysanoptera) and termites (Figures 26-37). Presumably, thrips, beetles larvae and lepidopterans larvae were attached to, and have fallen with, flowers and/or leaf litter but they do not play an important role to litter decomposion. Two species of termites, *Odontotermes* sp. (Termitidae) and *Coptotermes* sp. (Rhinotermitidae), were found in the litter bags (Figure 26). Springtails were the most prevalent soil fauna followed by larva and adult beetles in 2.0 mm-mesh litter bags. On the other hand, the high abundance of springtails followed by bark lice were found in 0.5 mm-mesh litter bags (Table 10).

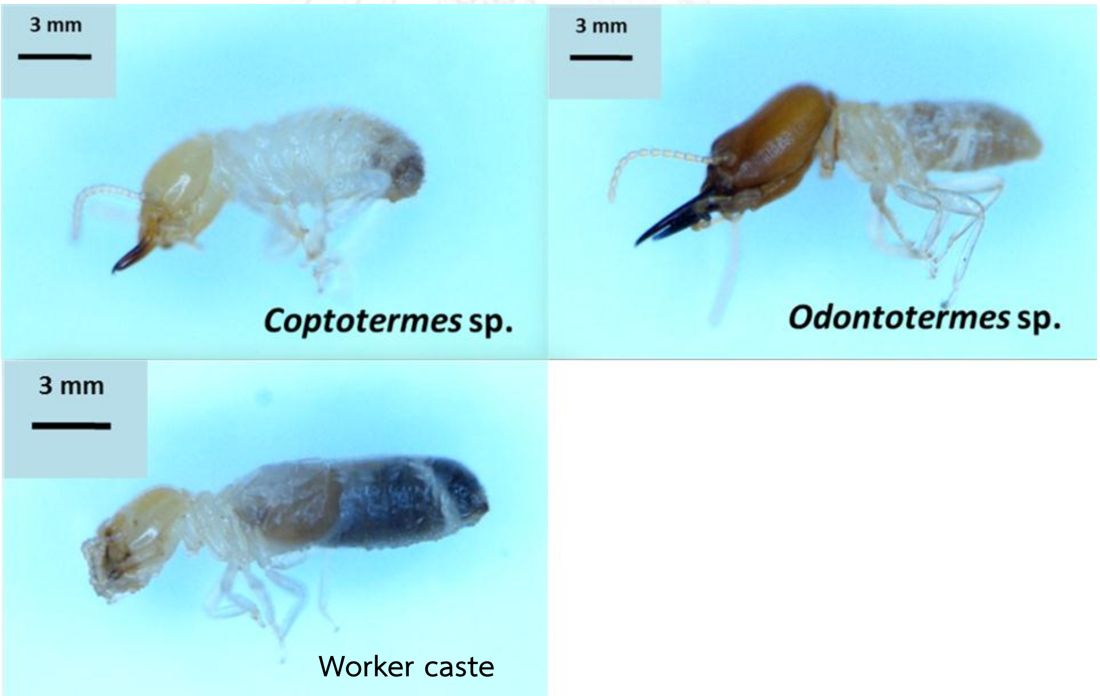

Figure 26 Termites found in litter bags extracted by Berlese-Tullgren funnel from plots A1-A4 from January-December 2013 at dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

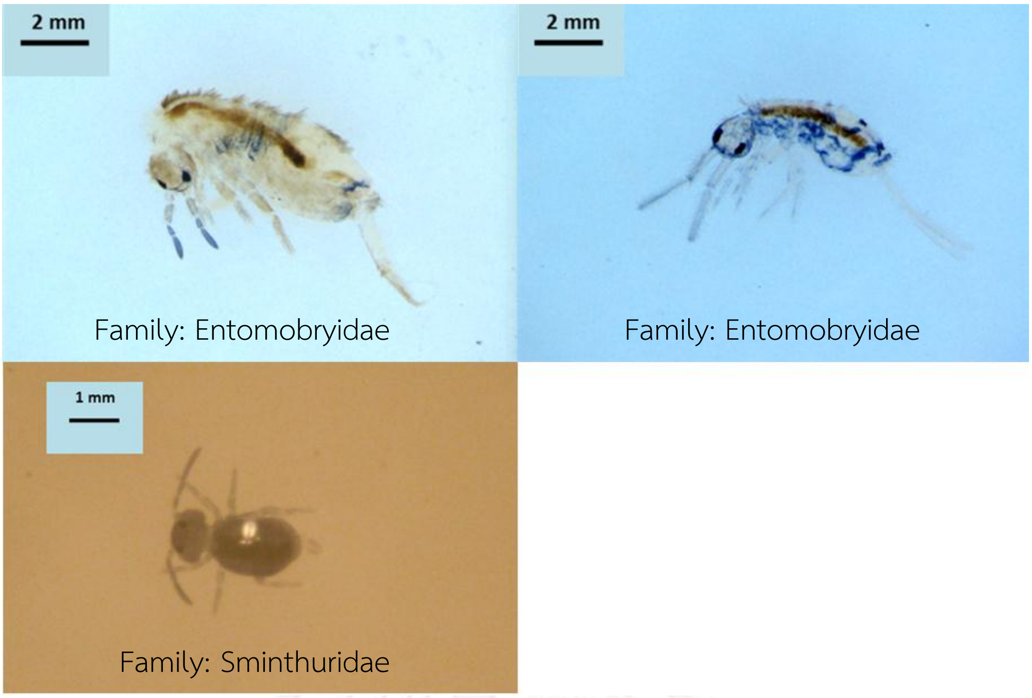

Figure 27 Springtails found in litter bags extracted by Berlese-Tullgren funnel from plots A1-A4 from January-December 2013 at dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

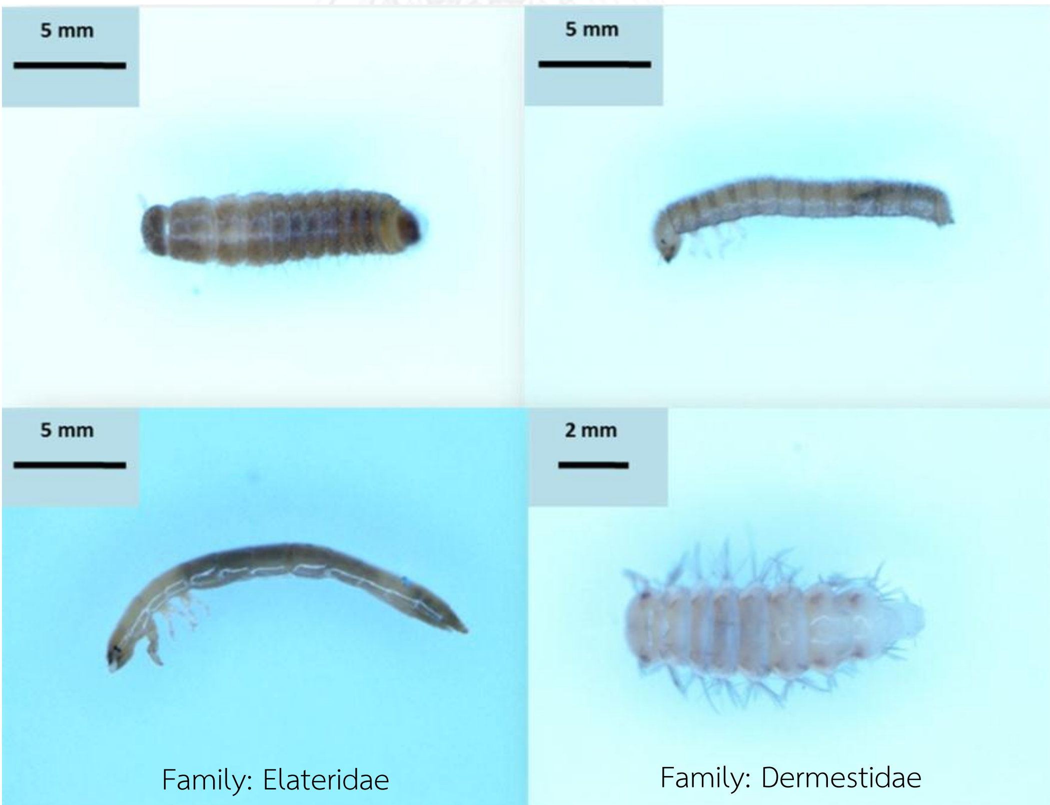

Figure 28 Beetle larvae found in litter bags extracted by Berlese-Tullgren funnel from plots A1-A4 from January-December 2013 at dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

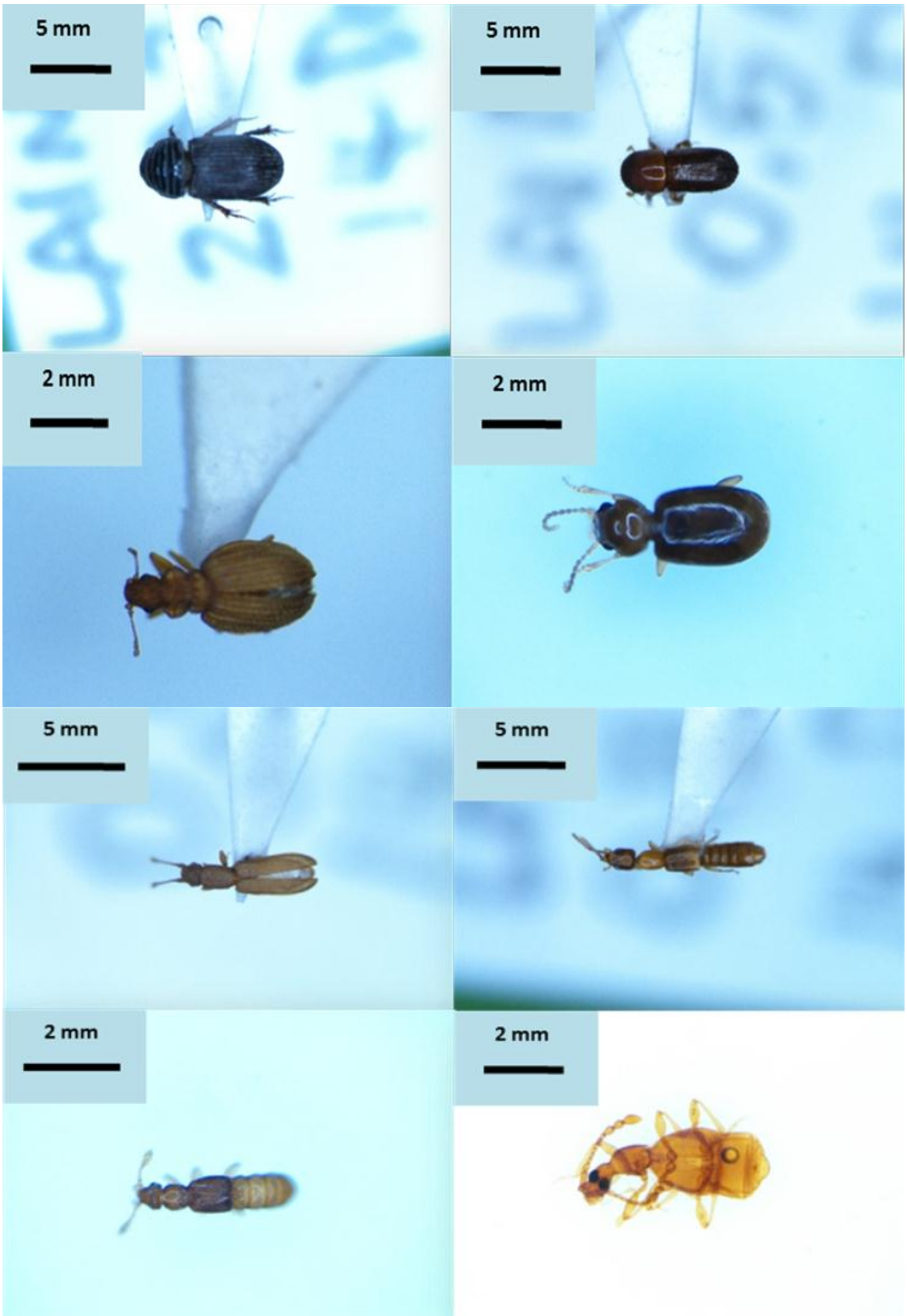

Figure 29 Adult beetles found in litter bags extracted by Berlese-Tullgren funnel from plots A1-A4 from January-December 2013 at dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

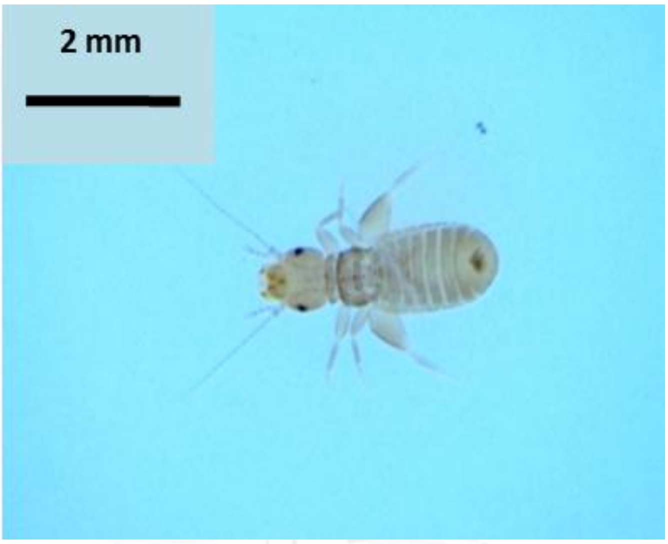

Figure 30 Bark louse (Psocoptera) found in litter bags extracted by Berlese-Tullgren funnel from plots A1-A4 from January-December 2013 at dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

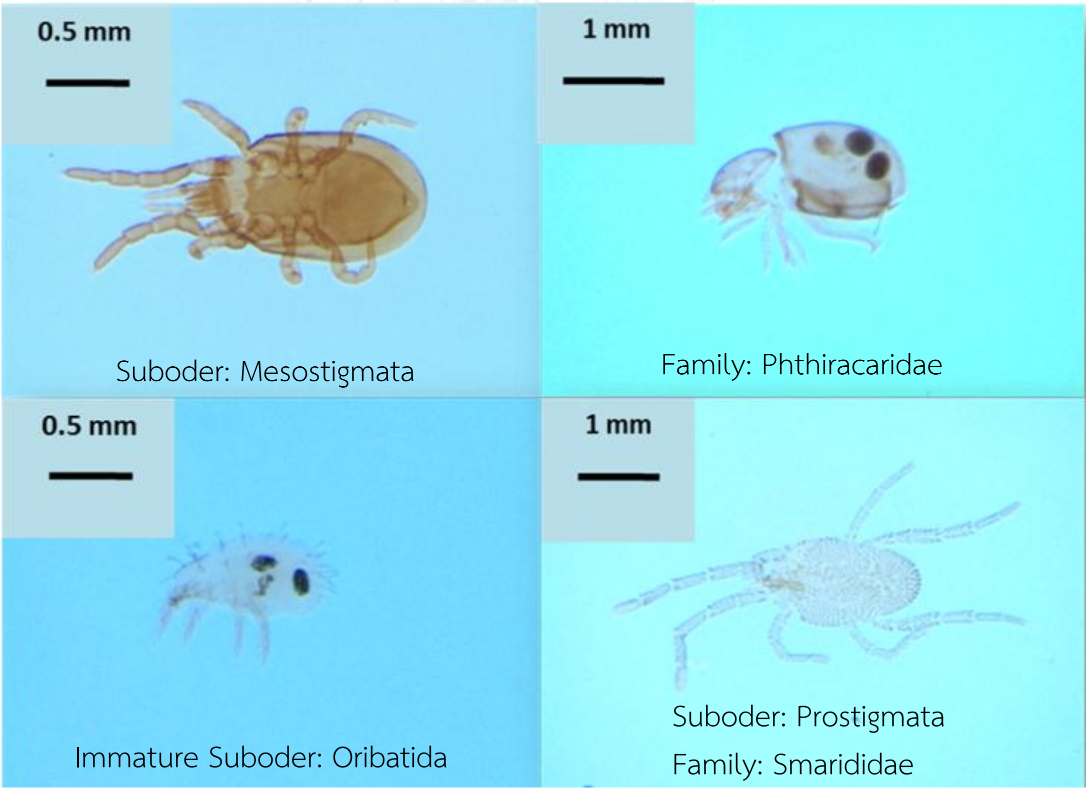

Figure 31 Mites found in litter bags extracted by Berlese-Tullgren funnel from plots A1-A4 from January-December 2013 at dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

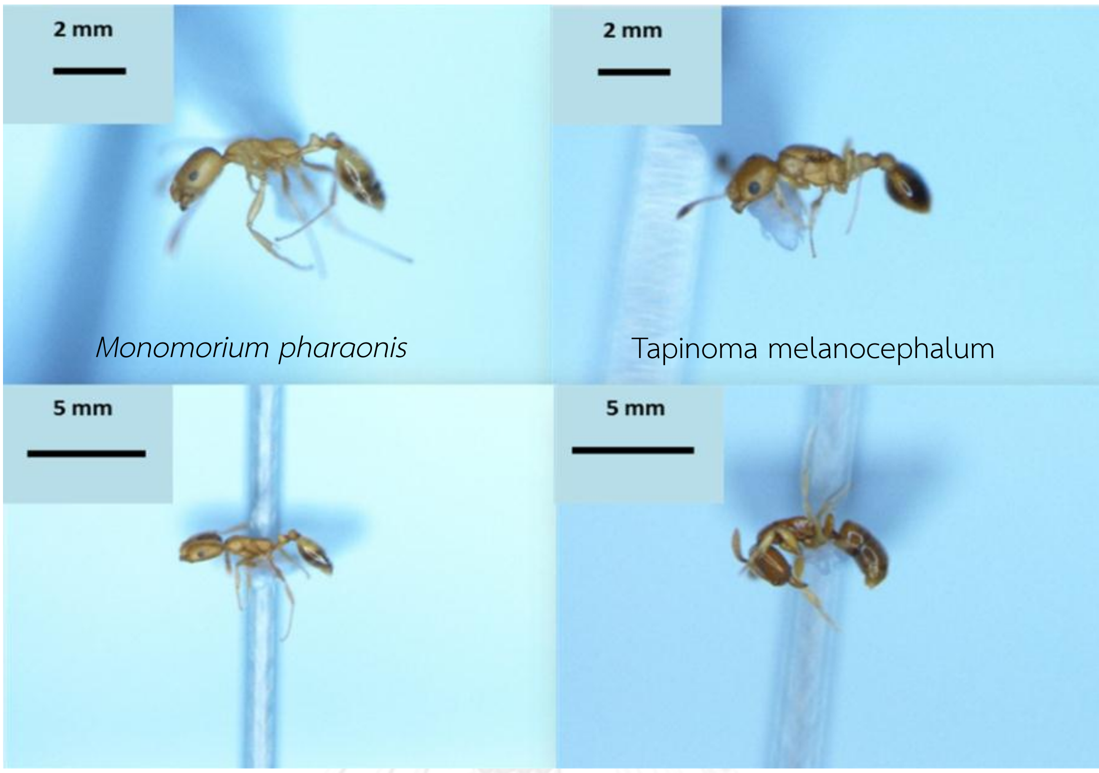

Figure 32 Ants found in litter bags extracted by Berlese-Tullgren funnel from plots A1-A4 from January-December 2013 at dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

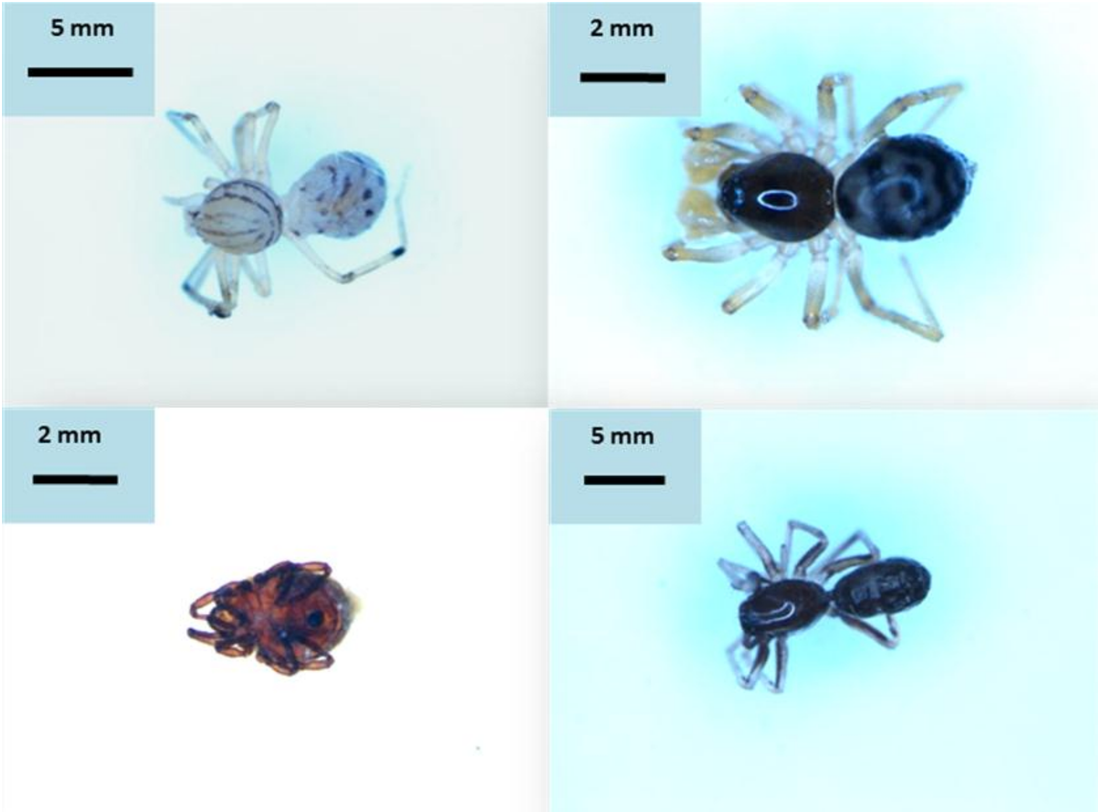

Figure 33 Spiders found in litter bags extracted by Berlese-Tullgren funnel from plots A1-A4 from January-December 2013 at dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

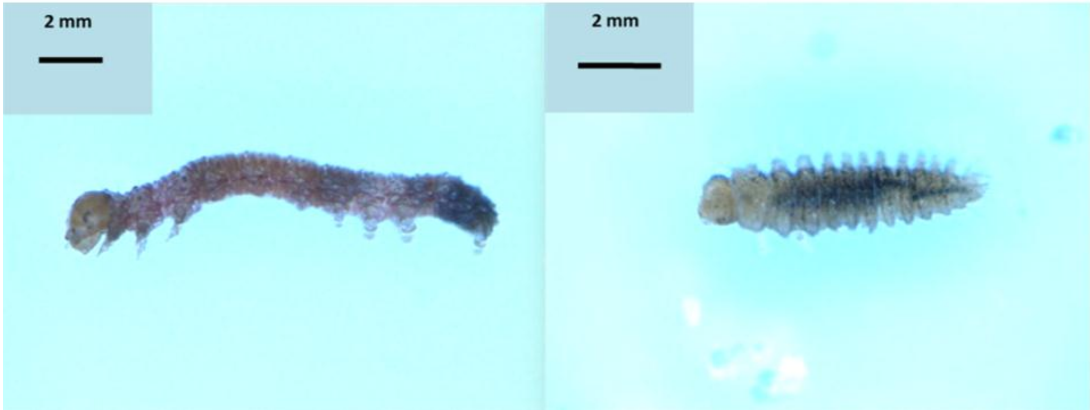

Figure 34 Lepidopterans larvae found in litter bags extracted by Berlese-Tullgren funnel from plots A1-A4 from January-December 2013 at dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

Figure 35 Pseudoscorpions found in litter bags extracted by Berlese-Tullgren funnel from plots A1-A4 from January-December 2013 at dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

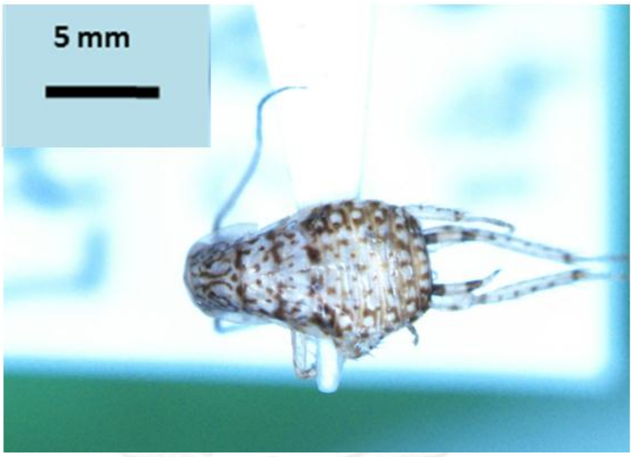

Figure 36 Cockroach found in litter bags extracted by Berlese-Tullgren funnel from plots A1-A4 from January-December 2013 at dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

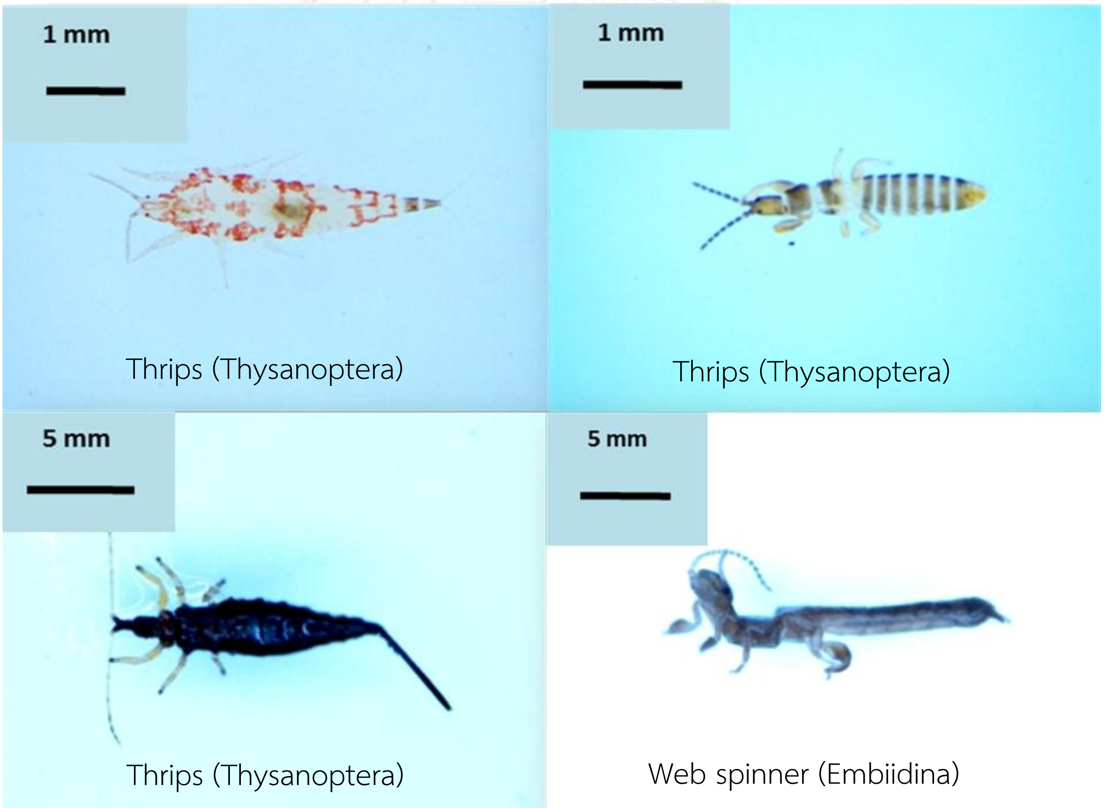

Figure 37 Other fauna found in litter bags extracted by Berlese-Tullgren funnel from plots A1-A4 from January-December 2013 at dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

Table 10 Soil fauna in litter bags arranged by the relative abundance (RA)

Rank	0.5 mm+Termites (n=15)	RA	0.5 mm (n=129)	RA	2.0 mm (n=13)	RA
1	Termites	7.26	Springtails	8.33	Springtails	3.44
2	Springtails	2.74	Bark lice	4.09	Beetles	2.40
3	Beetles	1.42	Beetles	4.04	Ants	2.14
4	Mites	1.78	Mites	2.84	Mites	1.98
5	Bark lice	1.28	Ants	0.70	Bark lice	0.90
6	Ants	0.35	Lepidopterans	0.28	Spiders	0.69
7	Pseudoscorpions	0.21	Spiders	0.14	Pseudoscorpions	0.66
8	Lepidopterans	0.14	–		Termites	0.50
9	Spiders	0.05	–		Lepidopterans	0.26
10			–		Cockroaches	0.17

Soil fauna from soil samples, extracted with Berlese-Tullgren funnel, was relatively low in abundance, but their diversity was comparable to soil fauna in the litter bags. However, the rank abundance of soil fauna in soil samples did not follow the rank of soil fauna in litter bags. Ants were the most abundant group in soil while springtails were the most abundant group found in the litter bags. Meanwhile, termites ranked fifth in both the soil samples and the litterbags (Table 11).

Table 11 Soil fauna in soil ranked by relative abundance

Rank	Relative abundance
1	Ants
2	Mites
3	Spiders
4	Beetles
5	Termites
6	Springtails
7	Lepidopterans
8	Cockroaches
9	Pseudoscorpions

4.4.1 Termite

Termites were found in the litter bags throughout the 12 month study period. They were found in the 2.0 mm mesh bags (n=13), with the highest relative abundance in October 2013. Even though the 0.5 mm mesh bags were designed to exclude termites, some termites were found in some bags (n=15) for all 4 plots via an invasion through holes larger than 2.0 mm. The remaining 0.5 mm litter bags (n=129) was non-infested from all four plots. In these termite-infested 0.5 mm-mesh bags, the highest relative abundance was observed in June 2013 (Figure 38) (Table 12).

High abundance of termites were observed from the 2.0 mm litter bags, particularly litter bags from A3 (relative abundance=12.5) and A4 (relative abundance=11.7) and some of the termite-infested 0.5 mm litter bags from A4 (relative abundance=25.6). These litter bags with high termite abundance contained soil debris presumably from the remnant of termite soil tunnels (Table 12) (Figure 39).

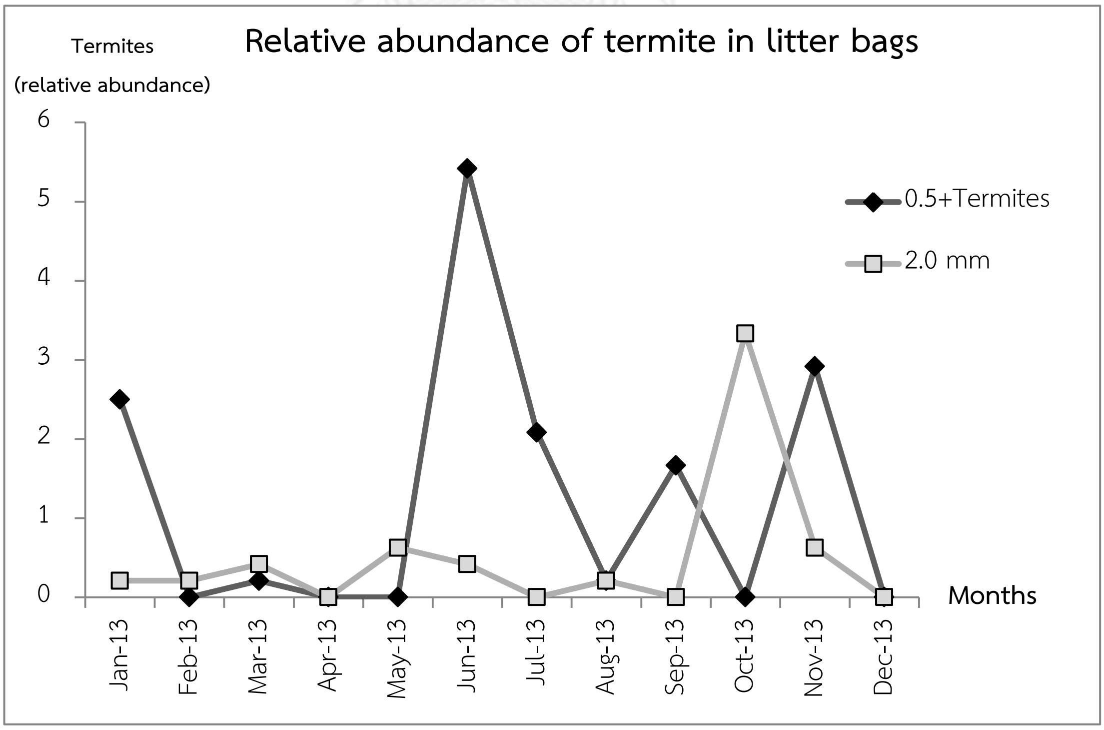

Figure 38 Termites abundance (mean±SE) in litter bags (non-infested 0.5 mm, termite-infested 0.5 mm, and 2.0 mm) extracted by Berlese-Tullgren funnel from plots A1-A4 from January-December 2013 at dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District

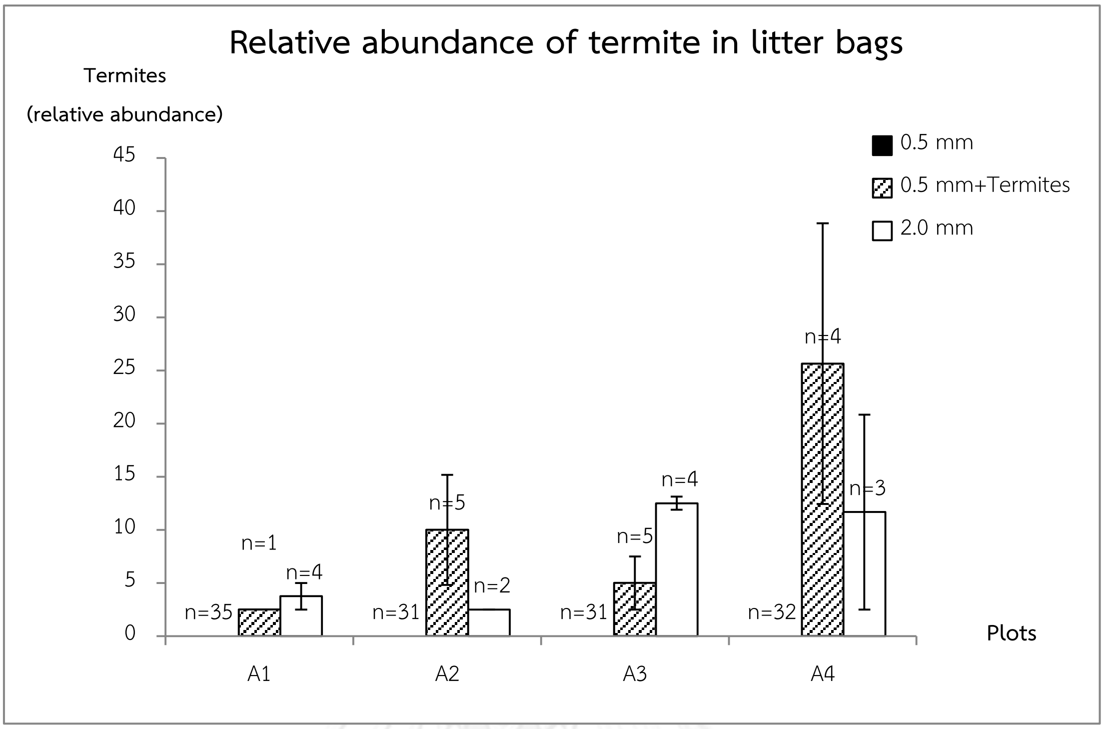

Figure 39 Relative abundance of termites in litter bags extracted by Berlese-Tullgren funnel from plots A1-A4 from January-December 2013 at dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

Table 12 Termites relative abundance in litter bags (termite-infested 0.5 mm, non-infested 0.5 mm, and 2.0 mm)

Plot	0.5 mm+Termites		0.5 mm		2.0 mm	
	Relative abundance	(n=15)	Relative abundance	(n=129)	Relative abundance	(n=13)
A1	2.5	n=1	0	n=35	3.8	n=4
A2	10.0	n=5	0	n=31	2.5	n=2
A3	5.0	n=5	0	n=31	12.5	n=4
A4	25.6	n=4	0	n=32	11.7	n=3

4.4.2 Other soil fauna

The relative abundance of springtails were high in the wet season (June-September 2013), with the highest in August 2013 for both sizes of litter bags. Springtails relative abundance in 0.5 mm mesh litter bags were significantly higher than in 2.0 mm mesh litter bags (F=13.03, df=1, 52, *p*=0.004) (Figure 40) (Appendix C, Table C-1).

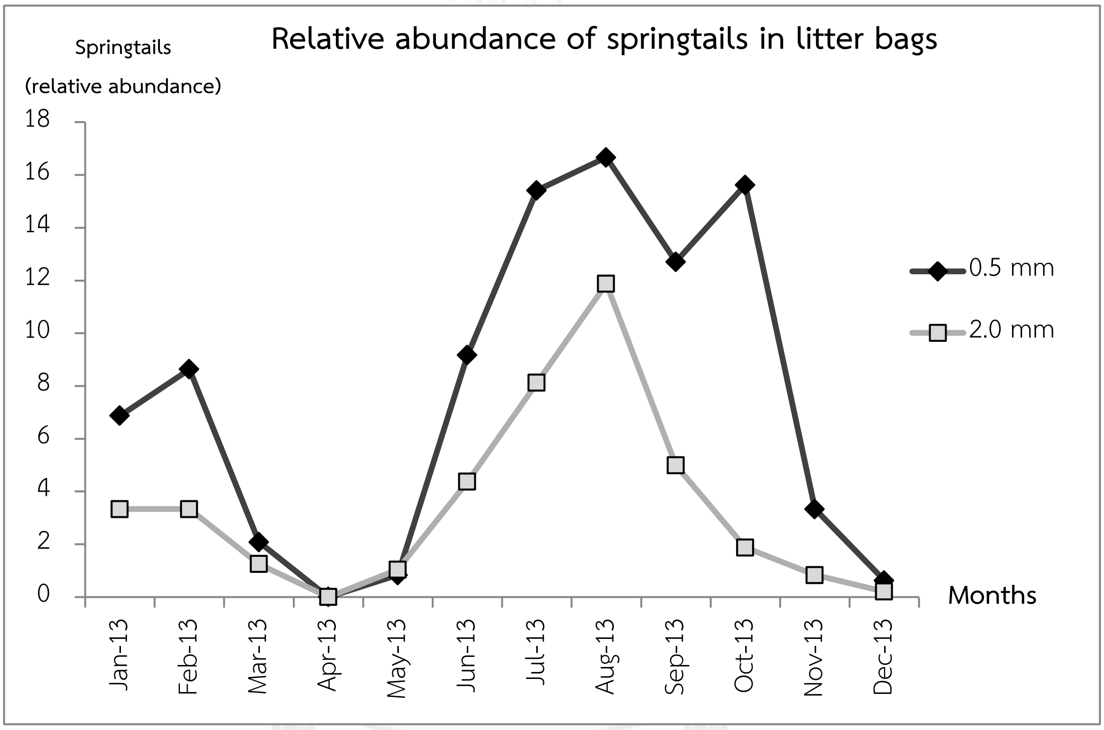

Figure 40 Relative abundance of springtails in litter bags extracted by Berlese-Tullgren funnel from plots A1-A4 from January-December 2013 at dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

Larva and adult beetles were found in high abundance in late dry season (October-December 2013), with the highest abundance in October 2013 for both sizes of litter bags. Beetles in 0.5 mm mesh litter bags were significantly higher than in 2.0 mm mesh litter bags (F=7.91, df=1, 52, p=0.017) (Figure 41) (Appendix C, Table C-2).

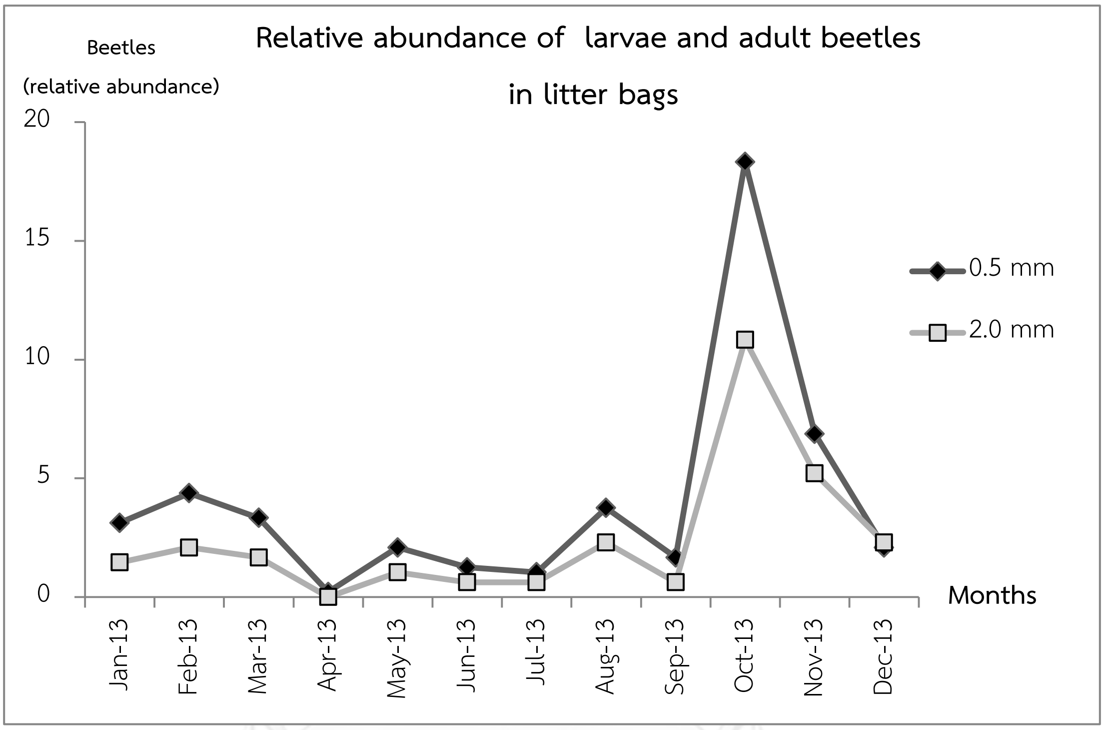

Figure 41 Relative abundance of larva and adult beetles in litter bags extracted by Berlese-Tullgren funnel from plots A1-A4 from January-December 2013 at dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

Bark lice were found in high abundance in wet season (June-September 2013), with the highest abundance in June 2013 for 0.5 mm mesh litter bags and May 2013 for 2.0 mm mesh litter bags. Bark lice in 0.5 mm mesh litter bags were significantly higher than in 2.0 mm mesh litter bags (F=7.8, df=1, 52, *p*=0.018) (Figure 42) (Appendix C, Table C-3).

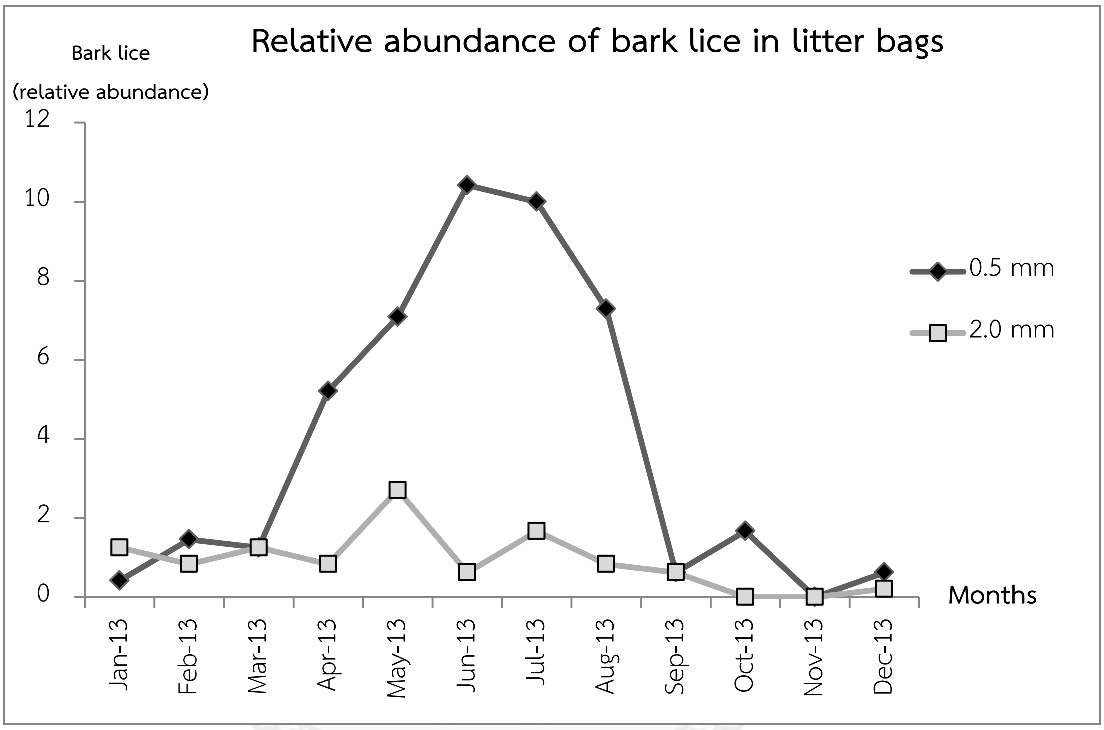

Figure 42 Relative abundance of bark lice in litter bags extracted by Berlese-Tullgren funnel from plots A1-A4 from January-December 2013 at dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

Mites were found in high abundance in wet season (June-September 2013), with the highest abundance in July 2013 for both sizes of litterbag. Mites in 0.5 mm-mesh size litter bags were higher than in 2.0 mm-mesh size litter bags (Figure 43) (Appendix C, Table C-4).

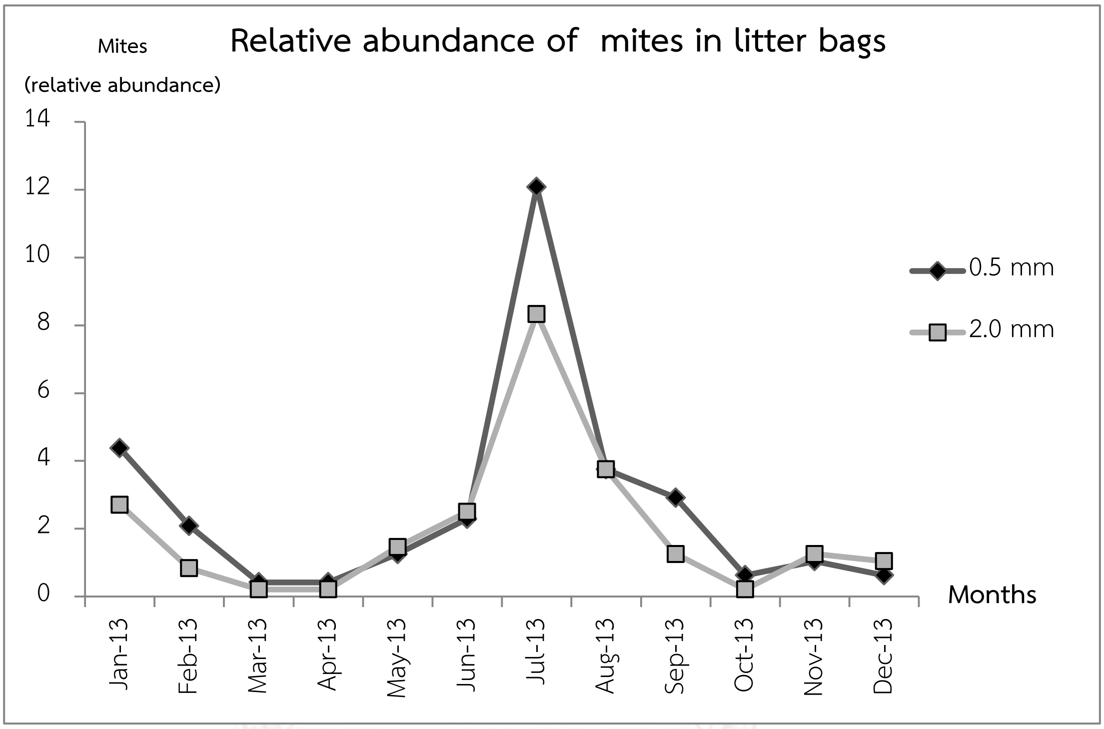

Figure 43 Relative abundance of mites in litter bags extracted by Berlese-Tullgren funnel from plots A1-A4 from January-December 2013 at dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

The relative abundance of termite from paper bait stations, located within each 10x10 m plot, showed that the plot A2 had the highest termite infestation at 92.31% followed by A1, A3, and A4, respectively (Figure 44) (Appendix C, Table C-5).

Termite abundance in litter bags were related to litter decomposition (R^2=0.6282) (Figure 45). The termite abundance and litter mass loss in litter bags mesh size 2.0 mm were higher than the litter bag mesh size 0.5 mm. High termite abundance in litter bags mesh size 2.0 mm were related with high litter mass loss comparing to low termite abundance in litter bags mesh size 0.5 mm were related with low litter mass loss (Figure 45).

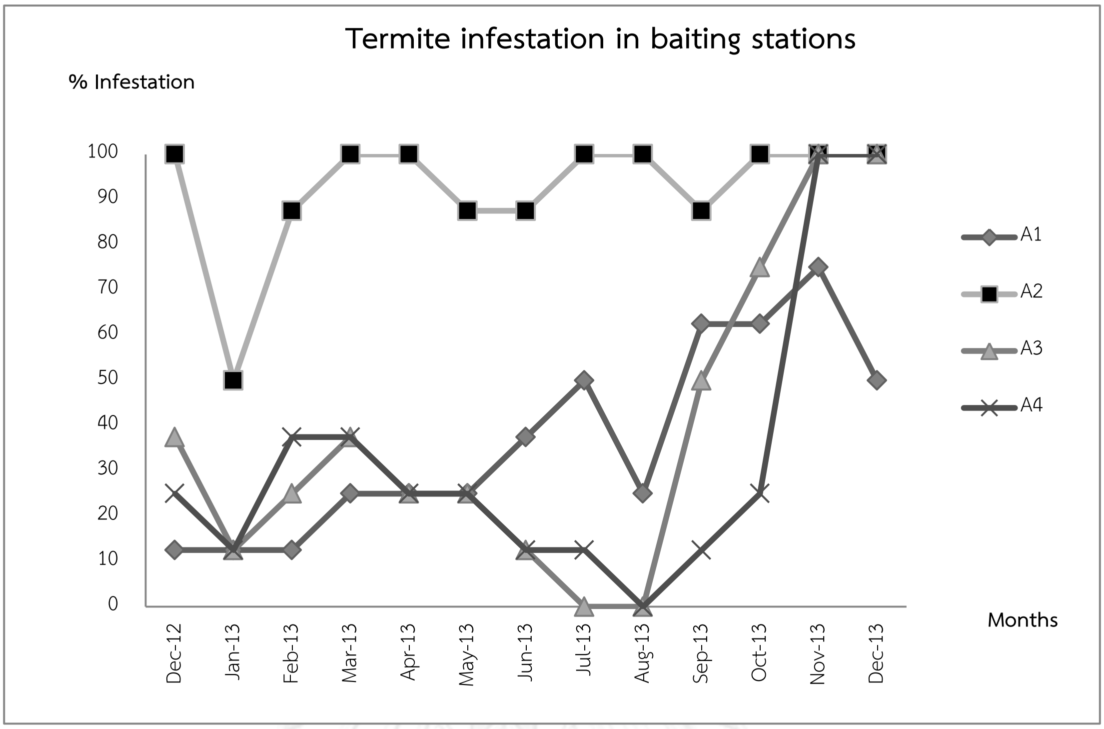

Figure 44 Percentage of termite infestation in the baiting stations (n = 8 per plot) surrounding litter bags in plot A1-A4 (December 2012-December 2013) at dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

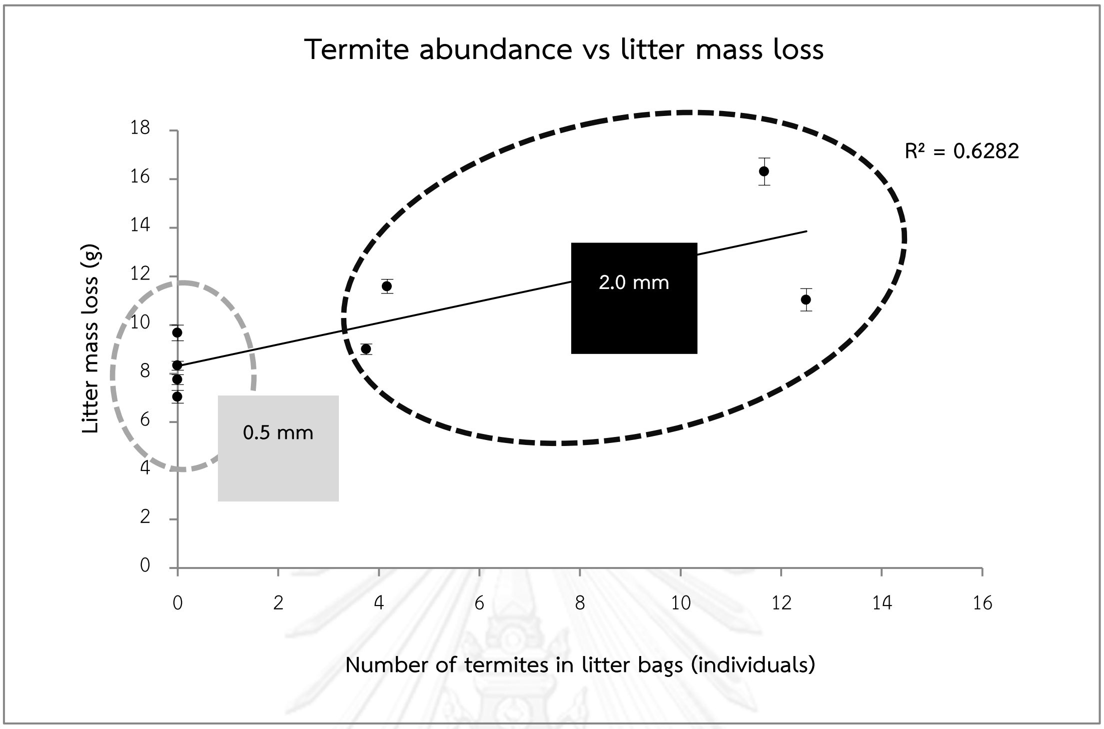

Figure 45 Comparison of termites in litter bags and litter mass loss in plots A1-A4 (December 2012-December 2013) at dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

4.4.3 Physical factors

Although temperature, rainfall and humidity were not different among the plots, seasonal variation was observed. The highest air temperature of 35.25˚C was observed in April 2013 and the lowest air temperature of 22.57˚C was recorded in January 2013. Additionally, the highest soil temperature was 31.6˚C in April 2013 and the lowest soil temperature was 20.8˚C in January 2013. During November 2012-December 2013, day-time air temperature ranged from 20 to 38℃ and soil temperature ranged from 20 to 33℃. Humidity ranged from 43 to76% (Figure 46).

The soil texture in all 4 plots was classified as loamy sand with the range of 70-90% sand, 8-15% silt, and 0-6% clay. The soil pH was 7-8 in all plots, except pH of 5-6 in April 2013 due to fire in A3 and A4 plots (Appendix D, Tables D-1, D-2, D-3, D-4).

Wet season and dry season in this study were determined based on the climate diagram plot between mean air temperature and total rainfall (Walter, Harnickell, and Mueller-Dombois, 1975). The seasons were designated as follows: dry season (January 2013-May 2013 and October-December 2013) with mean air temperature ranged from 22.6-35.3℃ and total rainfall ranged from 5.6-73.2 mm^3 and wet season (June-September 2013) with mean air temperature ranged from 27.9-33.8℃ and total rainfall ranged from 106.7-281.1 mm^3.

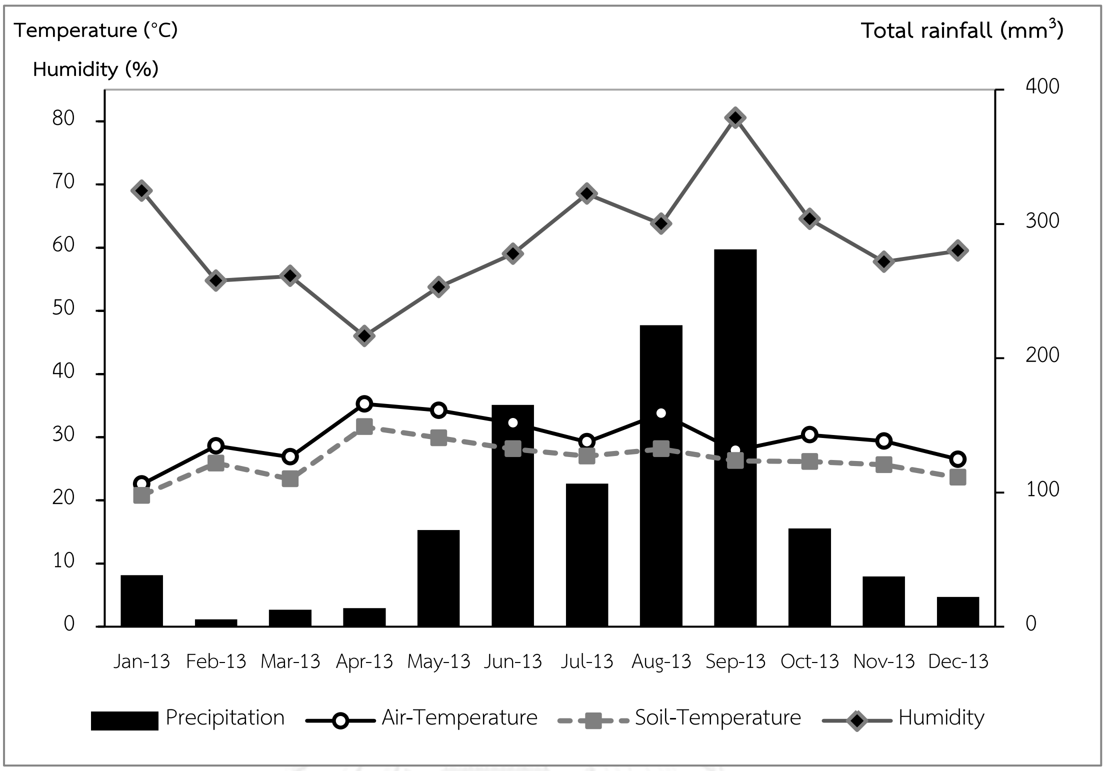

Figure 46 The January-December 2013 climograph at dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province, based on temperature and total rainfall

4.5 Relationship between biological factors, physical factors and leaf litter decomposition

Litter mass loss was positively correlated with humidity and mesh size while litter mass loss was negatively correlated with soil temperature, relative abundance of bark lice, air temperature, and relative abundance of mites, respectively. Relative abundance of termite was positively correlated with only mesh size. Among biological factors, relative abundance of bark lice, relative abundance of springtails and relative abundance of mites were negatively correlated with mesh size, because these fauna were found significantly in a large number in 0.5 mm mesh litter bags. For physical factors, air temperature, soil temperature and rainfall were positively correlated, while they were negatively correlated with both humidity and soil pH (Table 13).

Table 13 Pearson's Correlation

	Springtails	Bark lice	Beetles	Mites	Termites	Air-temp	Soil-temp	Humidity	Soil pH	Mass loss	Rainfall
Mesh size	-0.194**	-0.265***	-0.108	-0.052	0.122*	-0.013	-0.005	0.030	0.025	0.167**	0.035
Springtails		0.249***	0.329***	0.504***	-0.033	0.108	-0.019	0.172**	0.182*	-0.114	0.283***
Bark lice			-0.009	0.264***	0.011	0.220***	0.191**	-0.065	0.057	-0.198***	0.108
Beetles				-0.017	-0.031	0.029	-0.111	-0.03	-0.187**	0.101	0.108
Mites					0.003	0.006	-0.042	0.178**	0.193***	-0.124*	0.144*
Termites						-0.023	0.012	0.050	-0.003	0.074	0.043
Air-temp							0.825***	-0.572***	-0.37***	-0.179**	0.183**
Soil-temp								-0.393***	-0.376***	-0.226***	0.224***
Humidity									0.48***	0.211***	0.604***
Soil pH										-0.038	0.436***
Mass loss											0.032

Remark:

*	$p<0.05$
**	$p<0.01$
***	$p<0.001$

Multiple linear regression showed that mesh size, some biological factors such as relative abundance of termite, beetle and some physical factors, such as humidity and air temperature, had significant effects on the litter mass loss (F= 5.556, df=11, 261, p<0.001). Increasing mesh size, air temperature, relative abundance of termite, humidity, and relative abundance of beetle had positive effects on the litter mass loss while rainfall, relative abundance of bark louse, springtail, mite, soil-temperature, and soil pH had negative effects on the litter mass loss. The highest positive coefficient was observed in mesh size (1.368) while the highest negative coefficient was observed in soil temperature (1.185) and soil pH (1.278), respectively (Appendix E, Table E-1).

The multiple linear regression equation is as follows:

$$Y=9.298+\left(1.368*X_1\right)+\left(0.707*X_2\right)+\left(0.408*X_3\right)+\left(0.333*X_4\right)+\left(0.103*X_5\right)-\left(0.00381*X_6\right)$$
$$-\left(0.0994*X_7\right)-\left(0.111*X_8\right)-\left(0.146*X_9\right)-\left(1.185*X_{10}\right)-\left(1.278*X_{11}\right)$$

where:	Y	=	Litter mass loss
	X_1	=	Mesh size
	X_2	=	Air temperature
	X_3	=	Relative abundance of termite
	X_4	=	Humidity
	X_5	=	Relative abundance of beetle
	X_6	=	Rainfall
	X_7	=	Relative abundance of bark louse
	X_8	=	Relative abundance of springtail

X_9 = Relative abundance of mite

X_{10} = Soil temperature

X_{11} = Soil pH

CHAPTER V

DISCUSSIONS

Aboveground tree biomass and litter production

Leaf litter production was high in the late dry season, with the peak in March 2013, and low in the wet season (Figure 21). Sundarapandian and Swamy (1999) reported that the peak of litterfall occurred during the dry season (January-April 2013) in a deciduous forest in South India. The amount of litterfall increased in drier months, as in many other tropical forests (Muoghalu, Akanni, and Eretan, 1993; Rai and Proctor, 1986; Songwe, Fasehun, and Okali, 1988). This suggests that water deficit is a determinant of litterfall in many seasonal forests. Only a few studies have found peaks in both dry and wet seasons (Cornforth, 1970).

Although aboveground tree biomass and litter production were positively related, the plot with the highest plant biomass (A1) was different from the plot with the highest litter production (A2). It could be caused by the different size classes of tree circumference because the plot A2 had more sizable trees (DBH more than 10 cm) in than the plot A1, suggesting that the large trees produced higher litter production than small trees. Moreover, a number of small trees in this study was higher than large size trees, so the forest of this study was secondary or disturbed dry dipterocarp forest.

The average tree biomass was 81.4±13.5 tons/ha which was higher than 56.7 tons/ha measured in 2003 in the same study area (Pongchai Dumrongrojwatthana, 2004). Based on the average aboveground tree biomass annual increase of 4.2% in this study, the expected aboveground biomass over 10 years (2003-2013) from 56.7 tons/ha should be 85.6 tons/ha which is comparable to the measured aboveground biomass of 81.4 tons/ha. Therefore, the average annual increase of the forest in this study is approximately 4.2% with 1.24 tons/ha of accumulated carbon per year based on carbon stock from 50% of aboveground biomass (Heath and Smith, 2000).

The average leaf litter production was 7.9±0.9 tons/ha/yr whereas the recorded litterfall in other tropical forests elsewhere in Asia ranged from 3.4-12.0 tons/ha/yr (Lim, 1978; Rai and Proctor, 1986; Yamada, 1976). In Thailand, the annual litter production at dry diptercarp forest was found to be 4.664 tons/ha/yr (Siriwat Paowongsa, 1976). Only 70.3% of leaf litter was decomposed during the study period, so the annual leaf litter production in the dry dipterocarp forest could be accumulated from 2.1-2.6 tons/ha/yr, and the undecomposed leaf litter accumulated over years could be fuel for recurring bushfire common for dry dipterocarp forests.

Litter decomposition and factors influencing decomposition

The remaining litter in litter bags logarithmically decreased over the study period probably due to the diminishing size of litter. At the initial phase (0-3 months), the litter had a large size, and the rate of decomposition was slow because the breakdown process began with the leaching of dissolved nutrients from the leaves leaching of dissolved components. In the middle phase (4-9 months), the litter was changed to debris by soil fauna (macrofauna and mesofauna), and the small size of leaf litter induced a higher rate of decomposition than the initial phase. In the last phase (10-13 months), the litter was almost cleared by microbial decomposition (microfauna and microflora), and the leaf litter decomposition rate was highest at this stage (Cummins, 1974; Mathuriau and Chauvet, 2002).

There was no significant difference between the remaining in 0.5 mm mesh litter bags and 2.0 mm mesh litter bags at the initial phase and the middle phase but the litter mass loss of the 2.0 mm mesh litter bags was significantly higher than 0.5 mm mesh litter bags at the last phase. Thus, the soil fauna, particularly termites, may induce the breakdown of litter into small size at the middle phase, especially in 2.0 mm mesh size bags.

The litter mass loss of the 2.0 mm mesh litter bags was significantly higher than 0.5 mm mesh litter bags due to both physical factors, such as humidity and air temperature, and biological factors, such as mesofauna and macrofauna. Exclusion of macrofauna, such as termites, in 0.5 mm mesh litter bags significantly reduced the decomposition rate while mesofauna did not affect relatively the decomposition rate as much as termites did. More mesofauna were found in 0.5 mm mesh litter bags than in 2.0 mm mesh litter bags. Bradford et al. (2002) reported that decomposition in micromesh (100μm) litter bags, permitting entry of only microfauna, was significantly decreased by the effects of mesofauna and macrofauna comparing to mesomesh (2 mm) litter bags, permitting entry of only microfauna and mesofauna, and macromesh (4.7 mm) litter bags, permitting entry of microfauna, mesofauna, and macrofauna. Additionally, See and Koon (1985) also found that increased mesh size significantly increased decomposition through mesh and that the 2.0 mm mesh litter bags showed a higher decomposition rate than the 0.5 mm mesh litter bags in both hill dipterocarp forest and a pine plantation plots. Soil micro-arthopods were suspected to play a more important role in seraya leaf litter decomposition in the hill dipterocarp forest than in the pine plantation.

No significant differences were found in overall litter mass loss among plots in the litter bags. However, the litter mass loss and decomposition rate in the 2.0 mm mesh litter bags was different among 4 plots possibly due to the canopy cover in the study site. In addition, the different decomposition rate in 2.0 mm litter bags among plots might be influenced by increased exposure to light and rain under less-densed canopy. A less-densed canopy allows increased exposure to litght and rain, and therefore, the increase in temperature and moisture to litter bags, particularly in plots A3 and A4 than in plots A1 and A2. Kim, Sharik, and Jurgensen (1996) reported that leaf mass loss in the clearcut (no canopy cover) red oak treatment was significantly higher than in the uncut (high canopy cover) red oak treatment, due to a higher temperatures in the clearcut than in closed-canopy stands.

The leaf litter decomposition rate was higher in the wet season than the dry season, suggesting that the leaf litter decomposition was dominantly caused by rainfall or humidity. Moreover, the leaf litter decomposition rate in this study was lower than the other studies conducted in the dry dipterocarp forest with higher annual rainfall at Assam, India (Kumar et al., 2012) and Peninsular Malaysia (Yamashita and Takeda, 1998). This is possibly due to the inland nature of Nan in this study causing less than one-half annual rainfall of the other two studies. Thomas and Asakawa (1993) indicated that climate are responsible for the rates of decomposition during the forest distribution and the inclusion of rainfall data in the percentage of organic matter remaining. In addition, different species composition of leaf litter in litter bags test may possibly influence the decomposition rate. Kumar et al. (2012) used only leaves of *Dipterocarpus tuberculatus* in litter bags while this study used mixed leaves of dipterocarp species with 22% *D. tuberculatus* composition. The humidity and rainfall may increase the decomposition directly as well as possibly indirectly through the interactions with soil fauna.

The higher relative loss of litter biomass during the rainy season, compared to the dry season, might be due to physical factors, principally soil moisture content, temperature and evapotranspiration for the activity of decomposers (Facelli and Pickett, 1991). However, the interactions among physical factors may also increase the aboveground termite activity and consequently the role of termites in leaf litter decomposition. Moreover, the termites found in the litter bag represent only the snapshot of the total termite activities in leaf litter decomposition, suggesting that termites play an important role in leaf litter decomposition of dry dipterocarp forest.

Low precipitation in this study comparing to Malaysia (Yamashita and Takeda, 1998) and India (Kumar et al., 2012) might result in poor nutrients and higher lignin in litter which subsequently reduced decomposition rate. Several studies demonstrated that higher nitrogen content of leaf litter promoted fast decomposition rate (Couteaux, Bottner, and Berg, 1995; Melillo et al., 1982; Singh and Gupta, 1977). Tanner (1981) also stated that 27 to 96% of decomposition depends on the type of humus and contents of nutrients (N and P) in the leaves. Soil fauna may increase their abundance from higher nutrient content in leaf litter and promoted higher decomposition rate.

A variety of soil fauna were found in the litter bags, such as springtails, beetles, mites, bark lice, ants, lepidopterans larvae, spiders, pseudoscorpions, cockroaches, and termites. Springtails were the most prevalent soil fauna followed by larvae and adult beetles in 2.0 mm mesh size litter bags while the high abundance of springtails followed by bark lice were found in 0.5 mm mesh size litter bags. Two species of termites, *Odontotermes* sp. and *Coptotermes* sp., were found in the litter bags. Springtails, beetles and bark lice in 0.5 mm mesh size litter bags were significantly higher than in 2.0 mm mesh litter bags, that may be due to the litter bags of 0.5 mm mesh size have higher moisture than the litter bag of 2.0 mm mesh size. A study by Wachendorf et al. (1997) showed that the contribution of fauna to the decomposition process was studied at two field sites in an alder forest in Germany. The two sites differed in their moisture regime and nutrient status. Mass loss in litter bags was determined. The faunal biomass was greatest in the soil at the wet site. Leaching contributed to an 18% loss at the dry site and a 30% loss at the wet site, which supported the fact that the soil fauna was higher in moisture condition.

In Thailand, *Odontotermes* sp. was observed only in forest areas, while *Coptotermes* sp. was observed in both forest and urban areas (Sornnuwat et al., 1996). The results in this study showed that two species of termites, *Odontotermes* sp. and *Coptotermes* sp., were both found in the litter bags, meaning that both termites were foraging competitors to each other. *Coptotermes* spp. are regarded as the most important structural pests. Moreover, *Coptotermes* spp. may migrate from forest to urban area for foraging or remain in the area if the forest area was converted to urban area. Therefore, monitoring of *Coptotermes* spp. should be conducted and leaf litter can be used as bait.

The relative abundance of soil fauna was not significantly different among all plots. In addition, termites in the litter bags were not correlated with the litter mass loss. Although termites were found in a low number in litter bags, high termite foraging activities in the litter bag, particularly in litter bags of 2.0 mm, can accelerate the decomposition. Moreover, the termites found in the litter bag represent only the snapshot of the total termite activities in leaf litter decomposition. Coaton (1958) found that termite has a foraging distance, and some species build their nests entirely underground with a network of galleries leading aboveground and ending in many foraging holes (approximately 100-1000) scattered over territories of often more than 2,000 m.

In April 2013, fires burned through plots A3 and A4, the height of approximately 1 m reaching and clearing litter on the forest floor. The fires might be human-induced normally used for path clearance and a drive in hunting. Soil fauna were minimally affected from the fire because their populations recovered the following months. Soil fauna may take refuge in deeper soil, and particularly termites have underground nests. André, Noti, and Lebrun (1994) reported that the vertical distribution of collembolans and mites is roughly similar, at different soil depths. The density of collembolans varies from 1127 individuals dm^{-3} at 10 cm to 239 individuals dm^{-3} at 70 cm in tropical forest. Moreover, newly burned area may recruit soil fauna immigrating from the adjacent unburned area. Therefore, fires influences metapopulation dynamics of soil fauna. In other words, metapopulations of soil fauna are driven by habitat succession and disturbance, such as fires, (Parr and Chown, 2003; Wilcox, Cairns, and Possingham, 2006). In May 2013, fire did not affect to the number of soil fauna in litter bag. The soil fauna recovered nearly to the level before the fire because they were *r*-selection species. The population of *r*-selection species were reduced in unstable habitats, their survivorship pattern in which most of the individuals die within a short time but a few live much longer and the recovery of population could be rapidly (Parry, 1981). The result is consistent with the study by Springett (1976), which reported that the activity of microfauna was lessened in the burnt area even though the species diversity and the population densities were not affected. Certini (2005) showed that some effects of fires on biological properties of forest soil could decrease microbial biomass but the recovery of pre-fire level depended inevitably on soil moisture that caused plant re-colonization. In addition, the time of recovery could be predictable because it strictly depends upon soil moisture content after burning.

Mesh size, air temperature, termite, humidity, and beetle larvae had positive relation on the litter mass loss while rainfall, bark lice, springtail, mite, soil-temperature, and soil pH had inversed relation on the litter mass loss. Mesh size had the highest coefficient to litter decomposition. However, the effect of mesh size can be both from termites and some physical factors, such as rain and light. The small mesh size (0.5 mm) majorly excluded termites while the large mesh size (2.0 mm) completely allowed termites, suggesting that termite activity influences litter decomposition. In addition, some physical factors, such as rain, may affect litter decomposition through leaching process. (Moore et al. (1999)) used a multiple regression to analyze between the litter decomposition rate and the related factors, and found that mean annual temperature, mean annual precipitation and lignin:nitrogen ratio had positively affected 73% of the litter decomposition. Soil temperature and soil pH had significantly negative effects on the litter mass loss. This may be caused by the rise of soil temperature and soil pH during dry season, especially in plots with fire in April 2013.

CHAPTER VI

CONCLUSION AND RECOMMENDATIONS

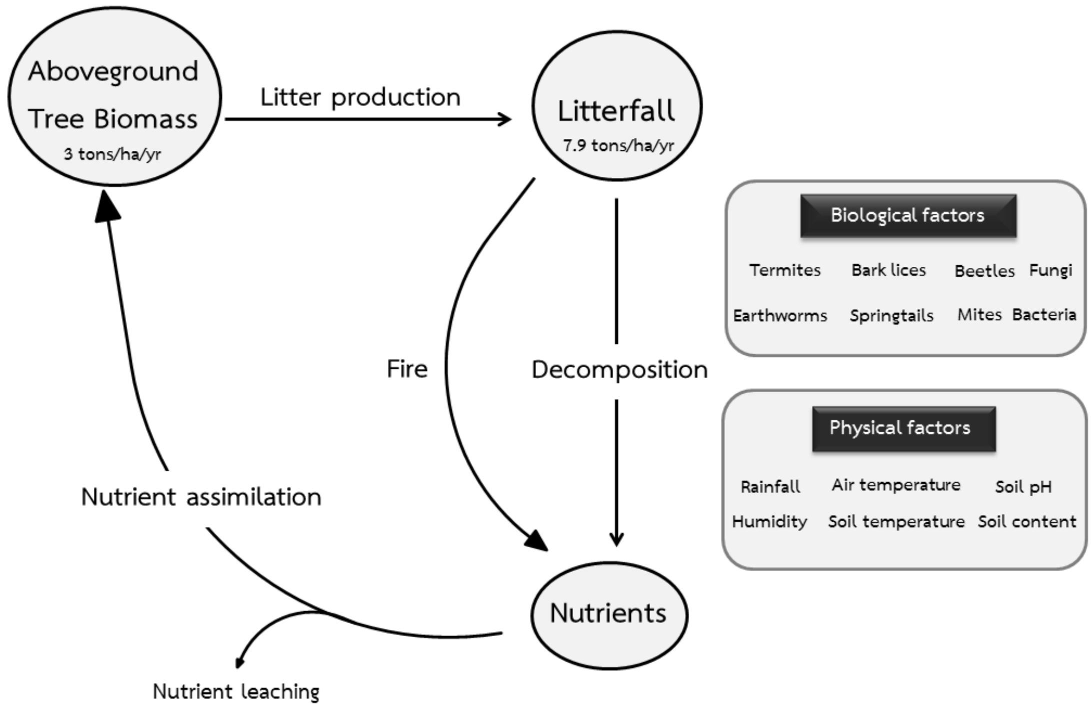

Figure 47 Conceptual framework of the study

Termites have an important role in the leaf litter decomposition in dry dipterocarp forest ecosystems, as shown in this research with no other macrofauna, such as earthworm, in forest with disturbance. Other soil fauna, such as springtails, mites, beetles and bark lice, have limited influence comparing to termites in the leaf litter decomposition in dry dipterocarp forest ecosystems. Earthworms were not found in the survey, but they could play an important role in litter decomposition in other forests because the mesh size used or type of soil were not suitable. Physical factors, such as humidity, air temperature, soil pH, and soil temperature importantly influenced litter decomposition in dry dipterocarp forest ecosystems, either directly or indirectly through soil fauna.

The termites found in the litter bags represented only the snapshot of the total termite activities in leaf litter decomposition. However, the interactions among physical factors may also increase the aboveground termite activity and consequently the termite's role in leaf litter decomposition. Termites have a large foraging distance. When the forest was destroyed by fire, termites may migrate to another location. Therefore, foraging distance of termite should be further determined. Moreover, termite mounds in natural forest should be protected, because termites play a rather important role on litter decomposition in forest as well as serve as food for several animals, such as amphibians, reptiles, and mammals.

The average aboveground tree biomass annual increase was 4.2% in the study area. The average leaf litter production was 7.9±0.9 tons/ha/yr. Only 70% of leaf litter production was decomposed during the study period. Therefore the remaining 30%, or 2.4 tons/ha/yr, could become fuel for bushfire in the dry dipterocarp forest. If people want to collect the leaf litter on forest floor to make a compost, they could harvest this amount for balancing and restoring the nutrient cycle. Different biomass values among plots may affect the canopy cover of each plot which may prevent the effects of rainfall and sunlight on litter decomposition. Therefore, the canopy cover of dry dipterocarp forest should be measured to determine the difference between plots.

Leaf litter management can help to prevent soil erosion because leaf litter on the forest floor may protect and prevent soil erosion from rainfall and wind. Therefore, leaf litter should be burned before the peak of litter production and to allow time for litter to accumulate on the forest floor.

The effects of fire on nutrient dynamics have been extensively investigated in both natural and plantation forests. Therefore, we should be conserving and managing the forest area to prevent fires (fire control area) by removing leaf litter from the network of tracks in the area. Moreover, fire does not always negatively impact the soil fauna. Therefore, limited controlled burning should be conducted and uncontrolled human-induced fires, such as path clearance and a drive in hunting, should be reduced to conserve nutrient cycling and ecological function.

As mentioned above, this research identified aboveground tree biomass accumulation, litter production, litter decomposition, and several physical and biological factors influencing litter decomposition which constitutes the nutrient cycling process in dry dipterocarp forest. Finally, this research on the role of termites in litter decomposition considerably elucidates the nutrient cycling process in dry dipterocarp forest.

REFERENCES

Abbott, I. 1989. The influence of fauna on soil structure. Animals in primary succession: the role of fauna in reclaimed lands 39-50.

André, H.M., Noti, M.-I., and Lebrun, P. 1994. The soil fauna: the other last biotic frontier. Biodiversity & Conservation 3: 45-56.

Barajas-Guzmán, G., and Alvarez-Sánchez, J. 2003. The relationships between litter fauna and rates of litter decomposition in a tropical rain forest. Applied Soil Ecology 24: 91-100.

Basuki, T., Van Laake, P., Skidmore, A., and Hussin, Y. 2009. Allometric equations for estimating the above-ground biomass in tropical lowland *Dipterocarp* forests. Forest Ecology and Management 257: 1684-1694.

Bignell, D. 2000. Termites in ecosystems. Termites: evolution, sociality, symbioses, ecology.

Bradford, M.A., Tordoff, G.M., Eggers, T., Jones, T.H., and Newington, J.E. 2002. Microbiota, fauna, and mesh size interactions in litter decomposition. Oikos 99: 317-323.

Brauman, A., Kane, M.D., Labat, M., and Breznak, J.A. 1992. Genesis of acetate and methane by gut bacteria of nutritionally diverse termites. Science(Washington) 257: 1384-1387.

Brune, A., and Friedrich, M. 2000. Microecology of the termite gut: structure and function on a microscale. Current opinion in microbiology 3: 263-269.

Bunyavejchewin, S. 1982. Canopy structure of the dry dipterocarp forest of Thailand. University of Washington.

Burt, R. 1992. Soil survey laboratory methods manual. USDA.

Cermak, R.W. 2005. Fire in the forest: a history of forest fire control on the National Forests in California, 1898-1956. Usda/Usda Forest Svc.

Certini, G. 2005. Effects of fire on properties of forest soils: a review. Oecologia 143: 1-10.

Chaiyo, U., Pizzo, Y., and Garivait, S. 2013. Estimation of Carbon Released from Dry Dipterocarp Forest Fires in Thailand. Analysis 65: 16845.

Change, I.P.O.C. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Institutefor Global Environmental Strategies, Hayama, Kanagawa, Japan.

Chompunut Songkhow. 2007. Comparison of forest restoration systems potential in Haen watershed of Nan province using soil properties and soil fauna. Master's

Thesis, Department of Environmental Science, Faculty of Science, Chulalongkorn University.

Coaton, W., and Sheasby, J. 1972. Preliminary report on a survey of the termites (Isoptera) of South West Africa. State Museum.

Coaton, W.G. 1958. The hodotermitid harvester termites of South Africa. Department of Agriculture, Union of South Africa.

Cornforth, I. 1970. Leaf-fall in a tropical rain forest. Journal of Applied Ecology 603-608.

Couteaux, M.-M., Bottner, P., and Berg, B. 1995. Litter decomposition, climate and liter quality. Trends in Ecology & Evolution 10: 63-66.

Cummins, K.W. 1974. Structure and function of stream ecosystems. BioScience 24: 631-641.

Davies, R.G. 1997. Termite species richness in fire-prone and fire-protected dry deciduous dipterocarp forest in Doi Suthep-Pui National Park, northern Thailand. Journal of Tropical Ecology 13: 153-160.

De Silva, P.M., Pathiratne, A., van Straalen, N.M., and van Gestel, C.A. 2010. Chlorpyrifos causes decreased organic matter decomposition by suppressing earthworm and termite communities in tropical soil. Environmental Pollution 158: 3041-3047.

De Souza, O.F.F., and Brown, V.K. 1994. Effects of habitat fragmentation on Amazonian termite communities. Journal of Tropical Ecology 197-206.

Desneux, J. 1904. A propos de la phylogénie des Termitides.

Desneux, J., and Wytsman, P.A.G. 1904. Isoptera. Fam. Termitidae. V. Verteneuil, L. Desmet.

Dickinson, C.H. 2012. Biology of plant litter decomposition. London and Newyork: Harcourt Brace Jovanovich, Publishers.

Dixon, R.K., Solomon, A., Brown, S., Houghton, R., Trexier, M., and Wisniewski, J. 1994. Carbon pools and flux of global forest ecosystems. Science 263: 185-190.

Donovan, S., Eggleton, P., and Bignell, D. 2001. Gut content analysis and a new feeding group classification of termites. Ecological Entomology 26: 356-366.

Donovan, S.E., Griffiths, G.J., Homathevi, R., and Winder, L. 2007. The spatial pattern of soil-dwelling termites in primary and logged forest in Sabah, Malaysia. Ecological Entomology 32: 1-10.

Eggleton, P., Homathevi, R., Jeeva, D., Jones, D.T., Davies, R.G., and Maryati, M. 1997. The species richness and composition of termites (Isoptera) in primary and regenerating lowland dipterocarp forest in Sabah, East Malaysia. Ecotropica 3: 119-128.

Eisenbeis, G. 2006. Intestinal Microorganisms of Termites and Other Invertebrates. Germany: Springer Berlin Heidelberg.

Engel, M.S., Grimaldi, D.A., and Krishna, K. 2009. Termites (Isoptera): their phylogeny, classification, and rise to ecological dominance. American Museum Novitates 1-27.

Evans, T. 2005. How Bait Design Affects Coptotermes Activity and Feeding in Baits. in Pacific Rim Termite Research Group, 2n Meeting, Bangkok. pp. 75-80.

Facelli, J.M., and Pickett, S.T. 1991. Plant litter: its dynamics and effects on plant community structure. The Botanical Review 57: 1-32.

FAO, I. 2006. Global forest resources assessment 2005: progress towards sustainable forest management.

Feller, C., and Beare, M. 1997. Physical control of soil organic matter dynamics in the tropics. Geoderma 79: 69-116.

Ferrar, P. 1982. Termites of a South African savanna. IV. Subterranean populations, mass determinations and biomass estimations. Oecologia 147-151.

French, J., Ahmed, B., and Ewart, D. 1995. Bait box technique for remedial subterranean termite control. Document-the International Research Group on Wood Preservation (Sweden).

Freymann, B.P., De Visser, S.N., and Olff, H. 2010. Spatial and temporal hotspots of termite-driven decomposition in the Serengeti. Ecography 33: 443-450.

Froggatt, W.W. 1897. Australian Termitidae.

Heath, L.S., and Smith, J.E. 2000. An assessment of uncertainty in forest carbon budget projections. Environmental Science & Policy 3: 73-82.

Höfer, H., et al. 2001. Structure and function of soil fauna communities in Amazonian anthropogenic and natural ecosystems. European Journal of Soil Biology 37: 229-235.

Holmgren, K., Holmgren, N.F., and Fletcher, T.B. 1917. Report on a collection of termites from India. Imperial department of agriculture.

Holmgren, N. 1910. Das system der termiten. Zoologischer Anzeiger 35: 284-286.

Holmgren, N. 1911. Termitenstudien, 2 et 3. Stockholm.

Jepsen, M.R. 2006. Above-ground carbon stocks in tropical fallows, Sarawak, Malaysia. Forest ecology and management 225: 287-295.

Jones, D.T., and Eggleton, P. 2000. Sampling termite assemblages in tropical forests: testing a rapid biodiversity assessment protocol. Journal of Applied Ecology 37: 191-203.

Jones, J., and Benton, J. 1999. Soil analysis handbook of reference methods. CRC Press.

Kim, C., Sharik, T.L., and Jurgensen, M.F. 1996. Canopy cover effects on mass loss, and nitrogen and phosphorus dynamics from decomposing litter in oak and pine stands in northern Lower Michigan. Forest Ecology and Management 80: 13-20.

Kimmins, J. 2004. Forest Ecology; A foundation for Sustainable Forest Management and Environmental Ethics in Forestry. Third Edition. Prentice Hall, New Jersey.

Krishna, K., and Grimaldi, D.A. 2003. The first Cretaceous Rhinotermitidae (Isoptera): a new species, genus, and subfamily in Burmese amber. American Museum Novitates 1-10.

Kumar, R., Tapwal, A., and Baruah, D.M. 2012. Leaf litter decomposition pattern in *Dipterocarpus tuberculatus* and *Dipterocarpus retusus* forests of North East India. Research Journal of Forestry 6: 1-8.

La Fage, J.P., Nutting, W.L., and Haverty, M.I. 1973. Desert subterranean termites: a method for studying foraging behavior. Environmental Entomology 2: 954-956.

Lasco, R., MacDicken, K., Pulhin, F.B., Guillermo, I., Sales, R.F., and Cruz, R. 2006. Carbon stocks assessment of a selectively logged dipterocarp forest and wood processing mill in the Philippines. Journal of Tropical Forest Science 18.

Latreille, P.A. 1802. 1802-1803. Histoire naturelle, générale et particulière, des crustacés et des insectes 3. Dufart: Paris 1-468.

Lavelle, P. 1984. The soil system in the humid tropics. Biology International (France).

Lavelle, P. 1996. Diversity of soil fauna and ecosystem function. Biology International 33: 3-16.

Lavelle, P., Blanchart, E., Martin, A., Spain, A.V., and Martin, S. 1992. Impact of Soil Fauna on the Properties of Soils in the Humid Tropics1. In R. Lal and P.A. Sanchez (ed.), Myths and Science of Soils of the Tropics, pp. 157-185. Soil Science Society of America and American Society of Agronomy.

Lavelle, P., and Spain, A.V. 2001. Soil ecology. Springer.

Lee, C., Vongkaluang, C., and Lenz, M. 2007. Challenges to subterranean termite management of multi-genera faunas in Southeast Asia and Australia. Sociobiology 50: 213-222.

Life after bugs. 2013. Termites. [Online]. Available from: http://www.lifeafterbugs.com/ic_termites.html [April 20, 2014]

Lim, M. 1978. Litterfall and mineral nutrient content of litter in Pasoh Forest Reserve. Malaysian Nature Journal 30: 375-380.

Mason, C.F. 1977. Decomposition. London: E. Arnold.

Mathuriau, C., and Chauvet, E. 2002. Breakdown of leaf litter in a neotropical stream. Journal of the North American Benthological Society 21: 384-396.

Meentemeyer, V., Box, E.O., and Thompson, R. 1982. World patterns and amounts of terrestrial plant litter production. BioScience 32: 125-128.

Meesuk, V., Boonya-aroonnet, S., Srimongkol, S., Chankarn, A., and Chitradon, R. 2011. Forest resources of Nan river basin. [Online]. Available from: http://www.haii.or.th/ [2013, December 12]

Melillo, J.M., Aber, J.D., and Muratore, J.F. 1982. Nitrogen and lignin control of hardwood leaf litter decomposition dynamics. Ecology 63: 621-626.

Moore, T., et al. 1999. Litter decomposition rates in Canadian forests. Global Change Biology 5: 75-82.

Muoghalu, J.I., Akanni, S.O., and Eretan, O.O. 1993. Litter fall and nutrient dynamics in a Nigerian rain forest seven years after a ground fire. Journal of vegetation Science 4: 323-328.

Nagy, L., and Macauley, B. 1982. *Eucalyptus* leaf-litter decomposition: Effects of relative humidity and substrate moisture content. Soil biology and biochemistry 14: 233-236.

Noble, J.C., Müller, W., Whitford, W., and Pfitzner, G. 2009. The significance of termites as decomposers in contrasting grassland communities of semi-arid eastern Australia. Journal of arid environments 73: 113-119.

Odum, E.P. 1983. Basic ecology. Saunders College Pub.

Ogawa, H., Yoda, K., Ogino, K., and Kira, T. 1965. Comparative ecological studies on three main types of forest vegetation in Thailand. II. Plant biomass. Nature and life in Southeast Asia 4: 49-80.

Olson, J.S. 1963. Energy storage and the balance of producers and decomposers in ecological systems. Ecology 44: 322-331.

Parr, C.L., and Chown, S.L. 2003. Burning issues for conservation: a critique of faunal fire research in Southern Africa. Austral Ecology 28: 384-395.

Parry, G.D. 1981. The meanings of r-and K-selection. Oecologia 48: 260-264.

Pongchai Dumrongrojwatthana. 2004. Impacts of forest disturbance on soil organic matter, soil nutrients and carbon sequestration in Nam Wa sub-watershad, Nan province. Master's Thesis, Department of Biology, Faculty of Science, Chulalongkorn University.

Rai, S., and Proctor, J. 1986. Ecological studies on four rainforests in Karnataka, India: II. Litterfall. The Journal of Ecology 455-463.

Sankaran, K. 1993. Decomposition of leaf litter of albizia (*Paraserianthes falcataria*), eucalypt (*Eucalyptus tereticornis*) and teak (*Tectona grandis*) in Kerala, India. Forest ecology and management 56: 225-242.

See, L.S., and Koon, Y.T. 1985. A comparative study of leaf litter decomposition rates in a hill forest and a forest plantation in Peninsular Malaysia. Pertanika 8: 373-379.

Senpaseuth Phouveth. 2009. The estimation of carbon storage in dry evergreen and dry dipterocarp forests in Sang Khom District, Nong Khai Province, Thailand. Master's Thesis, Tecnhology of environmental management, Mahidol University.

Singh, J., and Gupta, S. 1977. Plant decomposition and soil respiration in terrestrial ecosystems. The botanical review 43: 449-528.

Siriwat Paowongsa. 1976. Litterfall and mineral nutrient content of litter in dry dipterocarps forest. Master's Thesis, Department of biology, Faculty of Science, Kasetsart University.

Smitinand, T. 1969. The distribution of the Dipterocarpaceae in Thailand. National History Bulletin Siam Society 23: 67-75.

Smitinand, T. 1977. Plants of Khao Yai National Park. Friends of Khao Yai National Park Association.

Songwe, N.C., Fasehun, F., and Okali, D. 1988. Litterfall and productivity in a tropical rain forest, Southern Bakundu Forest Reserve, Cameroon. Journal of Tropical Ecology 4: 25-37.

Sornnuwat, Y. 1996. Studies on damage of constructions caused by subterranean termites and its control in Thailand. Wood research: bulletin of the Wood Research Institute Kyoto University 83: 59-139.

Sornnuwat, Y., Vongkaluang, C., Takahashi, M., Tsunoda, K., and Yoshimura, T. 1996. Survey and observation on damaged houses and causal termite species in Thailand. Jpn. Soc. Environ. Entomol. Zool 7: 191-200.

Sornnuwat, Y., Vongkaluang, C., and Takematsu, Y. 2004. A systematic key to termites of Thailand. Kasetsart Journal (Natural Science) 38: 349-368.

Springett, J.A. 1976. The effect of prescribed burning on the soil fauna and on litter decomposition in Western Australian forests. Australian Journal of Ecology 1: 77-82.

Stibig, H.J., Achard, F., and Fritz, S. 2004. A new forest cover map of continental southeast Asia derived from SPOT-VEGETATION satellite imagery. Applied Vegetation Science 7: 153-162.

Stott, P.A., Goldammer, J.G., and Werner, W. 1990. The role of fire in the tropical lowland deciduous forests of Asia. In (ed.), Fire in the tropical biota, pp. 32-44. Springer.

Su, N.-Y. 1994. Field evaluation of a hexaflumuron bait for population suppression of subterranean termites (Isoptera: Rhinotermitidae). Journal of Economic Entomology 87: 389-397.

Sundarapandian, S., and Swamy, P. 1999. Litter production and leaf-litter decomposition of selected tree species in tropical forests at Kodayar in the Western Ghats, India. Forest Ecology and Management 123: 231-244.

Supparat Samran. 2005. Effect of forest fire on change in above ground biomass in the Maeklong mixed deciduous forest, Kanchanaburi province, Thailand. in Climate Change in Forest: The Potential of Forest in Support of the Kyoto Protocol. pp. 351-362. Maruay Garden Hotel.

Surasak Ratree. 2003. The reproductive ecology of trees in dry dipterocarp forest at Nong Rawiang, Nakhon Ratchasima. Doctoral dissertation, Environmental Biology, Suranaree University of Technology.

Swift, M.J., Heal, O.W., and Anderson, J.M. 1979. Decomposition in terrestrial ecosystems. Univ of California Press.

Systat Software. 2008. SigmaPlot_11_1_0_Patch.msp. Systat Software, Inc.

Takeda, H. 1988. 5 year study of pine needle litter decomposition in relation to mass loss and faunal abundances. Pedobiologia.

Takeda, H. 1995. A 5 year study of litter decomposition processes in a *Chamaecyparis obtusa* Endl. forest. Ecological Research 10: 95-104.

Tanner, E. 1981. The decomposition of leaf litter in Jamaican montane rain forests. The Journal of Ecology 263-275.

Terakunpisut, J., Gajaseni, N., and Ruankawe, N. 2007. Carbon sequestration potential in aboveground biomass of thong pha phum national forest, Thailand. Applied ecology and environmental research 5: 93-102.

Thai Meteorological Department. 2014. Nan, Current Weather. [Online]. Available from: http://www.tmd.go.th/ [2014, March 11]

Thomas, R., and Asakawa, N. 1993. Decomposition of leaf litter from tropical forage grasses and legumes. Soil Biology and Biochemistry 25: 1351-1361.

Wachendorf, C., Irmler, U., Blume, H., Cadisch, G., and Giller, K. 1997. Relationships between litter fauna and chemical changes of litter during decomposition under different moisture conditions. UK: CAB INTERNATIONAL.

Walter, H., Harnickell, E., and Mueller-Dombois, D. 1975. Climate-diagram maps of the individual continents and the ecological climatic regions of the earth.

Warin Boonriam. 2010. Microbial congribution to the carbon mineralization and decomposition rate of litter on the forest floor in dry evergreen forest at Sakaerat Environmental Research Station. Master's Thesis, Department of Enviromental biology, Faculty of Science, Suranaree University of Technology.

Weatherspark. 2014. Average Weather For Nan, Thailand. [Online]. Available from: http://weatherspark.com/averages/33960/Nan-Thailand [2014, March 11]

Webb, W.L., Lauenroth, W.K., Szarek, S.R., and Kinerson, R.S. 1983. Primary production and abiotic controls in forests, grasslands, and desert ecosystems in the United States. Ecology 64: 134-151.

Wider, R.K., and Lang, G.E. 1982. A critique of the analytical methods used in examining decomposition data obtained from litter bags. Ecology 1636-1642.

Wikimedia Foundation. 2014. Nan, Thailand. [Online]. Available from: http://en.wikipedia.org/wiki/Nan,_Thailand [11 March 2014]

Wilcox, C., Cairns, B.J., and Possingham, H.P. 2006. The role of habitat disturbance and recovery in metapopulation persistence. Ecology 87: 855-863.

Witkamp, M. 1966. Decomposition of leaf litter in relation to environment, microflora, and microbial respiration. Ecology 194-201.

Wong, W.M. 1991. Rainfall interception in a tropical lowland dipterocarp forest. University of Manchester.

Yamada, A., et al. 2005. Carbon mineralization by termites in tropical forests, with emphasis on fungus combs. Ecological Research 20: 453-460.

Yamada, A., Wawatwitaya, D., and Inoue, T. 2005. Ecosystem-scale studies on the role of termites in decomposition processes of a dry evergreen forest, Northeast Thailand. in The Second Conference of Pacific Rim Termite Research Group Bangkok, Thailand. pp. 27-32.

Yamada, I. 1976. Forest Ecological Studies of the Montane Forest of Mt. Pangrango, West Java.

Yamashita, T., and Takeda, H. 1998. Decomposition and nutrient dynamics of leaf litter in litter bags of two mesh sizes set in two dipterocarp forest sites in Peninsular Malaysia. Pedobiologia 42: 11-21.

Zeidler, J., Hanrahan, S., and Scholes, M. 2004. Determining termite diversity in arid Namibian rangelands–a comparison of sampling methods. African Zoology 39: 285-292.

APPENDICES

Appendix A

Table A-1 Two way ANOVA to compare the aboveground biomass between plots

Source of Variation	DF	SS	MS	F	P
Area	3	295160.7	98386.92	9.23	<0.001
Biomass (Pre/Post)	2	4330.872	2165.436	0.203	0.816
Residual	2609	27810967	10659.63		
Total	2614	28106646	10752.35		

Table A-2 Frequency of tree class size in all plots A1-A4 at dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

DBH	Area							
	A1		A2		A3		A4	
	Frequency	Relative frequency (%)	Frequency	Relative frequency (%)	Frequency	Relative frequency (%)	Frequency	Relative frequency (%)
5	16	3.46	7	2.30	21	4.53	13	5.63
10	243	52.48	157	51.64	299	64.44	130	56.28
15	129	27.86	80	26.32	99	21.34	45	19.48
20	47	10.15	36	11.84	32	6.90	17	7.36
25	18	3.89	15	4.93	9	1.94	15	6.49
30	5	1.08	4	1.32	3	0.65	6	2.60
35	1	0.22	1	0.33	0	0.00	4	1.73
40	2	0.43	1	0.33	1	0.22	1	0.43
45	0	0.00	2	0.66	0	0.00	0	0.00
50	0	0.00	0	0.00	0	0.00	0	0.00
55	0	0.00	1	0.33	0	0.00	0	0.00
60	0	0.00	0	0.00	0	0.00	0	0.00
65	1	0.22	0	0.00	0	0.00	0	0.00
70	0	0.00	0	0.00	0	0.00	0	0.00
75	0	0.00	0	0.00	0	0.00	0	0.00
80	1	0.22	0	0.00	0	0.00	0	0.00
Total	463		304		464		231	

Table A-3 Two way ANOVA of litter production compared between plots

Source of Variation	DF	SS	MS	F	P
Area	3	90.916	30.305	3.152	0.073
Month	12	2979.842	248.32	25.824	<0.001
Residual	36	346.175	9.616		
Total	51	3416.933	66.999		

Appendix B

Table B-1 Two way ANOVA to compare the litter mass loss between the litter bag mesh size 0.5 mm and 2.0 mm

Source of Variation	DF	SS	MS	F	P
Mesh size	1	333.31	333.31	4.85	0.03
Area (plot)	3	231.63	77.21	1.123	0.344
Mesh size x Area	3	78.067	26.022	0.379	0.769
Residual	96	6598.069	68.73		
Total	103	7241.076	70.302		

Table B-2 Two way ANOVA of litter bag mesh size 2.0 mm compared between plots

Source of Variation	DF	SS	MS	F	P
Area	3	41.867	13.956	1.405	0.257
Months	12	2323.054	193.588	19.486	<0.001
Residual	36	357.647	9.935		
Total	51	2722.568	53.384		

Table B-3 Two way ANOVA of litter bag mesh size 2.0 mm compared between plots

Source of Variation	DF	SS	MS	F	P
Area	3	267.83	89.277	6.358	0.001
Months	12	3411.876	284.323	20.249	<0.001
Residual	36	505.492	14.041		
Total	51	4185.198	82.063		

Appendix C

Table C-1 Relative abundance of springtails in 0.5 mm and 2.0 mm mesh litter bags extracted by Berlese-Tullgren funnel from plots A1-A4 from January-December 2013

Mesh size	Months											
	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13
0.5 mm	6.88	8.64	2.08	0.00	0.83	9.17	15.42	16.67	12.71	15.63	3.33	0.63
2.0 mm	3.33	3.33	1.25	0.00	1.04	4.38	8.13	11.88	5.00	1.88	0.83	0.21

Table C-2 Relative abundance of larvae and adult beetles in 0.5 mm and 2.0 mm mesh litter bags extracted by Berlese-Tullgren funnel from plots A1-A4 from January-December 2013

Mesh size	Months											
	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13
0.5 mm	3.13	4.38	3.33	0.21	2.08	1.25	1.04	3.75	1.67	18.33	6.88	2.08
2.0 mm	1.46	2.08	1.67	0.00	1.04	0.63	0.63	2.29	0.63	10.83	5.21	2.29

Table C-3 Relative abundance of bark lice in 0.5 mm and 2.0 mm mesh litter bags extracted by Berlese-Tullgren funnel from plots A1-A4 from January-December 2013

Mesh size	Months											
	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13
0.5 mm	0.42	1.46	1.25	5.21	7.08	10.42	10.00	7.29	0.63	1.67	0.00	0.63
2.0 mm	1.25	0.83	1.25	0.83	2.71	0.63	1.67	0.83	0.63	0.00	0.00	0.21

Table C-4 Relative abundance of mites in 0.5 mm and 2.0 mm mesh litter bags extracted by Berlese-Tullgren funnel from plots A1-A4 from January-December 2013

Mesh size	Months											
	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13
0.5 mm	4.38	2.08	0.42	0.42	1.25	2.29	12.08	3.75	2.92	0.63	1.04	0.63
2.0 mm	2.71	0.83	0.21	0.21	1.46	2.50	8.33	3.75	1.25	0.21	1.25	1.04

Table C-5 Percentage of termite infestation in the baiting stations (n = 8 per plot) surrounding litter bags in plots A1-A4 (December 2012-December 2013)

	Month													Avg	Sd
	Dec-12	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13		
A1	12.5	12.5	12.5	25	25	25	37.5	50	25	62.5	62.5	75	50	36.54	21.32
A2	100	50	87.5	100	100	87.5	87.5	100	100	87.5	100	100	100	92.31	14.01
A3	37.5	12.5	25	37.5	25	25	12.5	0	0	50	75	100	100	38.46	34.03
A4	25	12.5	37.5	37.5	25	25	12.5	12.5	0	12.5	25	100	100	32.69	31.68

Appendix D

Table D-1 Air temperature (℃) in plots A1-A4 (November 2012-December 2013) at dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

Area	Months													
	Nov-12	Dec-12	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13
A1	28.6	24.7	25.5	32.5	32.5	37.5	37	36.5	28.5	37	28	31	29	28
A2	31.2	25.2	24	29.5	28.5	36.5	35	33	30	32	28	31	29.5	26
A3	33.3	22.8	20.2	26.5	22.5	31.5	32	29	28.5	32	27	29.5	30	27
A4	32	24.8	20.6	26	24	35.5	33	30.5	30	34	28.5	30	29	25

Table D-2 Soil temperature (°C) in plots A1-A4 (November 2012-December 2013) at dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

Area	Months													
	Nov-12	Dec-12	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13
A1	26.6	23.8	21.5	26	24	30	29	28	26.5	28.5	26	25.5	25	24
A2	27.3	24.5	21	26.5	23.5	32.5	28.5	28	26.5	27	26	26	24	23.5
A3	31.3	23.8	20	25.5	22.5	30	31	27	27	28	26	26.5	27.5	23.5
A4	28	24.7	20.6	25.5	23.5	34	31	29.5	28	29	27	26.5	26	23.5

Table D-3 Humidity (%) in plots A1-A4 (November 2012-December 2013) at dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

Area	Months													
	Nov-12	Dec-12	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13
A1	82	78	60	47	47	43	49	50	70	61	80	61	57	57
A2	83	77	65	54	47	44	55	62	69	69	85	61	58	61
A3	69	68	75	58	65	55	56	63	68	67	77	68	58	61
A4	76	69	76	60	63	42	55	61	67	58	80	68	58	59

Table D-4 Soil pH in plots A1-A4 (November 2012-December 2013) at dry dipterocarp forest, Lainan Subdistrict, Wiang Sa District, Nan Province

Area	Months													
	Nov-12	Dec-12	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13
A1	7	7	7.5	7.5	7.5	5	5	8	8	8	8	8	8	8
A2	7	7	7.5	7.5	7.5	5	8	8	8	8	8	8	8	8
A3	7	7	7.5	7.5	7.5	6	6	8	8	8	8	8	8	8
A4	7	7	7.5	7.5	7.5	6	6	8	8	8	8	8	8	8

Appendix E

Table E-1 Multiple linear regression

	Coefficient	Std. Error	t	P	VIF
Constant	9.298	20.216	0.46	0.646	
Mesh size	1.368	0.723	1.893	0.059	1.14
Air-temperature	0.707	0.376	1.882	0.061	9.452
Termites	0.408	0.263	1.553	0.122	1.06
Humidity	0.333	0.15	2.216	0.028	8.227
Beetles	0.103	0.0723	1.429	0.154	1.386
Rainfall	-0.00381	0.0156	-0.245	0.807	6.882
Bark lice	-0.0994	0.101	-0.983	0.327	1.275
Springtails	-0.111	0.0615	-1.812	0.071	1.865
Mites	-0.146	0.123	-1.192	0.234	1.557
Soil-temperature	-1.185	0.336	-3.522	<0.001	3.941
Soil pH	-1.278	0.768	-1.664	0.097	2.254

VITA

Miss Patthamas Yasang, was born on March 27, 1987, in Nan Province, Thailand. In 2008, she graduated with a Bachelor’s degree from the Department of Biology, Faculty of Science, Mahidol University. Then she obtained her Master of Science in Zoology from the Department of Biology, Faculty of Science, Chulalongkorn University in 2014.