SPECIES DIVERSITY OF MILLIPEDES IN SAKAERAT ENVIRONMENTAL RESEARCH STATION AND FOOD CONSUMPTION OF A CYLINDRICAL MILLIPEDE (*Thyropygus cuisinieri* Carl, 1917) IN CAPTIVITY

Sirirut Sukteeka

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Environmental Biology

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ความหลากชนิดของกิ้งกือในสถานีวิจัยสิ่งแวดล้อมสะแกราช และการบริโภคอาหารของกิ้งกือกระบอกหางแหลมอิสาน (*Thyropygus cuisinieri* Carl, 1917) ในบริเวณกักกัน

นางสาวสิริรัตน์ สุขฑีฆะ

มหาวิทยาลัยเทคโนโลยีสุรนารี

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต
สาขาวิชาชีววิทยาสิ่งแวดล้อม
มหาวิทยาลัยเทคโนโลยีสุรนารี
ปีการศึกษา 2555

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Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy.

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สิริรัตน์ สุขฑีมะ : ความหลากชนิดของกิ้งกือในสถานีวิจัยสิ่งแวดล้อมสะแกราช และการบริโภคอาหารของกิ้งกือกระบอกหางแหลมอิสาน (*Thyropygus cuisinieri* Carl, 1917) ในบริเวณกักกัน (SPECIES DIVERSITY OF MILLIPEDES IN SAKAERAT ENVIRONMENTAL RESEARCH STATION AND FOOD CONSUMPTION OF A CYLINDRICAL MILLIPEDE (*Thyropygus cuisinieri* Carl, 1917) IN CAPTIVITY) อาจารย์ที่ปรึกษา : ผู้ช่วยศาสตราจารย์ ดร.ณัฐวุฒิ ธานี, 164 หน้า.

ความหลากชนิดของกิ้งกือและความสัมพันธ์กับปัจจัยสิ่งแวดล้อมในสถานีวิจัยสิ่งแวดล้อมสะแกราช จังหวัดนครราชสีมา ทำการศึกษาในระบบนิเวศป่า 4 ชนิด ได้แก่ ป่าดิบแล้ง ป่าเต็งรัง แนวรอยต่อระหว่างป่าดิบแล้งและป่าเต็งรัง และป่าปลูก ในแปลงตัวอย่างป่าละ 20X20 ตารางเมตร ระหว่างเดือนมิถุนายน 2553 ถึง พฤษภาคม 2554 นอกจากนี้ยังศึกษาการกินอาหารของกิ้งกือกระบอกหางแหลมอิสาน (*Thyropygus cuisinieri* Carl, 1917) ในห้องปฏิบัติการ ผลการศึกษาพบว่า กิ้งกือ 17 ชนิด ใน 5 วงศ์ ที่พบในป่า 4 ชนิด ได้แก่ วงศ์ Zephroniidae (*Zephronia siamensis)*, Paradoxosomatidae (*Orthomorpha variegate*, *Orthomorpha* sp., *Antheromorpha festiva*, *Antheromorpha* sp. และ *Anoplodesmus* sp.) Pachybolidae (Pachybolidae1, Pachybolidae2, *Lithostrophus segregates*), Harpagophoridae (*Harpagophoridae*1, Harpagophoridae2, *Thyropygus* sp.1, *Thyropygus allevatus*, *Thyropygus induratus*, *Thyropygus* sp.2, และ *Anurostreptus sculptus*) และ Julidae (*Nepalmatoiulus* sp.) ความชุกชุมของกิ้งกือสูงที่สุด (14.41 ตัว/ตารางเมตร) ในเดือนมิถุนายน 2553 ความหนาแน่นของกิ้งกือสูงที่สุดในป่าดิบแล้ง (329 ตัว/ตารางเมตร) และต่ำที่สุดในป่าเต็งรัง (138 ตัว/ตารางเมตร) ความหลากชนิด (2.29) และความมากชนิดของกิ้งกือ (15) สูงสุด ในป่าดิบแล้ง ปัจจัยที่มีความสัมพันธ์กับความหนาแน่นของกิ้งกืออย่างมีนัยสำคัญ ได้แก่ ความชื้นของดิน ($p < 0.01$; $r = 0.970$) อุณหภูมิ ($p < 0.01$; $r = 0.887$) ฟอสฟอรัส ($p < 0.01$; $r = 0.265$) สารอินทรีย์ในดินประเภทคาร์บอน ($p < 0.01$; $r = 0.911$) และ อินทรีย์วัตถุในดิน ($p < 0.01$; $r = 0.911$) การศึกษากระบวนการกินอาหารของกิ้งกือกระบอกหางแหลมอิสาน เป็นเวลา 6 เดือน พบว่ากิ้งกือชนิดนี้กินเศษซากพืชเฉลี่ย 124.51±45.38 มิลลิกรัม/วัน/ตัว โดยอัตราการกิน (181.03±42.14มิลลิกรัม/วัน/ตัว) และอัตราการเจริญเติบโต (17.13±8.22 มิลลิกรัม/วัน/ตัว) สูงที่สุด ในเดือนที่สามของการทดลอง ในขณะที่อัตราการกินและอัตราการเจริญเติบโตต่ำที่สุดในเดือนสุดท้ายของการทดลอง ในการศึกษาทดลองพบว่าประสิทธิภาพการกินเศษซากพืช อยู่ระหว่าง 1.37±0.58-6.85±5.42% ประสิทธิภาพการเปลี่ยนอาหารเป็นชีวมวลมีค่า 0.96±0.31% และ ประสิทธิภาพการย่อยมีค่า 10.66±3.74% จากผลการศึกษาทดลองนี้สามารถสรุปได้ว่ากิ้งกือกระบอกหางแหลมอิสาน อาจทำ

หน้าที่สำคัญในการย่อยสลายเศษซากพืชในพื้นที่ภาคตะวันออกเฉียงเหนือ และอาจก่อให้เกิดการหมุนเวียนแร่ธาตุในระบบนิเวศ

มหาวิทยาลัยเทคโนโลยีสุรนารี

สาขาวิชาชีววิทยา

ปีการศึกษา 2555

ลายมือชื่อนักศึกษา__________

ลายมือชื่ออาจารย์ที่ปรึกษา__________

ลายมือชื่ออาจารย์ที่ปรึกษาร่วม__________

ลายมือชื่ออาจารย์ที่ปรึกษาร่วม__________

SIRIRUT SUKTEEKA : SPECIES DIVERSITY OF MILLIPEDES IN SAKAERAT ENVIRONMENTAL RESEARCH STATION AND FOOD CONSUMPTION OF A CYLINDRICAL MILLIPEDE (*Thyropygus cuisinieri* Carl, 1917) IN CAPTIVITY. THESIS ADVISOR : ASST. PROF. NATHAWUT THANEE, Ph.D. 164 PP.

MILLIPEDES/ SPECIES DIVERSITY/ SAKAERAT ENVIRONMENTAL STATION/ FOOD CONSUMPTION

The species diversity of millipedes and its relationship to environmental factors was studied in Sakaerat Environmental Research Station, Nakhon Ratchasima province. Millipedes were sampled from three 20 m x 20 m (400 m^2) permanent plots within each of four forest habitats, namely dry evergreen forest, dry dipterocarp forest, ecotone and plantation, between June 2010 and May 2011. In total, seventeen millipede species were found in five families: Zephroniidae (*Zephronia siamensis*); Paradoxosomatidae (*Orthomorpha variegate*, *Orthomorpha* sp., *Antheromorpha festiva*, *Antheromorpha* sp., *Anoplodesmus* sp.); Pachybolidae (Pachybolidae1, Pachybolidae2, *Lithostrophus segregates*); Harpagophoridae (Harpagophoridae1, Harpagophoridae2, *Thyropygus* sp.1, *Thyropygus allevatus*, *Thyropygus induratus*, *Thyropygus* sp.2, *Anurostreptus sculptus*); and Julidae (*Nepalmatoiulus* sp.). The maximum average number of adult millipedes per square meter across all forest types was 14.41 individuals and this occurred in June. The highest millipede density was found in dry evergreen forest (329 individuals/m^2) and the lowest millipede density was in dry dipterocarp forest (138 individuals/m^2). Both the highest index of diversity

(Shannon - Wiener index) was 2.29 and the highest species richness (15) were found in dry evergreen forest. Millipede densities was significantly correlated with soil moisture ($p < 0.01$; $r = 0.970$), air temperature ($p < 0.01$; $r = 0.887$), phosphorus ($p < 0.01$; $r = 0.265$), organic carbon ($p < 0.01$; $r = 0.911$) and organic matter ($p < 0.01$; $r = 0.911$). Cylindrical millipedes (*Thyropygus cuisinieri*) were kept in captivity and raised on leaf litter for six months between June and November 2011. These millipedes ate 124.51±45.38 g of leaf litter per individual per day. The highest consumption rate (181.03±42.14 mg/individual) and growth rate (17.13±8.22 mg/individual) occurred in the third month (August) while, the lowest consumption and growth rate both occurred in the sixth month (November). The efficiency of conversion of ingested food to biomass (ECI) on the leaf litter varied from 1.37±0.58-6.85±5.42%. Mean of the efficiency of conversion of digested food to biomass (ECD) was 0.96±0.31%. Furthermore, mean approximate digestibility (AD) was 10.66±3.74%. It can be concluded that this cylindrical millipede species has a high decomposition efficiency, plays an important role in leaf litter ingestion and assimilation in Northeast of Thailand, and has a highly significant effect on nutrient cycling that will be of importance to the maintenance of the ecological integrity of these forests.

School of Biology

Academic Year 2012

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Special thank is due to the Sakaerat Environmental Station (SERS) for the permission to use the study site. Thanks also to the Center for Scientific and Technological Equipment, Suranaree University of Technology for the laboratory facilities and scientific instruments. I would also like to express my special thank to Suranaree University of Technology for the supporting my study.

Special gratitude is expressed to my parents, my family, my friends, my seniors, my juniors, and other people who give me a supported power whenever I lose my own power.

Sirirut Sukteeka

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CHAPTER I

INTRODUCTION

1.1 The importance of problem

About 10,000 species of millipedes have been described (Ruppert et al., 2004). The animals have a long history on the earth over 400 million years. Their ecological importances are immense: the health and survival of various types of mostly tropical, since they are one of the prime biological decomposers of woods and leaf litters, especially in the tropics. Despite their importances, they are very poorly known and have long been neglected in all areas of biological research. Even basic identification of specimens is a challenge (Sierwald, 2007).

Thailand locates in the tropical region which encompasses diverse kinds of natural ecosystems. These natural habitats are homes to some of the world's richest and unique plants and animals, resulting in a high diversity of millipedes. However, the studies in biology and ecology dealing with millipedes in Thailand have been lagging behind due to the limited knowledge of their morphology, taxonomy and the role in ecosystems. Despite the impact of millipedes on litter fragmentation in tropical forests, there have been few studies dealing with factors determining their habitat preference in these ecosystems. This investigation provides information of millipedes on species diversity, abundance, distribution, food consumption and some ecological factors effecting millipede compositions.

Sakaerat Environmental Research Station (SERS) is one of the four UNESCO designated biosphere reserves of Thailand. Cylindrical millipedes of the genus *Thyropygus* are the dominant millipedes in the Northeast, Thailand. In addition, the consumption and utilization of leaf litter and food conversion efficiency of cylindrical millipedes should be investigated. Information from this study also increases knowledge and understanding of ecosystem changes, making it primary contribution to the work of people whose interests line in ecology, agriculture and other research fields in need of a coherent diversity and role of millipede species.

1.2 Research objectives

The aims of this thesis were therefore:

1.2.1 To investigate the species diversity and distributions of millipedes in 4 different forest types at Sakaerat Environmental Research Station.

1.2.2 To investigate the relationships between millipede species and environmental factors at Sakaerat Environmental Research Station.

1.2.3 To study the food consumption processes of cylindrical millipedes (*Thyropygus cuisinieri* Carl, 1917).

1.3 Research hypotheses

The diversity and distributions of millipede species vary in different forest types and the *Thyropygus cuisinieri* Carl, 1917 plays role as leaf litter decomposer.

1.4 Scope and limitations of the study

1.4.1 The millipedes were collected in Sakaerat Environmental Research Station once a month in June 2010- May 2011.

1.4.2 The species diversity and distributions of millipedes were studied in 4 forest types i.e., dry evergreen forest (DEF), dry dipterocarp forest (DDF), ecotone between dry evergreen forest and dry dipterocarp forest (ECO) and plantation forest (PTF).

1.4.3 The ecological factors affecting the millipedes were classified into three groups:

1.4.3.1 The soil properties: soil water content, pH, organic matter, total nitrogen, phosphorus, potassium and calcium.

1.4.3.2 The climatic factors: air temperature, relative humidity and light intensity.

1.4.3.3 The water content of leaf litter

1.4.4 The consumption processes of cylindrical millipedes were critically analyzed in the laboratory.

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1.5 Key words

Species diversity, Millipedes, Identification, Environmental factors, Sakaerat Environmental Research Station, Consumption rate.

1.5.1 Species diversity is the number of different species of living things living in an area. A species is a group of plants or animals that are similar and able to breed and produce viable offspring under natural conditions (Krebs, 1989).

1.5.2 Millipede is a common name referring to the diplosegments, Phylum Arthopod, Class Diplopoda (Hopkin and Read, 1992). Millipedes are diplopods that have two pairs of legs per segment. Each segment that has two pairs of legs is a result of two single segments fused together.

1.5.3 Identification is recognizing an unknown specimen with an already known taxon, and assigning a correct rank and position in an extant classification (Singh, 1999).

1.5.4 Environmental factors are the external elements and conditions which surround, influence, and affect the life and development of an organism or population (Park, 2001).

1.5.5 Sakaerat Environmental Research Station (see 2.10)

1.5.6 Consumption rate is the average quantity of a consumed during a given time interval, expressed in quantities by the most appropriate unit of measurement per applicable stated basis.

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CHAPTER II

LITERATURE REVIEW

Millipedes are classified in the Kingdom Animalia, Phylum Arthropoda, Class Diplopoda, with the most legs of any terrestrial animal. They are secretive, nocturnal detritivores that subsist on decaying vegetation. Negative phototactic, they avoid light and live beneath leaves, stone, bark and logs. Millipedes are common in soil and leaf litter and many are cave dwellers. They vary from 2 mm to almost 30 cm in length. The distribution is cosmopolitan but they are especially abundant in the tropics (Ruppert et al., 2004).

Millipedes are the major saprophagous macroarthropods in temperate and tropical ecosystems (Lawrence, 1984; Blower, 1985; Lawrence and Samways, 2003). Their abundance and diversity facilitate soil mineralization through mechanical fragmentation of plant litter and release of essential elements (Wallwork, 1976; Hopkin and Read, 1992; Dangereld and Milner, 1996). Even though only 10% of total decomposition of plant litter within an ecosystem takes place through millipedes, their feeding enhances microbial activities, resulting in breaking down of litter up to 90% (Anderson and Bignall, 1980).

2.1 Millipede classification

Enghoff (1984) and Ruppert et al. (2004) reported the classification of millipede superorders as follows:

Class Diplopoda

Superorder Penicillata

Order Polyxenida

Superorder Pentazonia

Order Glomeridesmida

Order Sphaerotheriida

Order Glomerida

Order Siphoniulida

Superorder Colobognatha

Order Platydesmida

Order Siphonophorida

Order Polyzoniida

Superorder Nematophora

Order Stemmiulida

Order Callipodida

Order Chordeumatida

Superorder Merochaeta

Order Polydesmida

Superorder Juliformia

Order Spirobolida

Order Spirostreptida

Order Julida

The important characteristics of the six superorders

Penicillata (bristly millipedes): They are very small (4 mm), distinctly bristly due to unique lateral and posterior tufts of serrate setae. Cuticle is uncalcified, soft, and flexible, unlike that of all other millipedes. Trichobothria are present on head. Repugnatorial glands, which are present in some members of all other higher diplopod taxa, are absent. Sperm transfer is indirect, with spermatophores left on a silk web.

Pentazonia (pill millipedes): They are unlike other millipedes; superficially look more like crustacean pill bugs, or wood lice. Legs are inconspicuous. Body is short, strongly convex dorsally. Capable of rolling the body into a sphere (like pill bugs), with vulnerable ventral parts tucked inside and protected by heavily sclerotized tergites on the outside. The resulting ball is invulnerable to most would-be predators. Last pair of male legs with enlarged telopods is used to hold the female's vulva during sperm transfer.

Colobognatha (sucking millipedes): They are slow-moving. Colobognaths are even more wormlike than the juliforms although at 3 to 50 mm long they are usually much smaller. Body is arched dorsally. Their legs are small, so that they can be mistaken for worms. Pointed head is narrower than body. Mouthparts are reduced, mandibles are stylets used for piercing and sucking. Food is assumed to be decayed and partially liquefied vegetation. Females and occasionally male protect the eggs by curling around them.

Nematophora: Body is cylindrical, may appear flattened if paranota are well developed. Three setae on the dorsal posterior margin of the telson ring are spinnerets.

They have a mandibular molar with a strong posterior cusp, unknown in other millipedes.

Merochaeta (flat-backed millipedes): They are common and widespread. Large lateral paranota create a depressed appearance. Three to 130 mm long. Most have 20 diplosegments.

Juliformia (worm millipedes): The most common and familiar millipedes. The body is cylindrical, smooth, shiny, often large, with elongate, wormlike bodies. The largest millipedes, with some reaching 30 cm in length. To facilitate movement through the substratum, the collum is enlarged and covers part of the head capsule and anterior trunk. Repugnatorial secretions contain benzoquinones that are unique in millipedes but common in other arthropods.

Diagnostic features of millipede orders are shown as fallow (Table 2.1).

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Table 2.1 Diagnostic features of millipede orders: body shape, length and paranota (Sierwald, 2007).

Superorder	Order	Body-shape	Dorsal groove	Paranota	Rings	Body length
Penicillata	Polyxenida	unique through the tufts of setae	absent	never	-	up to 4 mm
Pentazonia	Glomeridesmida	flat	absent	never	22	
	Sphaerotheriida	large,flat; tank-like	absent	never	13	up to 95 mm and 50 mm wide
	Glomerida	short,flat	absent	never	12 (may look like11)	2.5-20 mm
	Siphoniulida	nematode-like	absent	never	>30	less than 7 mm
Colobognatha	Platydesmida	flat	present	always	>30, up to 110	up to 60 mm
	Siphonophorida	long, worm-like and thin	absent	never	>30, up to 192	up to 36 mm
	Polyzoniida	leech-shaped; back domed or arched, belly-side flat	absent	never	>30	

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Table 2.1 (Continued)

Superorder	Order	Body-shape	Dorsal groove	Paranota	Rings	Body length
Nematophora	Stemmiulida	laterally compressed, higher than wide	present	-	>30	up to 50 mm
	Callipodida	round, with longitudinal ridges	present	never	>30	up to 100 mm
	Chordeumatida	short, body tapering to end, long legs	present	with or without	26-32, most with 30	4-25 mm
Merochaeta	Polydesmida	in dorsal view forms without paranota resemble meal-worm larvae	absent	with or without	19-21, most with 20	3-130 mm

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Table 2.1 (Continued)

Superorder	Order	Body-shape	Dorsal groove	Paranota	Rings	Body length
Juliformia	Spirobolida	snake-like	absent	never	>30	up to 200 mm
	Spirostreptida	snake-like	mainly absent, except in some Cambalidea	never	>30, up to 90	6-300 mm
	Julida	snake-like	absent	never	>30	10-120 mm

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Table 2.2 Diagnostic features of millipede orders: head, eyes and others (Sierwald, 2007).

Superorder	Order	Head	Eyes/ocelli	Diagnostic features	Body end/ other title	Modified anterior legs in males	Telopods Gonopods
Penicillata	Polyxenida	large, round	1-3 small ocelli	distinct setal tufts	-	-	neither
Pentazonia	Glomeridesmida	large, round	Absent	cerci at body end, female with large ovipositors	-	-	1 pair telopods
	Sphaerotheriida	large, round	large kidney-shape eyes with many ocelli	2 nd tergite large, 13 th ring large antennae short, thick; often with numerous sense cones	-	-	2 pair telopods

Table 2.2 (Continued)

Superorder	Order	Head	Eyes/ocelli	Diagnostic features	Body end/ other title	Modified anterior legs in males	Telopods Gonopods
Pentazonia	Glomerida	large, round	few ocelli in a row or blind	2 nd tergite large, long, slender antennae, articles 3 and 6 the longest	-	-	2 pair telopods
	Siphoniulida	small beak	absent	collum enlarged	spinnerets	-	L 8; L 9 normal walking leg
Colobognatha	Platydesmida	small triangular	absent	long horizontal paranota	-	-	L9 and L10 ;leg like
	Siphonophorida	small long beak	absent	worm-like appearance	-	-	L9 and L10; leg like

Table 2.2 (Continued)

Superorder	Order	Head	Eyes/ocelli	Diagnostic features	Body end/ other title	Modified anterior legs in males	Telopods Gonopods
Colobognatha	Polyzoniida	small cone-shape	few ocelli	collum enlarged, gnathochilarium undivided	-	-	L9and L10;leg like
Nematophora	Stemmiulida	large, round	2 large ocelli	some can jump	spinnerets	-	L8, L9 reduced
	Callipodida	large, round	mostly present	longitudinal ridges in most species	spinnerets	-	L8, L9 reduced
	Chordeumatida	large, round	mostly present	3+3 setal pattern on tergites; collum segment often slender, giving the appearance of a 'neck'	spinnerets	-	L8 and L9, L10 reduced in size in Chordeumatidea and Heterochor-deumatidea

Table 2.2 (Continued)

Superorder	Order	Head	Eyes/ocelli	Diagnostic features	Body end/ other title	Modified anterior legs in males	Telopods/ Gonopods
Merochaeta	Polydesmida	large, round	blind	rings lack any signs of sutures	-	-	L8, L 9 normal walking leg
Juliformia	Spirobolida	large, round	mostly present	labrum with suture	-	-	L8 and L9
	Spirostreptidas	large, round	mostly present	-	-	-	L8 and L9
	Julida	large, round	present	in fresh specimens often with fringe of setae around the posterior end of the body rings	-	1 st hook-like	L8 and L9

2.2 Morphology of millipedes

Millipedes consist of three main parts; head, body, and telson (Hopkin and Read, 1992).

The head bears the mouthparts and a number of sensory structures including the antennae, Tomosvary organs, and eyes (if present) (Figure 2.1). The head capsule is usually heavily calcified to facilitate burrowing between soil particles, fragments of leaf litter, or rotting wood.

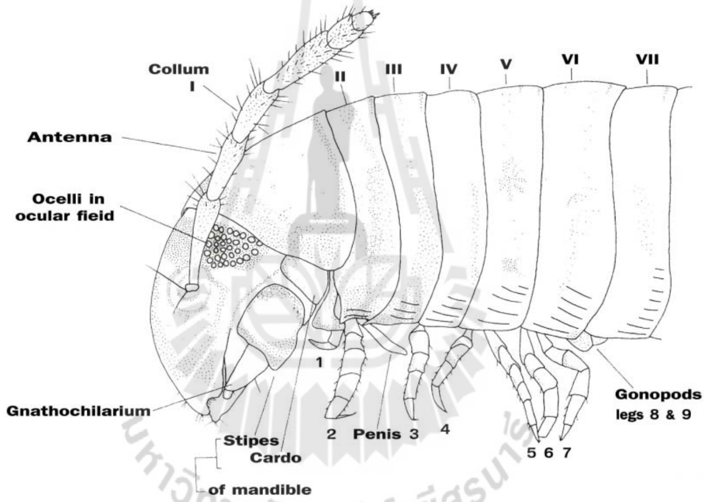


Figure 2.1 Head and anterior body segments of male *Cylindroiulus waldeni*. Scale bar= 0.1 mm (Hopkin and Read, 1992).

The body is generally long and cylindrical, although in some groups there are prominent lateral projections. The surface may be smooth or covered in hairlike projections, bumps, or spines.

Adult millipedes carry two pairs of legs on most body rings (Figure 2.2). The first body rings right after the head, the collum, is legless. The collum counts as the first body ring. The following three rings (body rings 2 through 4) carry one leg pair each. A juvenile millipede often has legless rings at the end of its body. It is very difficult to identify juvenile millipedes. Therefore, adult millipedes, those without or only a few legless rings at the end of their bodies were selected for further identification.

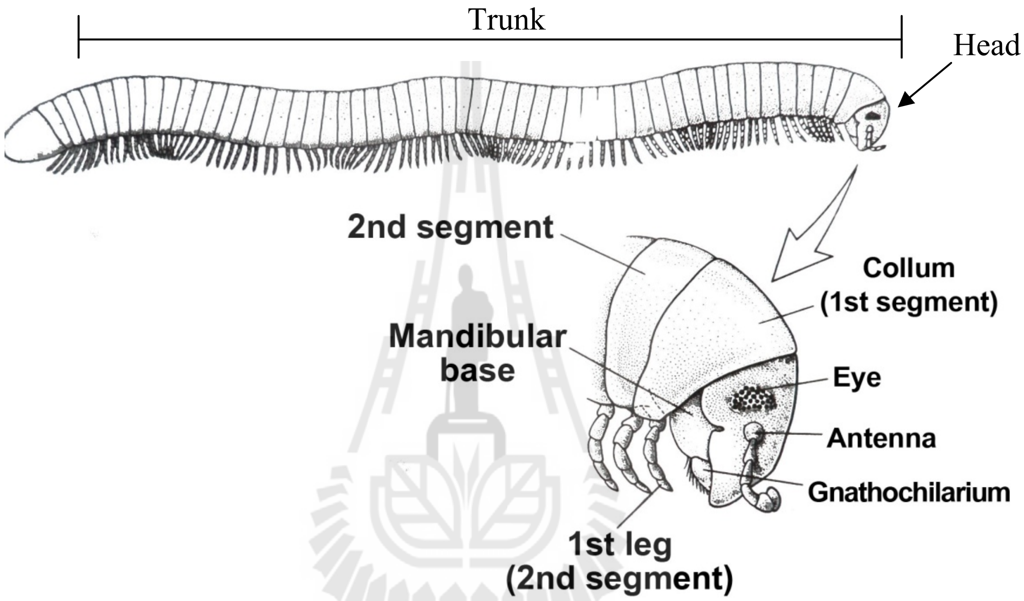


Figure 2.2 Morphology of a juliform millipede (Ruppert et al., 2004).

2.2.1 External morphology

Externally, the trunk consists of a series of segment like cuticular rings which are diplosegments, derived during development from fusion of two segments (Figure 2.3).

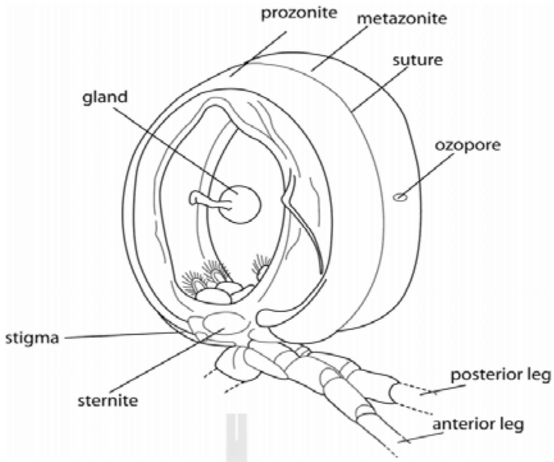


Figure 2.3 Structure of a body ring (diplosegment) (Demange, 1961).

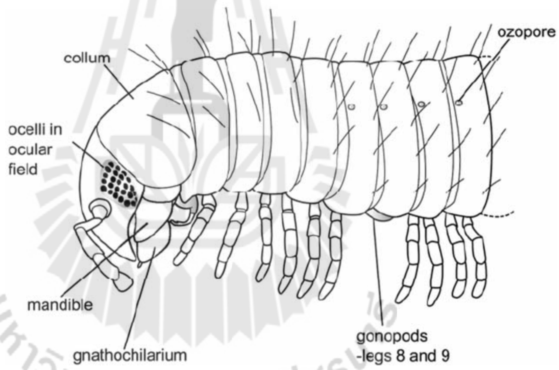


Figure 2.4 Body parts of a male millipede of the order Julida (Blower, 1985).

Eyes: Many millipedes have eyes at the side of the head. These consist of few to many individual ocelli grouped together in an ocular field (Figure 2.4). Some millipedes, like the order Polydesmida, never have ocelli. This character is used in the key several times. Caveliving millipedes of many orders have lost their eyes, while their above-ground living cousins have well-developed eyes.

Mouthparts: Millipedes have only two sets of mouthparts, the mandibles used for chewing and a plate behind them, the gnathochilarium (Figure 2.5). For identification of the certain order of millipedes, it is important to look at the underside of the gnathochilarium. The millipede showed be part on its back, legs up, and search for the first pair of legs.

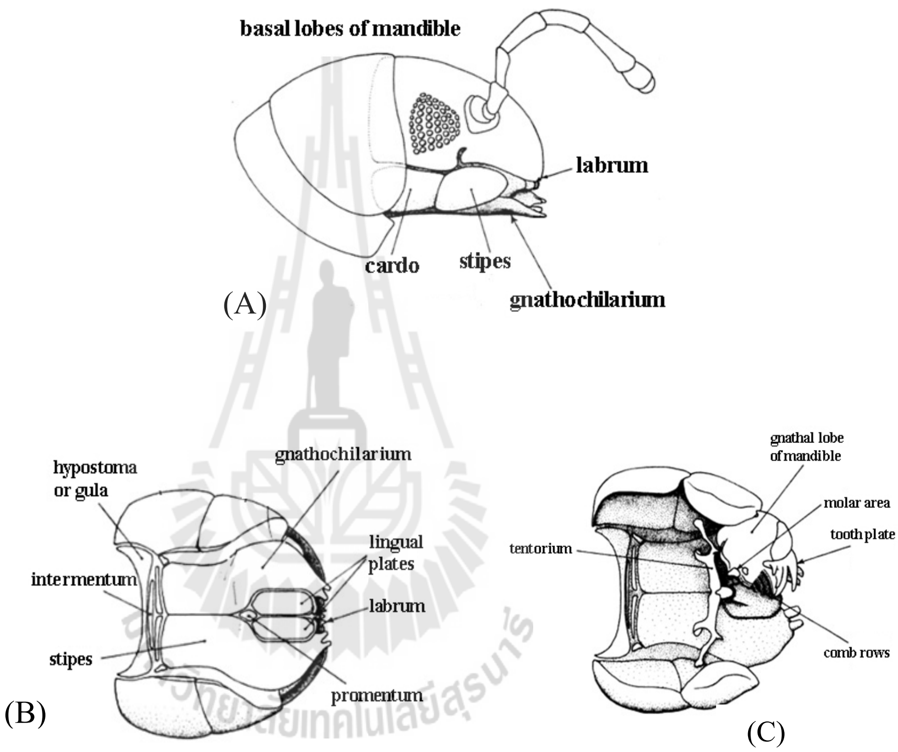


Figure 2.5 Mouth part of millipede (Blower, 1985).

(A) Lateral view (B) Ventral view (C) Dorsal view

Tomosvary organ: This is a sense organ located on the head of many millipedes. It forms a raised ring, a horse-shoe, or may be only a small pore. It is found behind the antenna sockets. Not all millipede orders have this organ.

Ozopores: In many orders, some trunk segments carry ozopores, the openings of the stink glands. These may be very obvious or hard to see. In most groups that have them, they occur along both sides of the trunk, starting at the 6th ring. In a few groups the pores are located along the dorsal midline (Figure 2.6).

Paranota: The back of each ring of the millipede is covered with a hard plate termed a tergite. Lateral extensions of the tergites are called paranota (Figure 2.6).

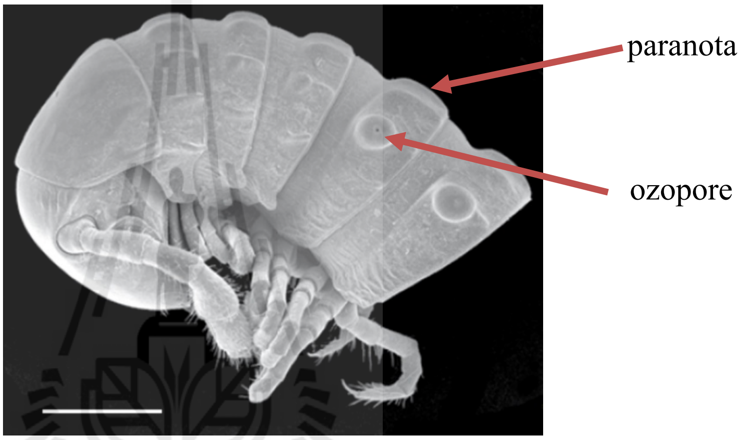
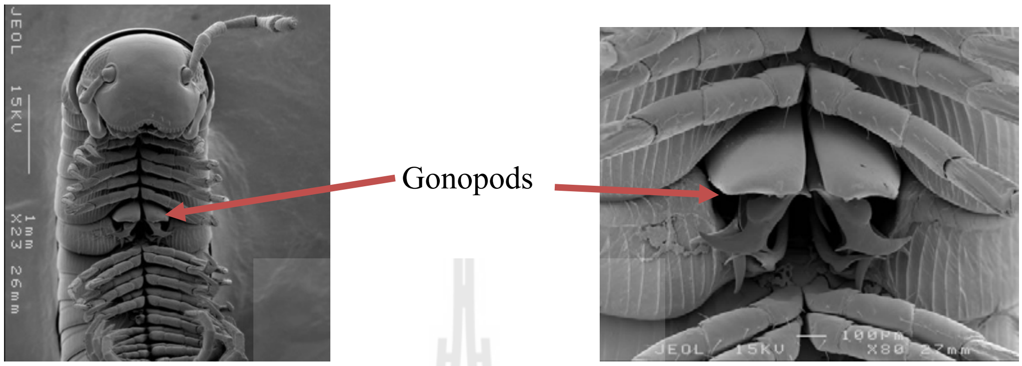


Figure 2.6 Anterior part of body, lateral view (Golovatch et al., 2007).

Telopods/Gonopods: Adult millipedes of many groups have distinct sexual organs, which can be easily seen with a dissecting microscope. These sexual organs occur in both sexes, but are most obvious in males. Modified legs occur in males in two body areas, either around the 7th body ring or at the end of the body, comprising the two last pairs of legs. The latter are called telopods. The modified legs on the 7th ring are sometimes withdrawn into a pouch in the body. In such groups the adult male appears to lack legs on the 7th ring. The modified legs of the 7th ring are called gonopods (Figure 2.7) and are very important in making species identifications.

Females have sex organs, sometimes called cyphopods, found just behind the second pair of legs. The female organs are rarely used for identification.



(A) (B)

Figure 2.7 Gonopod part of millipede.

(A) The male gonopods on the body ring

(B) Gonopod part

Source: http://www.abc.net.au/science/scribblygum/april2007/gallery.htm

The telson consists of a pre-anal ring, often developed into a projection, a pair of anal plates that form a valve which opens during defaecation, and a sub-anal scale (Figure 2.8). The shape of the projection may vary between and within species. In some cases, the sub-anal scale may also bear a projection (e.g. *Enantiulus armatus*). Between the telson and the most posterior leg-bearing ring are one or more apodous rings. Between the apodous rings and the telson lies the proliferation zone where new trunk units are initiated and develop (Hopkin and Read, 1992).

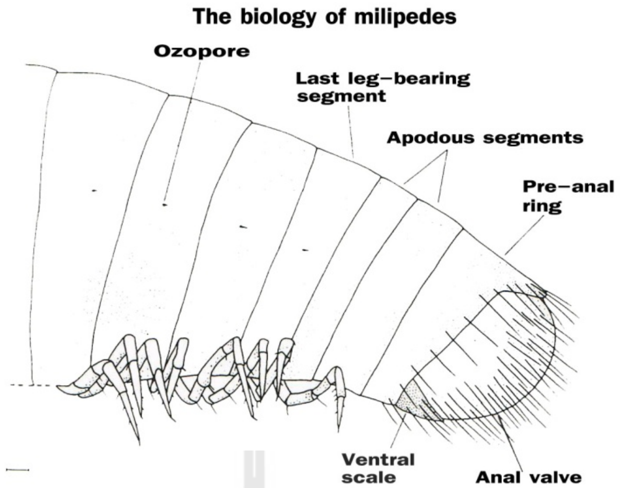


Figure 2.8 Posterior end of a male *Cylindroiulus waldeni*. The pre-anal ring is also known as the telson. Scale bar = 0.1 mm (Hopkin and Read, 1992).

2.2.2 Internal form and function

Although earthworms are the principal detritivores in most woodland ecosystems, millipedes share this niche and contribute importantly to the recycling of plant debris on the forest floor. Up to 90% of detritus that enters the millipedes gut is egested back into the habitat as faeces. Passage of this material through the gut facilitates later microbial assimilation of its organic compounds and nutrients. In typical woodland communities, millipedes may process up to 10% of the annual leaf fall, but up to 25% if earthworms are absent. Coprophagy (ingestion of faeces) is common in millipedes and may be a mechanism for recovering additional nutriment from food by passing it through the gut twice. Some species die if prevented from ingesting their own faeces. Like earthworm, some millipedes ingest soil, from which they digest the organic matter (Hopkin and Read, 1992).

The gut typically is a straight tube with a long midgut. Salivary glands open into the preoral cavity (Figure 2.9). Digestion and absorption occur in the midgut, which produces a peritropic membrane to surround the food, as hexapods and crustaceans do. The midgut is covered by a layer of tissue known as the “liver” that appears to be similar to the chlorogogen tissue of annelids. Its cells store glycogen and may also function as accumulation kidneys where toxins are sequestered. A fat body in the hemocoel stores glycogen, lipids, protein, and uric acid.

Gas exchange is entirely via the segmentally organized tracheae. Each diplosegment has two pairs of spiracles located on the sterna, an unusual position for them. Each spiracle opens into an internal atrium, from which arises a bundle of unbranched tracheae that extend to the tissues. The atria are hollow, rigid apodemes that also function as sites for muscle attachment. The spiracles of most millipedes cannot be closed, but those of *Glomeris* are an exception.

The heart is a dorsal tube extending the length of the trunk, and the hemocoel is divided into pericardial, perivisceral, and perineural sinuses. The heart is perforated by two pairs of ostia per diplosegments, but the anterior segments, which are not diplosegments, have only one pair of ostia each. The heart ends blindly at the posterior end of the trunk, but anteriorly a short cephalic aorta extends into the head.

The two Malpighian tubules that arise from the midgut-hindgut junction often are long and looped. Like centipedes, millipedes excrete both ammonia and uric acid. Also like centipedes, millipedes have saccate nephridia in the maxillary segments, but the function is unknown.

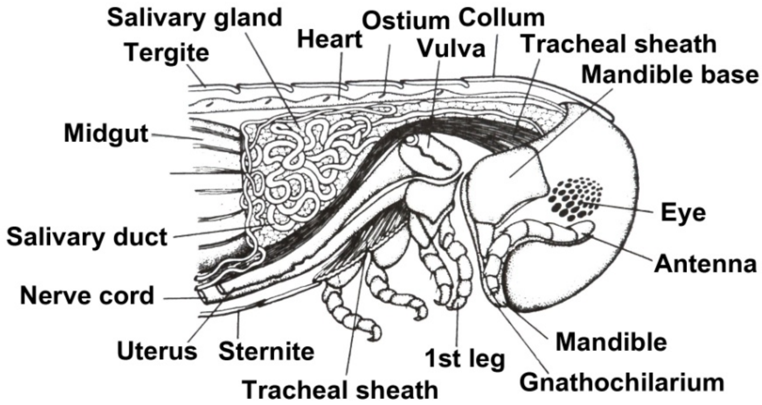


Figure 2.9 Lateral view of the head and anterior trunk segments of juliform (Ruppert et al., 2004).

2.3 Feeding and digestion of millipedes

2.3.1 Ingestion

In the great majority of millipedes, dead plant material is chewed by the mandibles into small pieces (Enghoff 1979a, 1990; Manton, 1964) and passed into the lumen of the foregut where it receives secretions from the salivary glands (Nunez and Crawford, 1977). The distal segment of the mandible, the gnathal lobe, is the most complex structure of the mouthparts. The biting and crushing parts of the mandibles are based on the same general scheme but modifications exist which are taxon-specific.

In millipedes that feed on dead leaves, the density of teeth on the pectinate lamella determines the size of food fragments ingested. The size of food particles which pass into the gut is correlated with digestive efficiency the smaller the particles, the greater the proportion of food that is assimilated (Kohlre et al., 1991).

2.3.2 Structure and function of digestive tract

Digestion take place in the midgut (Figure 2.10). Enzymes are secreted onto the food particles by the epithelial cells and others may be derived from microorganisms in the lumen. Products of digestion are assimilated by the midgut cells and some pass through to the "liver" a layer of cells that surrounds the midgut.

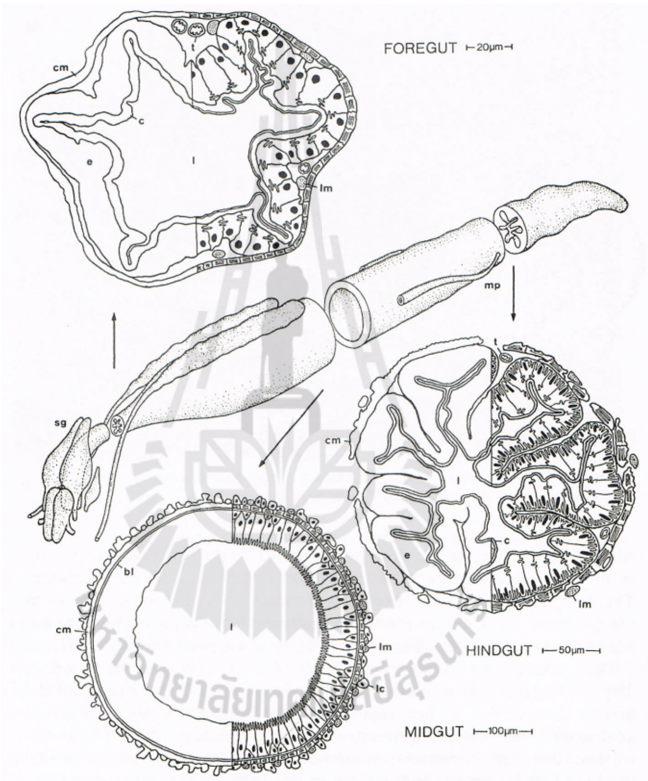


Figure 2.10 Schematic diagrams of the intestinal tract of millipede (*Craspedosoma alemannicum*) and sections of the foregut, midgut and hindgut (Hopkin and Read, 1992).

The faecal pellets (Figure 2.11) are formed in the rectum. The rectum can be everted and is capable of absorbing water from a moist substrate. For example, the alpine species *Mastigona mutabilis*, when dehydrated, is able to reabsorb water via its everted rectum at a rate of 79 percent of its body weight per hour (Meyer and Eisenbeis, 1985).

Figure 2.11 The faecal pellets of millipedes.

2.3.3 Diet

The vast majority of millipedes eat dead plant material and fragments of organic matter. Some millipedes have a more specialized diet. *Polyxenus lagurus* grazes algae from the bark of trees (Eisenbeis and Wichard, 1987). A few species are carnivorous (Hoffman and Payne, 1969) and several will eat dead animal remains including snails (Srivastava and Srivastava, 1967). However, the digestive system is poorly adapted for consuming a carnivorous diet in most species. Schluter (1980d) showed that the gut epithelium of *Scaphiostreptus* sp. broke down within two weeks when the millipedes were forced to eat a carnivorous diet instead of their usual detrivorous fare.

Millipedes need to avoid food which might poison them. Hopkin et al. (1985) and Read and Martin (1990) found that millipedes avoided eating food that was contaminated heavily with zinc, cadmium, and lead. However, this does not necessarily mean that millipedes possess receptors that respond specifically to toxic levels of zinc, cadmium, and lead in their diet. A more likely explanation is that they simply avoid eating something which tastes unpleasant. Thus in toxicity experiments, or in the field, millipedes may be dying of starvation through rejection of contaminated food rather than being killed directly by toxic levels of pollution.

2.3.4 Digestion

Animals that consume dead plant remains rely on food of relatively poor quality for their nutrients. Millipedes deal with this food in two stages.

The first stage involves the rapid assimilation of soluble materials released from the food after mechanical breakdown by the mandibles. Nutrients pass through the peritrophic membrane in the midgut and are assimilated across the microvilli. A recent work by Kohler et al. (1991) has shown that assimilation is greatest in those millipedes with mouthparts that grind food into the smallest particles.

The second wave of nutrients are released following digestion of the food. Digestive enzymes are derived from the secretions of the salivary glands (Nunez and Crawford, 1977), and the cells of the midgut epithelium. The enzymes pass from the midgut cells through the peritrophic membrane and may be supplemented by enzymes released from microorganisms mixed with the food in the lumen. Some desert millipedes ingest sand grains, and other more temperate species may take soil into the gut, possibly to strip off adhering organic material.

In many millipedes, enzymes that are capable of digesting lipids, proteins, and simple carbohydrates have been detected (Kaplan and Hartenstein, 1978; Marcuzzi and Turchetto-Lafisca, 1977; Neuhaused and Hartenstein, 1976; Neuhauser et al., 1978; Nielson, 1962; Nunez and Crawford, 1976). However, there is some controversy as to whether millipedes are able to digest the more refractory components of leaves.

Cleavage of aromatic rings during digestion of food by millipedes is due also to the activities of microorganisms in the lumen rather than enzymes derived from the midgut epithelium or salivary glands (Kaplan and Hartenstein, 1978).

2.3.5 Microorganisms

Most ecologists now accept that the main role of detritivorous invertebrates in enhancing decomposition of dead plant material is to stimulate microbial activity. The fragments of leaf that are voided in the faeces have a greater surface area available for colonization by bacteria and fungi than the original leaf material. Crawford (1988) has suggested that the behavioural ecology of desert millipedes (in terms of temperature preferences etc.) may depend to a large extent on the optimum conditions for digestive activities of their gut microorganisms. Anderson and Ineson (1983) stated that although it was beyond question that microorganisms were of vital importance in digestion (particularly with regard to cellulose digestion), there was no evidence that millipedes possess a permanent symbiotic microflora similar to that of termites as shown in Table 2.3.

Table 2.3 Bacteria in food, gut contents and faeces of *Glomeris marginata* (Anderson and Ineson, 1983).

Sample	Replicate No.	Viable bacteria (10^8 g^{-1})	Mean (10^8 g^{-1})
Litter	1	3.4	
	2	6.7	
	3	2.8	4.3
Gut	1	13.0	
	2	11.9	
	3	43.5	22.8
Faeces	1	695.5	
	2	306.9	
	3	209.9	404.1

2.3.6 Assimilation

The importance of millipedes in the decomposition of plant remains in terrestrial ecosystems has led several authors to examine rate of ingestion and assimilation of food. However, much of this work needs to be read with care since it is not always clear what is actually being measured.

Ingestion or feeding rates are a measure of intake of food into the gut. Interpreting published figures can be difficult because there is no standard method of reporting rates of ingestion.

In most cases, total “assimilation” of food by millipedes is calculated by subtracting the weight of faeces from the weight of food consumed. A wide range of values for assimilation have been reported with a probable maximum of about 30 percent on a dry weight basis (Wooten and Crawford, 1975; Crawford et al., 1987;

Kayed, 1978; McBrayer, 1973). Smaller species tend to have higher assimilation efficiencies than larger ones (Kohler et al., 1989).

However, several errors can creep in if this approach is adopted. Moisture content of food and faeces is very variable and errors can occur if dry weights are calculated assuming a constant wet/dry weight relationship. Furthemore, food can remain in the gut for long periods after feeding has stopped. If this is not allowed for, and the duration of experiments is short, it is possible to come up with some very high (and probably unrealistic) values for "assimilation" in excess of 50 percent (Striganova, 1971; Striganova and Prishutova, 1990).

2.4 Cylindrical millipedes

Thyropygus Pocock, 1894 (cylindrical millipedes) is classified in family Harpagophoridae, order Spirostreptida, superorder Juliformia. The largest Thai millipedes belong to this family, sometimes reaching more than 20 cm in length and more than 15 mm in diameter (Figure 2.12). The family Harpagophoridae is "probably the most characteristic and conspicuous element in the millipede fauna of the Oriental Region" (Hoffman, 1975). The genus *Thyropygus* Pocock, is the largest genus in species number of Harpagophoridae in Southeast Asia. It has had a complicated history but, mainly due to the work of Hoffman (1975), the genus is now quite well circumscribed.

Figure 2.12 *Thyropygus* (Pocock, 1894).

Thyropygus currently includes 35 recognized species and a number of named subspecies (Jeekel, 2006). The genus is broadly distributed in Southeast Asia: Thailand, Myanmar, Vietnam, Laos, Cambodia, Peninsular Malaysia, and some islands of Indonesia such as Sumatra, Java, and Borneo (Jeekel, 2006; Enghoff, 2005).

The genus was placed in the subfamily Harpagophorinae by Demange (1961) and in the tribe *Thyropygini* by Hoffman (1975). The circumscription of *Thyropygini* was later modified by Jeekel (2006). The following diagnosis of *Thyropygus* has been extracted from these authors (Pimvichai et al., 2009a):

- ozopores starting on body ring 6th
- body rings not strongly wrinkled dorsally
- stigmatic grooves very long, reaching at least the middle of the leg prefemora
- postfemur and tibia of male walking legs with ventral soft pads
- gonopod sternum present, triangular
- gonopod telopodite with a femoral and mostly also a tibial spine, but without numerous spines along all its length

- prostatic groove terminating apically on a solenomere or prostatic lobe (apical palette of telopodite) in a narrowly expanded area set with a series of long, slender, stiffened, usually pigmented spines ("blepharochaetae" of Hoffman, 1975)

- apical palette voluminous, more or less expanded, forming somewhat gutter-like structure

- some external features of *Thyropygus chelatus* male are illustrated in Figure 2.13.

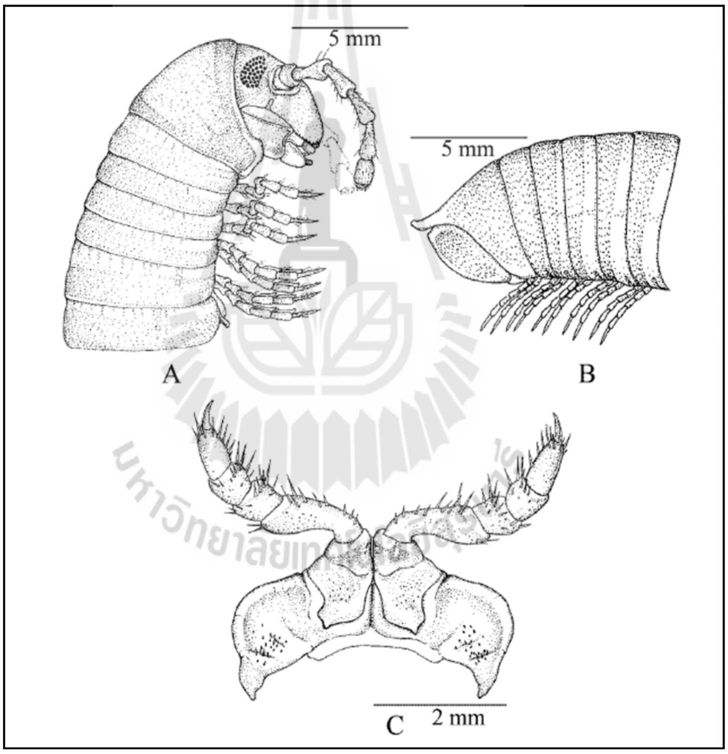


Figure 2.13 *Thyropygus chelatus*., male. A: anterior end B: posterior end C: first pair of legs (Pimvichai et al., 2009a).

Hoffman (1975) grouped the genus of *Thyropygus* into four species groups: the *allevatus*, *aterrimus*, *luxuriosus*, and *erythropleurus* groups. The last group contains the type species of *Thyropygus*, *T. erythropleurus* Pocock, 1894 (Sumatra) and might alternatively be termed "*Thyropygus s.s*".

2.5 The influence of environmental factors on millipedes

Ashwini and Sridhar (2006) described that millipedes were often favoured by high soil Ca content and thus higher pH. Millipede abundances and biomass were positively correlated with rainfall, soil moisture, soil Ca content and soil temperature in forest of Southwest India.

One of the aims of this research is to study the factors that come into play in determining the abundance and distributions of millipedes. These ecological factors may be grouped under three headings. The first involves the elements of climate. The second involves various physical and chemical soil properties. Finally involves water content in leaf litter.

2.5.1 Role of millipedes in environment

Millipedes have a wide dietary range which includes leaf litter, soil, algae, fruits, dead invertebrates, mammalian faeces and seeds (Lawrence, 1984). Richness and diversity of saprophagous fauna are influenced by a wide range of land use, agriculture, forestry and wildlife conservation practices (Curry, 1994; Edwards and Bohlen, 1995; Wardle, 1995). Most diplopods are considered to be litter transformers (Lavelle et al., 1997). Millipedes are known as indicators of environmental alteration as they are sensitive to a narrow change in edaphic factors (Kime and Golovatch, 2000).

Jonespeltis splendidus is a millipede inhabiting garden and forest floors in and around Bangalore, India, these millipedes lower the C/N and H/F ratios and increase the availability of minerals in their habitats through their feeding and digestive activities, and thus serve as humifying and mineralizing agents in their ecosystems (Bano, 1990). Soil microcosms with and without millipedes (one and two pairs of adults) were set on a forest floor, and soil respiration. Dissolved ion concentration in leacheate water were observed for 8 weeks. The millipedes ingested both leaf litter and soil which increased soil respiration, leaching of Ca^{2+}, Mg^{2+}, and nitrate from the soil whereas the soil microbial biomass was not changed at 8 weeks after introduction of the animals. Millipedes feeding on soil enhanced microbial activity and nutrient leaching from the forest soil (Kaneko, 1999). Diplopoda was the most abundant among them of which 87.3% was the train millipede. The total biomass in wet weight of soil macro-invertebrates was 34.9±70.5 g/m^2 when the millipede was pre-adult or adult. It decreased to 3.5± 6.7 g/m^2 when it was young. The train millipede is one of the most important soil invertebrates affecting soil properties (Niijima, 1998).

2.5.2 Effects of millipedes on soil

Rice seedlings were either grown in soil samples amended with faecal pellets of diplopods and isopods fed on leaf litter of a legume cover crop (*Pueraria phaseoloides*) and a peach palm (*Bactris gasipaes*) or in soil amended with finely ground leaf litter. The positive effect of the soil fauna on soil fertility and indicate differences in the availability of nutrients from the organic substrates to higher plants and soil microorganisms (Forstera, et al., 2006). The effect of mechanical breakdown of detritus by the millipedes *Centrobolus fulgidus*, *Centrobolus richardii* and

Spinotarsus sp. on selected soil elements was investigated. Soil concentrations of the elements investigated were higher in microcosms subjected to millipede activity than in controls. *Spinotarsus* sp. and *C. richardii* were found to have the highest concentrations of Mg, K, N and C (Smit and Vanaarde, 2001). The biomass of *Arthrosphaera* was significantly correlated ($p = 0.01$, $r = 0.45$) with soil organic carbon rather than other edaphic features (pH, phosphate, calcium and magnesium) (Ashwini and Sridhar, 2008).

2.5.3 Litter ingestion by millipedes

Soil macroinvertebrates are very important in improving the structure, content of organic matter, and nutrient elements of soil (Loranger-Merciris et al., 2007; Seeber et al., 2008). Synergistic function of saprophagous fauna and microflora in soil results in decomposition of organic matter and nutrient release (Kurzatkowski et al., 2004). Saprophagous invertebrates (e.g., millipedes, woodlice and dipteran larvae) are known to ingest up to 20-100% of annual litter production (Tajovský et al., 1992). The excrements of saprophagous fauna consist of undigested plant residues, fine particulate organic matter, mineral particles and microorganisms with higher pH (acidic to neutral), water holding capacity, and surface/volume ratio than standing dead litter (Kheirallah, 1990; Tajovský et al., 1992; Lavelle and Spain, 2001; Kurzatkowski et al., 2004; Seeber et al., 2008). Transformation of organic matter into rich inorganic nutrients and nutrient fluxes by saprophagous fauna in a specific habitat can be evaluated indirectly through the assessment of their abundance, population dynamics, diversity, succession, and energy budgets based on feeding and excretion (Anderson, 1987; Pramanik et al., 2001; Loranger-Merciris et al., 2008). Estimates of litter ingestion by millipedes vary considerably (Neuhauser and Hartenstein, 1978;

Striganova, 1972). These differences are mainly the results of body size effects although other factors such as food type (Pobozsny, 1986) and temperature (Iatrou and Stamou, 1989; Wooten and Crawford, 1975) also play a role, with larger individuals consuming more food than smaller ones (Dangerfield and Milner, 1993). Determine leaf litter preference, consumption rate, growth rate, food conversion efficiency, and quality of faecal pellets of two endemic pill millipedes (*Arthrosphaera dalyi* and *Arthrosphaera davisoni*) of the Western Ghats of India by laboratory microcosm experiments. In 4-week trial, preference of mixed litter diet was higher than single litter diet, which resulted in enhanced growth as well as food conversion efficiency of millipedes. Among *Hopea, Pongamia*, and *Areca* litters, *A. dalyi* preferred the combination of *Hopea* and *Pongamia*, and its consumption was significantly correlated with contents of organic carbon ($p < 0.05$; $r = -0.97$) and nitrogen ($p < 0.01$; $r = 0.99$), while growth rate with phosphorus content ($p < 0.05$; $r = 0.97$) and food conversion efficiency with contents of organic carbon ($p < 0.05$; $r = 0.98$) and calcium ($p < 0.01$; $r = -0.99$) (Kadamannaya and Sridhar, 2009). Ingestion and assimilation rates in six species of tropical millipede (Diplopoda: Spirostreptidae) from southern Africa were estimated for the first time and were found to vary both within and between species. A proportion of this variability was attributable to variation in body size effects as individuals ranged from 0.2 to 2.9 g dry mass. Mean ingestion rates for each species were 17, 30, 34.32 and 75 mg dry leaf litter per day (7.6 to 2.6% of body mass). Within species, ingestion rates explained between 35 and 53% of the variation in assimilation. Large size did not necessarily enhance assimilation efficiencies, which were between 7 and 26% and comparable to assimilation efficiencies reported for temperate species, but did result in greater absolute ingestion and assimilation of organic material per individual.

2.6 Species diversity measures

2.6.1 Defining biodiversity

Wilson (1992) defined biodiversity as “The variety of organisms considered at all levels from genetic variants belong to the same species through arrays of species to arrays of genera, families, and still higher taxonomic levels; including the variety of ecosystems which comprise both communities of organisms within particular habitats and the physical conditions under which they live”.

Biodiversity is an all-inclusive term to describe the total variability that occurs among living organisms of our planet and it includes three main components:

1) The diversity of species that occurs in the world, from the familiar plants and animals to the less conspicuous fungi, bacteria, protozoan and virus.

2) The genetic variation that occurs within individual species that causes them to vary in their appearance (phenotype) or their ecological responses and allows them to react to the process of evolutionary section.

3) The diversity of habitat or ecological complexes in which species occur together whether they be such well-known ones as rain forest, tundra, and coral reef or the complex of bacteria that in habitant the human body or a gram of soil.

2.6.2 Species diversity

The study of biodiversity often begins with species diversity because it is the most familiar aspect of biodiversity as a whole. In ecological studies, samples will frequently consist of information on the number and relative abundance of the species present. The diversity of the sample will depend on two distinct components, species richness and species evenness or equability. Species richness simply refer to the total number of species present. Evenness is concerned with the relative abundance of species. In a community with high evenness, many species will have similar levels of abundance, no single species being significantly more abundant. Thus ecological communities may differ in terms of their species richness and evenness.

2.7 Millipede diversity and geographical distribution

The most species-rich group of the Myriapoda is the millipedes which are more than 10000 described species, classified in at least 15 orders, 144 families and 2950 genera (Shelley, 2003).

Twenty-two species of millipedes (Diplopoda) were recorded during a survey of the Aggtelek National Park in north-eastern Hungary, consisting of one-fifth of the total Hungarian millipede fauna (Lazanyi and Korsos, 2009). *Noteremus summus* gen. n., sp. n. occurs at 1100-1300 m on the summit of Mt Weld, southern Tasmania, while its congener *N. inimus* sp. n. is troglobitic in caves in the Junee-Florentine karst, 30-40 km to the northwest (Mesibov, 2009). Fifty-six species of millipedes belonging to ten different orders of Diplopoda are listed as members of the Taiwanese fauna (Korsos, 2004). Fourteen millipede species representing nine genera, within six families and three orders were sampled from a savanna ecosystem, South Africa (Drurce et al., 2004). Millipede species richness, particularly within the order Spirostreptida and millipede endemism were positively associated with large within-cell differences in elevation (mountainous regions). Large variation in taxonomic distinctness (unevenness in the taxonomic tree) in higher-rainfall areas was mainly due to speciation within the Spirostreptida genus *Atelomastix* (Melinda et al., 2009). A total of seventeen species of millipedes (2968 individuals.) were sampled in urban environments in the city of Olomouc Czech Republic (Riedel et al., 2009).

Biogeography of millipedes

Many of the 146 currently recognized millipede families (Shelley, 2003) have a restricted (known) distribution. After a specimen has been identified to order, numerous families can be eliminated from consideration based on the geographic origin of the respective specimen. Development of a comprehensive key to all millipede families is currently beyond the scope of this project, since many millipede families are not clearly defined on the basis of apomorphic (or at least on a unique combination of plesiomorphic) characters. Geographic names in quotation marks refer to areas in the sense of previous boundaries, usually before 1990.

Table 2.4 Biogeography of millipede orders.

Order	Distribution
Callipodida	North America, Europe, west Asia, southern China and SE Asia
Chordeumatida	worldwide, except for tropical South America and sub-Saharan Africa (present on Madagascar)
Glomerida	Northern Hemisphere and SE Asia
Glomeridesmida	Mexico, northern South America, West Indies, SE Asia
Julida	North America to Panama, Europe, Asia north of the Himalayas, SE Asia. Mainly temperate
Penicellata	Worldwide. Dry (not arid) habitats

Table 2.4 (Continued)

Order	Distribution
Platydesmida	North and Central America, Europe, SE Asia, Japan
Polydesmida	Worldwide
Polyzoniida	North America, Caribbean, Europe, Southern Africa, eastern and southern Asia, Indian Ocean Islands, New Zealand
Siphonocryptida	Canary and Madeira Islands, Sumatra, Malacca
Siphonophorida	North, Central and South America, Caribbean, South Africa and southeast Asia, Australia and New Zealand
Sphaerotheriida	Southern Hemisphere: southern Africa and Madagascar, India, SE Asia, Australia, New Zealand
Spirobolida	Western Hemisphere, sub-Saharan Africa, SE Asia, Australia. Mainly tropical
Spirostreptida	Western Hemisphere, Africa, Asia south of the Himalayas, Australia. tropical
Stemmiulida	Tropical South America and Central America, West Indies, central Africa, southern India and Sri Lanka, New Guinea

2.8 Distribution and abundance of millipedes

Seasonal occurrence and activity of endemic pill millipedes (*Arthrosphaera magna*) were examined in organically managed mixed plantation and semi-evergreen forest reserve in southwest India between November 1996 and September 1998. Abundance and biomass of millipedes were highest in both habitats during monsoon season. Soil moisture, conductivity, organic carbon, phosphate, potassium, calcium and magnesium were higher in plantation than in forest (Ashwini and Sridhar, 2006). The millipede order Siphonocryptida previously consisted of three species. Its distribution demonstrates an unusual geographical pattern with one species in the Canary Islands and Madeira, one in Sumatra, and one in Malaya Penninsular. (Voigtländer and Düker, 2001). A fourth species, *Hirudicryptus taiwanensis* sp. n., here described from Taiwan, complicates the pattern, and suggests an ancient, relictual trans-Palaearctic distribution (Korsos et al., 2008). Collecting 1605 isopod individuals (8 species) and 671 diplopod individuals (17 species) in four primeval forests of the Western Carpathians, Central Slovakia, by leaf litter extraction. The forests are of different temperate deciduous forest types varying in tree species, aspect, elevation and soil characteristics. Millipede density close to Western Carpathians, Central Slovakia (CWD) ranged from 60 to 230 individuals m^{-2} (15-75 individuals m^{-2} distant from CWD). Species richness of both taxa close to CWD varied from 13 to 16 species m^{-2} (7-12 species m^{-2} distant from CWD) (Toppa et al., 2006). Seven sampling sites in each of three biomes (Western Ghats, foothills of Western Ghats and west coast) of southwestern India were investigated to study the distribution, abundance and ecology of pill millipedes (*Arthrosphaera*) and associated fauna in relation to edaphic features. Abundance and biomass of *Arthrosphaera* and other millipedes were the highest in Western Ghats (Ashwini and Sridhar, 2008). The habitat preferences of two closely related millipede species, *Centrobolus richardii* and *Centrobolus fulgidus*, were investigated on three different seral stages of a coastal dune forest successional sere north of Richards Bay, South Africa. Fixed-width transects were used to survey millipedes in three habitats of different ages. Habitat preference occurred on both inter-site and intra-site levels and was influenced by seasons (Greyling et al., 2001).

2.9 Millipedes of Thailand

Millipedes from Myanmar were described in the 19^{th} century and more than half of those from Vietnam in the 1930's and 1950's (Enghoff et al., 2004). Descriptions and records of millipedes from Thailand, however, there is absolutely no record in Thailand until the 1960's.

Flower (1901) gave an account of millipedes from Thailand with biological notes on several species, and the information that millipedes are called "king keu" in Siam (Thailand). One hundred and five (105) species of millipedes are recorded from Thailand, based on a scrutiny of literature and a study of hitherto unpublished material (Enghoff, 2005).

The millipedes of Thailand consist of 8 orders, 17 families, 36 genera and 105 species (Enghoff, 2005). The classification followed Hoffman (1980) and also including the updating by Shelley (2003) as follows:

Order Glomerida

Family Glomeridae

Genus *Hyleoglomeris* Verhoeff, 1910

Genus *Rhopalomeris* Verhoeff, 1906

Order Sphaerotheriida

Family Zephroniidae

Genus *Zephronia* Gray, 1832

Order Platydesmida

Family Andrognathidae

Genus *Pseudodesmus* Pocock, 1887

Order Julida

Family Julidae

Genus *Nepalmatoiulus* Mauriès, 1983

Order Spirobolida

Family Pseudospirobolellidae

Genus *Benoitolus* Mauriès, 1980

Genus *Pseudospirobolellus* Carl, 1912

Family Pachybolidae

Genus *Litostrophus* Chamberlin, 1921

Genus *Tonkinbolus* Verhoeff, 1938

Family Trigoniulidae

Genus *Trigoniulus* Pocock, 1894

Order Spirostreptida

Family Cambalopsidae

Genus *Trachyiulus* Peters, 1864

Family Glyphiulidae

Genus *Glyphiulus* Gervais, 1847

Genus *Hypocambala* Silvestri, 1897

Family Harpagophoridae

Genus *Anurostreptus* Attems, 1914

Genus *Cornugonus* Demange, 1961

Genus *Gonoplectus* Chamberlin, 1921

Genus *Humbertostreptus* Demange, 1969

Genus *Thaiogonus* Demange, 1986

Genus *Thyropygus* Pocock, 1894

Order Chordeumatida

Family Heterochordeumatidae

Genus *Infulathrix* Shear, 2000

Family Megalotylidae

Genus *Nepalella* Shear, 1979

Family Metopidiotrichidae

Genus *Metopidiothrix* Attems, 1907

Order Polydesmida

Family Platyrhacidae

Genus *Platyrhachus* C. L. Koch, 1847

Family Paradoxosomatidae

Genus *Anoplodesmus* Pocock, 1895

Genus *Antheromorpha* Jeekel, 1968

Genus *Asiomorpha* Verhoeff, 1939

Genus *Carinorthomorpha* Golovatch, 2000

Genus *Desmoxytes* Chamberlin, 1923

Genus *Haplogonomorpha* Mrši´c, 1996

Genus *Kronopolites* Attems, 1914

Genus *Orthomorpha* Bollman, 1893

Genus *Streptogonopus* Attems, 1914

Genus *Substrongylosoma* Golovatch, 1984

Genus *Tylopus* Jeekel, 1968

Family Doratodesmidae

Genus *Dyomerothrix* Hoffman, 1982

Family Polydesmidae

Genus *Pacidesmus* Golovatch, 1991

A shocking pink, very spiny new species of “dragon millipede*”, Desmoxytes purpurosea* (Enghoff and Panha, 2007) is described from Uthaithani province, Thailand (Enghoff et al., 2007). *Sinocallipus thai* is described from Saraburi Province, Thailand. This is the second species in the suborder Sinocallipodidea Shear, 2000, hitherto known only from *S. simplipodicus*, discovered in a cave in Yunnan, southern China. (Stoev et al., 2007). The *Thyropygus opinatus* subgroup of the *T. allevatus* group has been revised. Eight new species are described in Thailand: *T. bearti*, *T. brachyacanthus*, *T. loxia*, from Suratthani province, *T. bispinus*, from Uthaithani and Phrae provinces, *T. bispinispatula*, from Chumphon province, *T. chelatus*., from Nakhonsrithammarat province, *T. cristagalli*, from Phang Nga province and *T. erectus*, from Satun province (Pimvichai et al., 2009a). The *Thyropygus bifurcus* subgroup of the *T. allevatus* group is revised. Four new species are described from Southern of Thailand: *T. demangei*, *T. quadricuspis*, *T. richardhoffmani*, from Trang province and *T. casjeekeli*, from Krabi province (Pimvichai et al., 2009b).

The Natural History Museum of Denmark (The Copenhagen Zoological Museum), where more than half of the primary types of Thai millipedes are housed, still has numerous samples of unidentified specimens.

2.10 Sakaerat Environmental Research Station

Sakaerat Environmental Research Station (SERS) is one of the four UNESCO designated biosphere reserves of Thailand. It was first established in September, 1967 by the Applied Scientific Research Corporation of Thailand to use as a national forest reserve for scientific propose by the Royal Forest Department, Ministry of Agriculture and Cooperatives. In 1976, SERS was delegated by the UNESCO to be a world Biosphere Reserve of Thailand (Hanboonsoog, 2000).

SERS is in Phu luang ,Wang Nam Khieo, Udomsap subdistricts and Pak Thong Chai districts Nakhon Ratchasima province, Northeast Thailand. SERS cover 78 km^2 (approximately 48,750 rai) and is situated approximately at 14^{o} 30′ N, 101^{o} 55′ E, about 300 km northeast of Bangkok and about 60 km of Nakhon Ratchasima city (Figure 2.14).

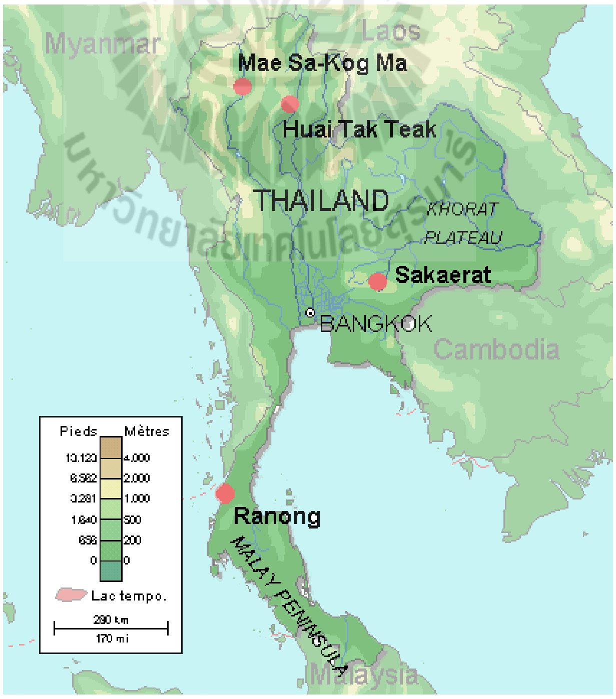


Figure 2.14 Location of Sakaerat Environmental Research Station.

Source: http://www.unesco.org/mabdb/br/brdir/asia/Thailandmap.htm

2.10.1 Geography / Climate

SERS is situated in mountainous terrain at an altitude of 280-762 meters above sea level. Important mountains on the station grounds are Khao Phiat (762 meters), Khao Khieo (790 meters) and Khao Sung (682 meters). The station office is at 390 meters. Average annual temperature at Sakaerat is 26°C and average annual rainfall is 1260 millimeters.

2.10.2 Vegetation and forest types

SERS is covered by two major forest types, dry evergreen forest and dry dipterocarp forest. The vegetation in dry evergreen forest includes trees like *Hopea ferrea, H. adorata*, and *Hydrocarpus illicifolius*. Vegetation in dry dipterocarp forest is more seasonal and includes *Shorea obtusa*, *S. siamesis*, and *S. floribunda*. Together, the two forest types cover 70 percent of the station gounds. Other areas have bamboo, plantation forests, and grasslands.

Vegetation types of the area are dry evergreen forest (29.5 km or 36.4%), dry dipterocarp forest (12.2 km or 15.1%), bamboo forest (1.4 km or 1.7%) grassland, and an agricultural area (37.9 km or 46.8%). The dry evergreen forest (DEF) occupies the Southwestern portion, while the dry dipterocarp forest (DDF) occupies the Northeastern portion of the reserve area, mostly in response to altitude and soil types distribution (Tongyai, 1980). The DDF is deciduous broad-leaved forest community type occurring on relatively dry sites, and is mainly composed of trees belonging to the Dipterocarpaceae family (Sahunalu and Dhanmanonda, 1995).

Deforestation has been given much attention in land use and landscape changes because of the high rate of forest change and the ecological importance of forest ecosystems. Land use and landscape structure had been changes between 1990 and 2002. DEF was replaced by plantation and natural regeneration. The coverage of dry evergreen forest by plantation and secondary growth in the SERS landscape had been increased during 1990-2002 (Trisurat, 2009) (Figure 2.15).

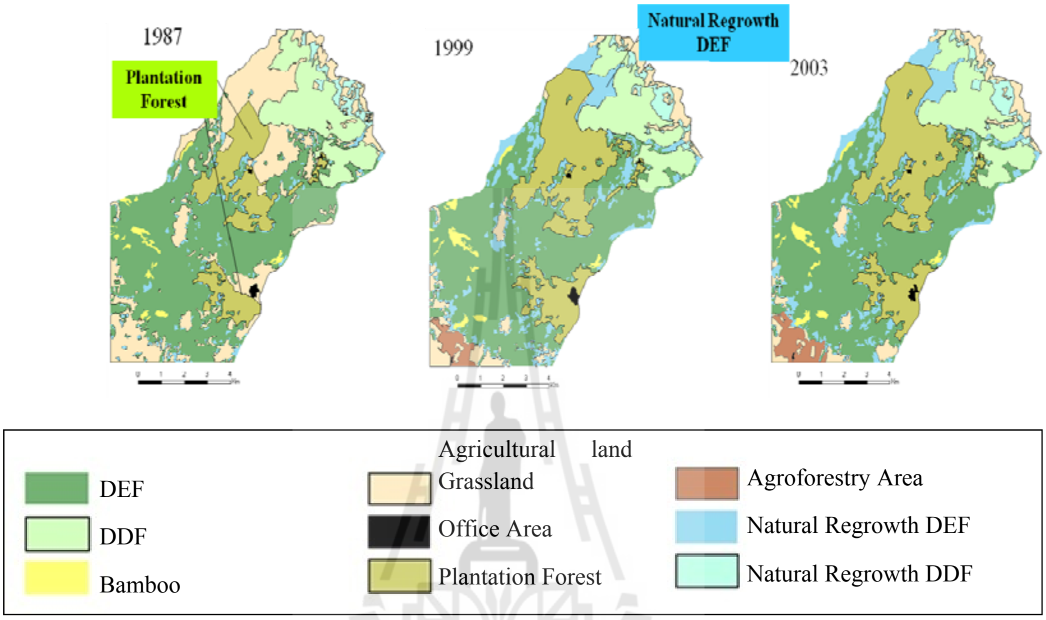


Figure 2.15 Area of SERS analysis by aerial photographs from 1987 to 2003.

มหาวิทยาลัยเทคโนโลยีสุรนารี

2.10.3 Soil

The dominant great soil group of the SERS, occuring in all topographic positions is Red-Yellow Podzolic soils, on materials derived from both sandstone and shale. Series are Khao Yai for the deep members, Tha Yang for the shallow stony members, and Muak Lek for the deeper soils on shale-derived material. The depths of soil are 40-120 centimeters. Soil texture is mainly coarse sandy clay loam to sandy loam and clay loam. The scarps mostly consist of rock outcrop and some stony scree materials.

CHAPTER III

MATERIALS AND METHODS

3.1 Study site description

This study was conducted at SERS, which situated between latitude 14º 05´ to 14º 15´ N and longitude 101º 05´ to 101º 50´ E. Millipede sampling areas were selected from 4 different forest types: the dry evergreen forest (DE), the dry dipterocarp forest (DDF), the ecotone of dry evergreen forest and the dry dipterocarp forest (ECO) and the plantation forest (PTF) as shown in Figure 3.1. Each forest type consists of dominant plant species which differ from forest to forest.

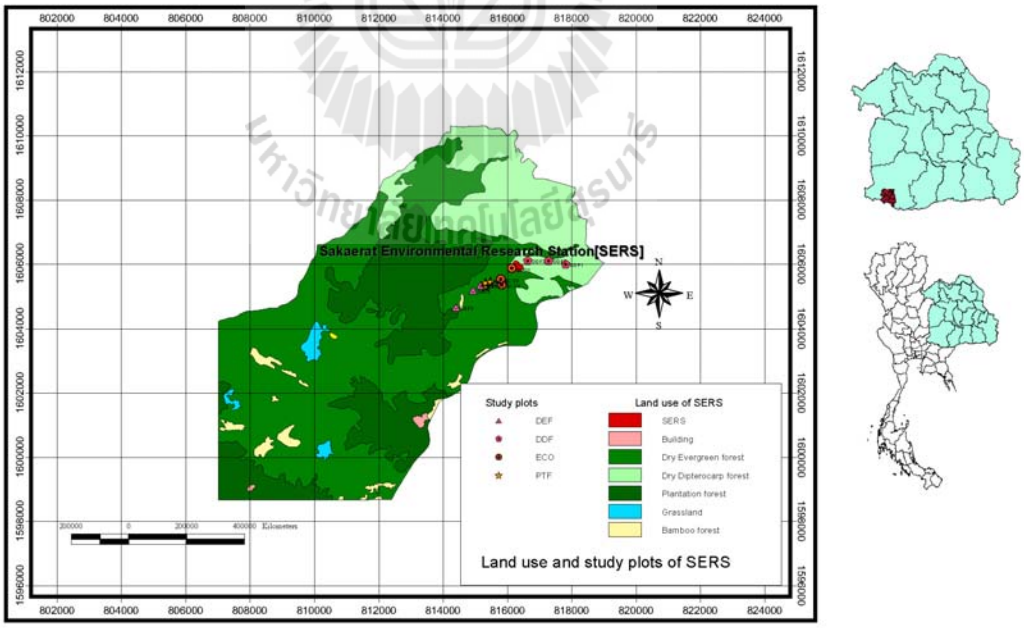


Figure 3.1 Land use and study plots of SERS.

Source: Modified from map of SERS (2009)

3.1.1 The dry evergreen forest (DEF)

The study plots were situated at approximately altitude 520 m, 14° 29’ 30.9” N 101° 55’ 00.4” E. These plots were chosen as a representative of the major forest areas in the least disturbed area (Figure 3.2A). The area includes good stands of DEF and consists of dominant plant species such as *Hopea ferrea* Pierre., *Hopea odorata* Roxb. and *Hydrocarpus illicifolius* King. The canopy trees attain 30 to 40 meters (Suriyapong, 2003).

3.1.2 The dry dipterocarp forest (DDF)

The study plots were situated at approximately altitude 346 m, 14° 30’ 34.1” N 101° 56’ 14.8” E, and lies on the main road to the head quarter. The condition of the second plot is similar to that of the first plot. The area includes good stands of DDF. They are dominated by *Shorea obtusa* Wall, *Shorea siamensis* Miq, *Arundinaria pusilla* A. Chev & A. Camus, *Dipterocarpus intricatus* Dryer, and *Dipterocarpus tuberculatus* Roxb (Figure 3.2B).

3.1.3 The ecotone (ECO)

The study plots were situated at approximately altitude 376 m, 14° 30’ 26.4” N 101 55’ 59.5” E. These plots are joints between the dry evergreen forest and dry dipterocarp forest (Figure 3.2C). It consists of large trees (dipterocarpus) sparingly distributed amongst small shrubs and short grasses (Suriyapong, 2003).

3.1.4 The plantation forest (PTF)

The study plots were situated at approximately altitude 397 m, 14° 30’ 09.2” N 101°55’31.6” E. In the previous time, these areas used to be DEF and were deforested about 30 years ago. In 1977, the SERS planted with lines of *Acacia mangium* at a spacing of 5mx5m in this area. Fire lines and road were also constructed surrounding the plantation area in order to protect them from the forest fire (Figure 3.2D).

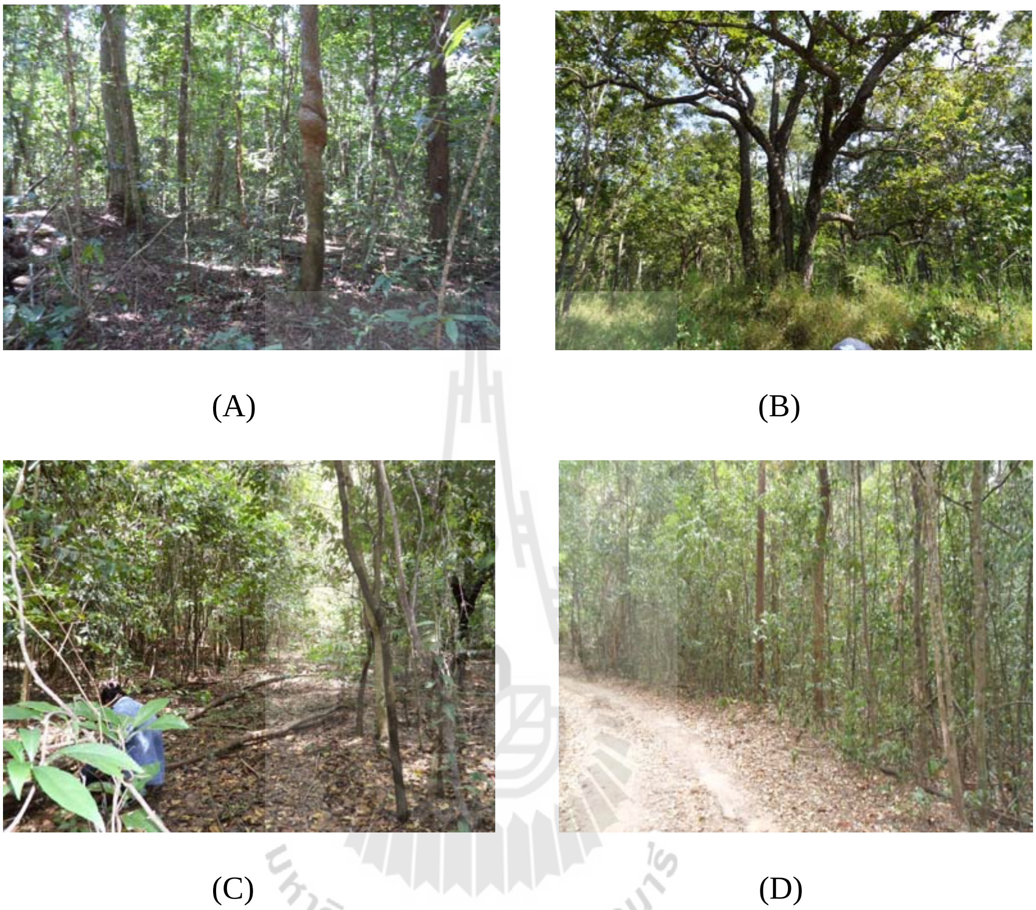


Figure 3.2 Characteristics of the four study areas in the SERS.

(A) The dry evergreen forest (DEF) (B) The dry dipterocarp forest (DDF)

(C) The ecotone (ECO) (D) The plantation forest (PTF)

3.2 Millipede sampling and identification

Three replicates of millipedes, soil and leaf litter were collected from dry evergreen forest, dry dipterocarp forest, ecotone and plantation forest once a month in June 2010 - May 2011 to determine millipedes diversity in these areas. Three sampling sites in each forest of SERS were investigated to study the distribution of millipedes in relationship to environmental factors.

The sampling method involved the selection of a good stand sampling area and establishment of the permanent plot of 20 m x 20 m (400 m^2). The areas were divided into 5 rows and each row further divided into 5 sample plots of 5 m x 5 m. Each sample plot was further divided to 25 quadrats of 1 m x 1 m for each month study. Five quadrats were chosen after the selection by randomized block design (Figure 3.3). Soil samples (30 cm x 30 cm x 30 cm) were removed from each quadrat and handsorted to collect millipedes. The millipedes were anesthetized with 10% ethanol and placed into containers of 70% ethanol for preservation pending identification at the laboratory of Center for Scientific and Technological Equipment, Suranaree University of Technology. Millipedes collected were identified to species level as for comparing with the collections of Museum of Zoology, Chulalongkorn University, Bangkok, Thailand (CUMZ).

For identification, a Nikon SM-800 stereo microscope and the relevant publications were used (Enghoff, 2005; Pimvichai et al., 2009a; Pimvichai et al., 2009b).

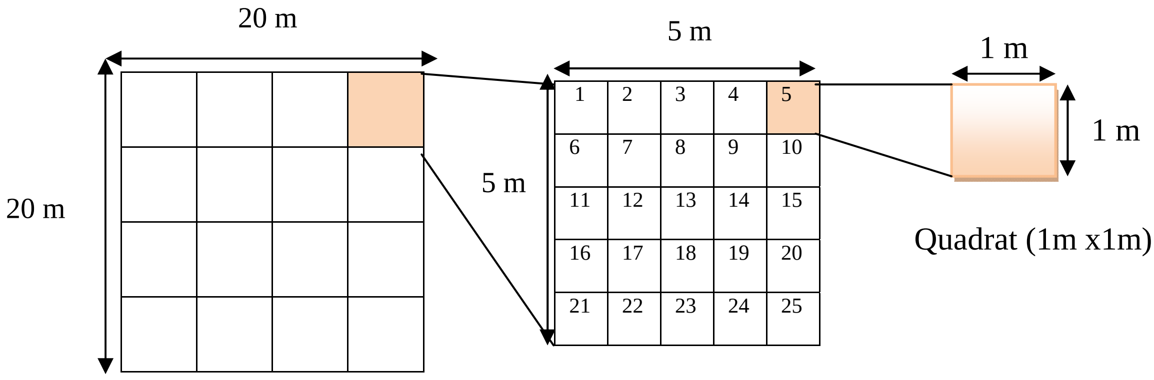


Figure 3.3 Sampling grid design used for sampling the milipedes within each quadrat.

The Order identification key

The identification key to order (Sierwald, 2007) is as follows:

1A Body wall soft; tergites -- **Polyxenida**

1B Body wall hard and rigid -----Chilognatha -- 2

2A [1b] Body with up to 22 body rings -- 3

3a ---------12 rings ------------Gomerida

3b ---------13 rings ------------Sphaerotheriida

3c -----19-20 rings-------------Polydesmida

3d ---------22 rings------------Glomeridesmida

2B Body with more than 22 body rings --- 4

4A Tergites with dorsal midline groove: Chordeumatida, Platydesmida, Callipodida, Spirobolida, Stemmiulida, Siphonocryptida --- 5

5a -------------------26-32 rings--- Chordeumatida

5b ----more than 32 body rings -------------------- 6

6a -----------------ocelli present -------------------- 7

6b ------------------ocelli absent ------Platydesmida

7a -------------------many ocelli -------------------- 8

7b ------------One or two ocelli --------Callipodida

8a -------------------- with crests --------Spirobolida

8b ---------------- without crests -------------------- 9

9a -----head large, 1 or 2 ocelli -------Stemmiulida

9b --------------------head small -----Siphonocryptida

4B Tergites without longitudinal dorsal groove -- 10

10 [4b]: Millipedes without a dorsal, longitudinal groove

10A Head triangular or snout-shaped, males with two pairs of leg-like gonopods

Polyzoniida, Siphonophorida, Siphoniulida -- 11

11a -- blind -- 12

11b -- 2 dark eye spots --------------------------Polyzoniida

12a ---cross section half circle- ----------------Siphonophorida

12b ---cross section circle ----------------------Siphoniulida

10B Front of head not beak-shaped --- 13

13A [10b] 32 rings or fewer -- **Chordeumatida**

13B More than 32 body rings: Spirobolida, Spirostreptida, Julida] ------------------- 14

14A [13b] Median suture line present-- **Spirobolida**

14B Median suture line on front of head not extending to labrum, Julida

Spirostreptida-- 15

15A Gnathochilarium-- **Spirostreptida**

15B Side pieces of gnathochilarium meet at midline------------------------------- **Julida**

The species identification key

The identification key to species of the *Thyropygus opinatus* subgroup (Pimvichai et al., 2009a) is as follows:

1 Spatulate lobe (sl) distally drawn out into one (rarely two) sharp dark brown spine (s) ……... **2**

1* Spatulate lobe (sl) distally expanded and/or rounded, spoonlike, without a spine.. **6**

2 Spatulate lobe (sl) terminating in two sharp brown spines, the outer spine slightly smaller and shorter than the inner one; lateral process of anterior coxal fold (alp) slender, slightly curving mesad; mesal process of anterior coxal fold (amp) almost as long as alp, flattened...***Thyropygus bispinispatula***

2* Spatulate lobe (sl) terminating in a single sharp dark brown spine **3**

3 Telopodite distally to fe with a large, round lobe (lo) projecting distolaterally......... **4**

3* Telopodite without a lobe distal to fe; lateral process of anterior coxal fold (alp) long, slender, regularly curved, tip close to tip of opposite alp, the two together forming a circle; mesal process of anterior coxal fold (amp) straight, shorter than alp; femoral spine (fe) directed distad, pointed......................................***Thyropygus erectus***

4 Lateral process of anterior coxal fold (alp) very slender, regularly curved, simple, tip close to tip of the opposite side, the two together forming a circle; mesal process of posterior coxal fold (pmp) strongly developed along anterior-posterior axis ....***Thyropygus floweri***

4* Lateral process of anterior coxal fold (alp) different, broader and/or with several apical denticles **5**

5 Lateral process of anterior coxal fold (alp) broad, apically gradually narrowed; mesal process of anterior coxal fold (amp) almost as long as lateral process (alp), slender, straight, terminally slightly curved, pointed ....***Thyropygus opinatus***

5* Lateral process of anterior coxal fold (alp) apically bent abruptly mesad, tip with serrate margins; mesal process of anterior coxal fold (amp) much shorter than lateral process (alp), directed meso-distad, simple, pointed; mesal process of posterior coxal fold (pmp): strongly developed along anterior-posterior axis…***Thyropygus implicatus***

6 Lateral process of anterior coxal fold (alp) broad, mesal margin concave, tip with serrate margins, cockscomb-like; mesal process of anterior coxal fold (amp) much shorter than lateral process (alp), directed meso-distad, simple, pointed; an additional spine-like process (aip) between alp and amp ....***Thyropygus cristagalli***

6* Lateral process of anterior coxal fold (alp) slender, regularly curved, no additional process between lateral (alp) and mesal (amp) ones **7**

7 Lateral process of anterior coxal fold (alp) apically abruptly truncate

……………………………………………………………………………***Thyropygus bearti***

7* Lateral process of anterior coxal fold (alp) apically pointed................................... **8**

8 Mesal process of anterior coxal fold (amp) very small, telopodite distally to fe with a small round lobe (lo) projecting distolaterally.................................***Thyropygus loxia***

8* Mesal process of anterior coxal fold (amp) relatively long **9**

9 Mesal process of anterior coxal fold (amp) much shorter than lateral process (alp), directed obliquely disto-mesad, slender, straight. ....***Thyropygus chelatus***

9* Mesal process of anterior coxal fold (amp) directed distad, thicker, straight or slightly sigmoid **10**

10 Mesal process of anterior coxal fold (amp) almost as long as lateral process (alp), slightly sigmoid, pointed; mesal process of posterior coxal fold (pmp) directed distolaterad...***Thyropygus brachyacanthus***

10* Mesal process of anterior coxal fold (amp) longer than lateral process (alp), directed distad, parallel with opposite process... **11**

11 Lateral process of anterior coxal fold (alp) apically with a crest extending caudad and ending in a small spine; mesal process of anterior coxal fold (amp) apically irregularly tuberculate; telopodite distally without a rounded lobe (lo); femoral spine (fe) short; spatulate lobe (sl) distally rounded, with smooth edges

…………………………………………………………………...***Thyropygus inflexus***

11* Lateral process of anterior coxal fold (alp) apically without a crest; mesal process of anterior coxal fold (amp) apically sharp; telopodite distally with a rounded lobe (lo); femoral spine (fe) long; margins of spatulate lobe (sl) terminally meeting in a distinct angle ....***Thyropygus bispinus***

The identification key to species of the *Thyropygus bifurcus* subgroup ((Pimvichai et al., 2009b) is as follows:

1 Telopodite with a single femoral spine... **2**

1* Telopodite with a double femoral spine.. **3**

2 Lateral process of anterior coxal fold (alp) without an apical crest; mesal process of anterior coxal fold (amp) shorter than and as broad as alp, directed distad; femoral spine (fe) very long and slender..***Thyropygus casjeekeli***

2* Lateral process of anterior coxal fold (alp), with a sharp crest on the posterior surface near the tip mesal process of anterior coxal fold (amp) almost as long as alp, straight, directed distad; femoral spine (fe) very long, slender, with an additional lamella at base ………………..***Thyropygus quadricuspis***

3 Lateral process of anterior coxal fold (alp) broader, terminating in a very short external spine and a very long internal one; mesal process of anterior coxal fold (amp) as long as alp; first femoral spine (fe 1) very short, pointed; second femoral spine (fe 2) very long, as long as tibial spine (ti); an additional lamella at both side of base of fe 2..***Thyropygus richardhoffmani***

3* Lateral process of anterior coxal fold (alp) slender, regularly curved, sickle-shaped **4**

4 Mesal margin of lateral process of anterior coxal fold (alp) simple, without a caudad spine or crest; mesal process of anterior coxal fold (amp) much shorter than lateral process (alp), curved, pointed ....***Thyropygus enghoffi***

4* Mesal margin of lateral process of anterior coxal fold (alp) with a caudad small spine or crest **5**

5 Mesal margin of lateral process of anterior coxal fold (alp) with a small caudad crest; mesal process of anterior coxal fold (amp) slightly shorter than alp, slightly sigmoid, pointed...***Thyropygus bifurcus***

5* Mesal margin of lateral process of anterior coxal fold (alp) with a short curved caudad spine; mesal process of anterior coxal fold (amp) as long as alp, straight ....***Thyropygus demangei***

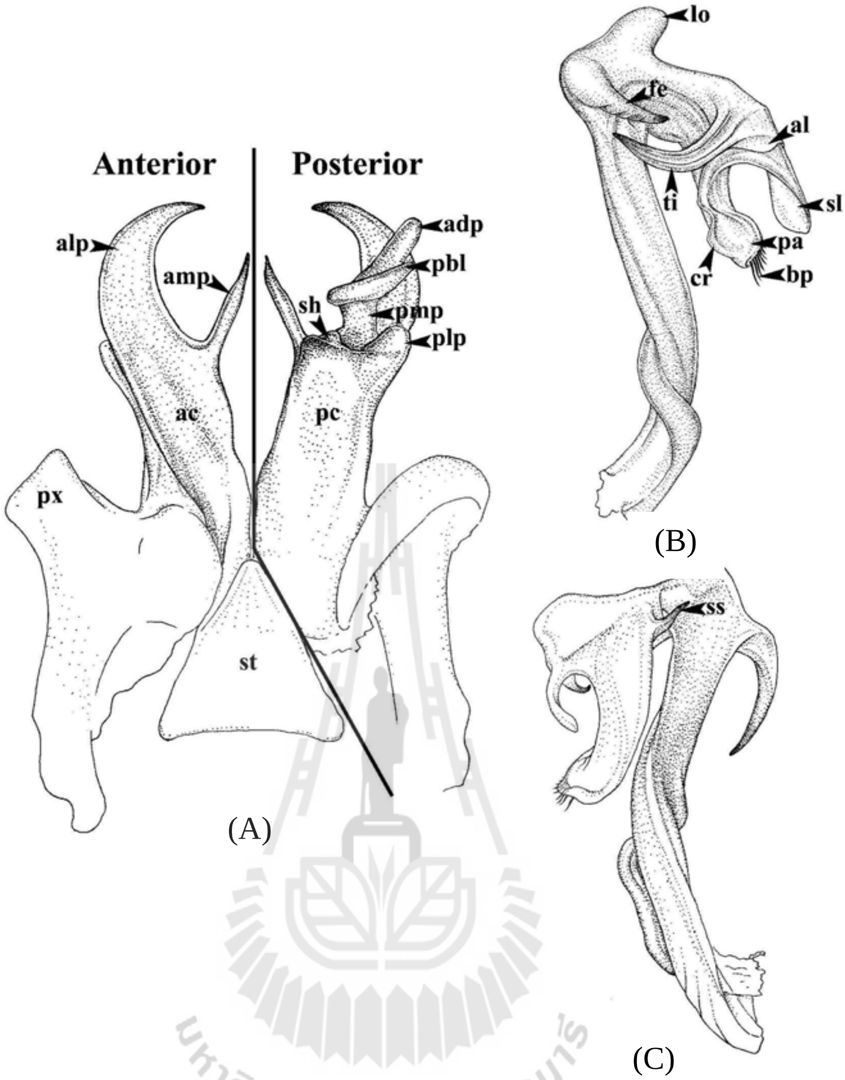


Figure 3.4 Semidiagrammatic sketches of *T. allevatus* group gonopod structure labelled according to the terminologyemployed (Pimvichai et al., 2009a).

(A) Gonopods, without telopodites.

(B) Telopodite (anterior view).

(C) Telopodite (posterior view).

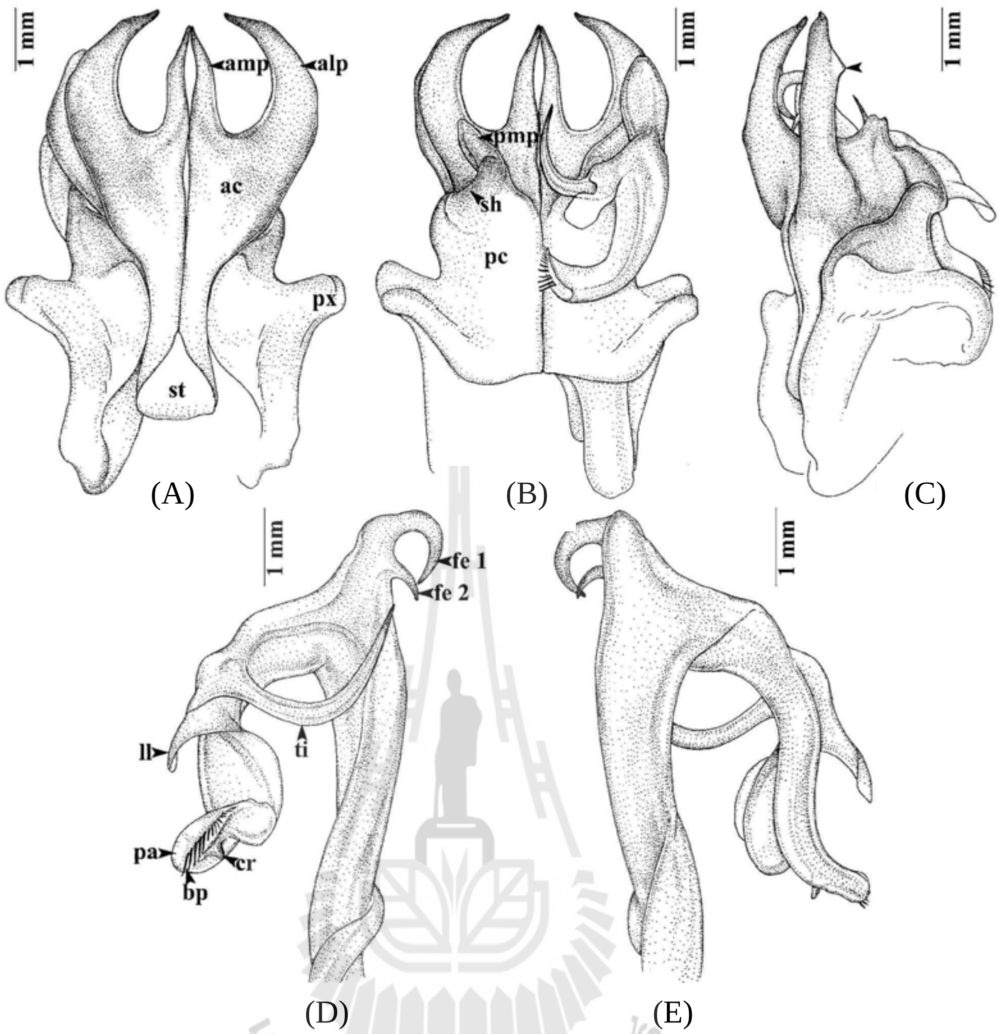


Figure 3.5 *Thyropygus bifurcus*, holotype, gonopods (Pimvichai et al., 2009a).

(A) Anterior view, right telopodite removed

(B) Posterior view right telopodite removed

(C) Lateral view

(D) Right telopodite, posterior-mesal view

(E) Rright telopodite, anterior-lateral view

3.3 Methods for measuring species diversity

An alternative for assessing community diversity is to calculate diversity indices based on the proportional abundance of species. A diversity index is a mathematical measure of species diversity in a community. Diversity indices provide more information about community than simply species richness (i.e., the number of species present); they also take the relative abundance of different species into account. Diversity indices provide important information about rarity and commonness of species in a community. The ability to quantify diversity in this way is an important tool for biologists trying to understand community structure. There are many diversity indices that can be used to calculate biodiversity. Of the many available, Shannon-Wiener index and Simpson's index have been widely used (Stephen, 2000). Hence, these two indices were applied for this study.

Abundance and density of millipedes were calculated as follows (Krebs, 1985):

$$\text{Abundance} = \frac{\text{number of adult individuals of species x}}{\text{number of plots of species x}}$$

$$\text{Density} = \frac{\text{number of adult individuals of species x}}{\text{total areas of sampling}}$$

3.3.1 Shannon diversity index

This index is symbolized by *H*, and is also known as the Shannon-Wiener index. It is the most commonly used to characterize species diversity in a community. Shannon's index accounts for both abundance and evenness of the species present. The proportion of species *i* relative to the total number of species (*pi*) is calculated, and then multiplied by the natural logarithm of this proportion (*lnpi*). The resulting product is summed across species, and multiplied by –1.

$$H = -\sum_{i=1}^{S} pi \ln pi$$

H = Shannon's diversity index

S = total number of species in the community (richness)

pi = proportion of sample belonging to *i* species

For natural community, the Shannon index usually falls between 1.5 and 3.5 and rarely exceed 4.5.

3.3.2 Evenness (Equitability)

As diversity is at a maximum when all species within a community are equally abundant, a measure of evenness is the ratio of the observed diversity to the maximum possible for the observed species number. The calculation of evenness or equitability index were determined of the form:

$$j = \frac{H'}{H'\max}$$

J = Evenness or Equitability index

H' = Shannon diversity index

$H'\max = ln\ s$

3.4 Methods for measuring environmental factors

The computer statistical package Microsoft, SPSS version 11.5 for window was used to perform the following statistical analysis. Duncan's new multiple range test of one-way ANOVA was used to compare the differences of means of environmental factors in terms of air temperature, relative humidity, litter and soil properties. The stepwise multiple regressions were used to examine correlation between the number of millipede species and various environmental factors.

3.4.1 Climate

The following climate characteristics were considered; air temperature, relative humidity, light intensity and rainfall.

3.4.2 Soil sampling and analysis

In each forest type, soil samples of 0-30 cm depth and 500 g, were collected from five quadrats (where millipedes are sampled) and then these 3 soil samples were mixed together in a plastic bag to made one sample for subsequent analyses.

After extracting millipedes from all soil samples, the soil samples were carried back to the Suranaree University of Technology Laboratory, at Center for Scientific and Technological Equipment 2 (F2), where various analyses were conducted. After returning to the laboratory then the soil samples were dried indoor under laboratory conditions for 24 hours. The soil were crushed using a pestle and mortar and filter-tipped with a 2 mm sieve, rejecting roots and stones to give the fine earth fraction. Then an analysis was conducted in the following steps:

1) Soil pH was measured by suspending soil sample in water and KCl at soil-water ratio 1:1 and soil-KCl ratio 1:1.

2) Organic matter was measured by the Walkley-Black wet oxidation. The organic carbon in the sample was oxidized with a mixture of potassium dicromate and sulphuric acid without external heating. The excess potassium dicromate were tritrated with ferrous sulphate.

3) Total nitrogen was measured using a Kjeldahl oxidation. The analysis of total nitrogen requires the complete breakdown or oxidation of organic matter. Hydrogen peroxide was added as an additional oxidising agent. Selenium took place of the traditional mercury catalyst and lithium sulphate was used to raise the boiling point.

4) Phosphorus was measured using the perchloric acid digestion method.

5) Potassium was measured by the atomic emission spectrometer (AES) after diluting the extraction solution with the 0.63% cesium-solution.

6) Calcium and magnesium were measured by the atomic absorption spectrophotometer (AAS) after diluting the extraction solution with the 1.25% lanthanum solution.

7) The water content was measured from the weight loss of the known amount of the soil samples after drying for 24 hours at 105°C in the oven.

3.4.3 Litter sampling and analysis

In each forest type leaf litter samples were collected from quadrats. The leaf litters were kept in a plastic bag for subsequent analyses. The leaf litters were dried at 105°C to a constant weight (18-24 hours). The oven dry weight of litter is the fixed reference weight used to quantify the amount of water in litter. Water content of litter by weight was calculated as follows:

$$\% \ H_2O = \frac{\text{(wet weight litter – oven dry weight litter)}}{\text{wet weight litter}} \times 100$$

3.5 Methods for measuring food consumption of cylindrical millipedes

3.5.1 Cylindrical millipedes sampling

Adult cylindrical millipedes (*Thyropygus cuisinieri*) were collected from the field. However, adults tend to be more opportunistic feeders than the immatures. This limitation in food selection by immatures may be due to the structure and functioning of the mouth parts, with tough plant material being unable to be broken down into small enough particles to allow ingestion (Dangerfield and Telford, 1989).

Figure 3.6 Cylindrical millipedes (*Thyropygus cuisinieri*).

3.5.2 Leaf litter

The major leaf litter available in the vicinity of sampling locations of millipedes in the field was employed as diets. Freshly fallen leaf litter was spreaded over on the soil floor of the field for partial decomposition.

Figure 3.7 Leaf litter.

3.5.3 Feeding trials

1) The millipedes were maintained in a temperature-controlled room at 27°C ± 3 with uniform illumination and a photoperiod of light:dark region = 12:12

2) A total of 1000 g air-dried soil was offered per replicate in circular containers (30 cm diameter, 30 cm height).

3) A total of 50 g air-dried leaf litter was cut into 5 cm diameter offered per replicate in circular containers in five replicates (Figure 3.6).

Figure 3.8 Air-dried leaf litter.

Figure 3.9 Circular containers.

4) For each replicate, four adult millipedes (two males and two females) were weighed and marked on the second tergite with different colors for identification for subsequent weighing.

5) The millipedes were then placed in each circular container (Figure 3.8). They were allowed to feed on the moist leaf litter up to 6 months (June-November).

Figure 3.10 The millipedes in each circular container.

6) The containers were covered with cotton cloth and 20 ml of water were sprinkled once a day on the leaf litter in each container.

7) After 7 days, animals were reweighed, faecal pellets were separated.

8) At the end of each month, the uneaten leaf litter and faecal matter (Figure 3.9) were removed and dried to a constant weight before weighing.

Figure 3.11 The faecal pellets of millipedes.

3.5.4 The consumption rate analysis

The experiment was run in a laboratory room under a 12:12 light: dark photoperiod. Animals were reweighed weekly. Leaf litter was sorted out and air-dried and the remaining weight was determined to estimate the litter consumption rate, growth rate, and food conversion efficiency.

Paired *t* test was employed to determine the difference in consumption rate of leaf litter (6 months trial), consumption rate, growth rate, and food conversion efficiency between leaf litter and digestibility of millipedes using the StatSoft Inc. 1995. Pearson correlation was performed using Graph Pad Prism version 4.0 b for windows, GraphPad Software, San Diego California, USA to determine the relationship between consumption rate, growth rate, and food conversion efficiency of millipedes vs. and digestibility of millipedes (parameters: p values, two tailed; confidence intervals, 95%).

Nutritional indices

Nutritional indices are modified from the methods of Waldbauer (1968), Scriber and Slansky (1981) and Wooten and Craword (1975).

CR = consumption rate

GR = growth rate

ECI = efficiency of conversion of ingested food to biomass

ECD = efficiency of conversion of digested food to biomass

AD = approximate digestibility

These indices were calculated on a dry weight basis as follows:

$$CR = \frac{\text{Weight of leaf litter eaten}}{\text{Duration of experiment (days)}}$$

$$GR = \frac{\text{Weight gain}}{\text{Duration of experiment (days)}}$$

$$ECI = \frac{\text{Weight gain}}{\text{Weight of leaf litter eaten}} X\ 100$$

$$AD = \frac{\text{Weight of leaf litter eaten} - \text{Weight of faeces}}{\text{Weight of leaf litter eaten}} X\ 100$$

$$ECD = \frac{\text{Weight gain}}{\text{Weight of leaf litter eaten} - \text{Weight of faeces}} X\ 100$$

CHAPTER IV

RESULTS AND DISCUSSION

The results of the study are divided into three main parts. First, it details the species diversity and distributions of millipedes. Second, it describes the relationships between millipede species and environmental factors. Third, it explains the food consumption processes of cylindrical millipedes (*Thyropygus cuisinieri* Carl, 1917).

4.1 Millipede identification

A total of seventeen millipede species were found in five families (Zephroniidae, Paradoxosomatidae, Pachybolidae, Harpagophoridae, and Julidae) and five orders (Sphaeroteriida, Polydesmida, Spiroborida, Spirostreptida and Julida) in the present study. The results of orders, families and species of millipedes are listed in Table 4.1.

Table 4.1 Occurrence of orders, families and species of millipedes collected in Sakaerat Environmental Research Station.

Order	Family	Species
Sphaeroteriida	Zephroniidae	1. *Zephronia siamensis*
Polydesmida	Paradoxosomatidae	2. *Orthomorpha variegate*
		3. *Orthomorpha* sp.
		4. *Antheromorpha festiva*
		5. *Antheromorpha* sp.
		6. *Anoplodesmus* sp.
Spiroborida	Pachybolidae	7. Pachybolidae 1
		8. Pachybolidae 2
		9. *Lithostrophus segregatus*
Spirostreptida	Harpagophoridae	10. Harpagophoridae 1
		11. Harpagophoridae 2
		12. *Thyropygus* sp.1
		13. *Thyropygus allevatus*
		14. *Thyropygus induratus*
		15. *Thyropygus* sp.2
		16. *Anurostreptus sculptus*
Julida	Julidae	17. *Nepalmatoiulus* sp.

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4.1.1 Diagnostic characters of millipedes

Family Zephroniidae

Body of a 13 rings adult (Figure 4.1A), counted on the back of the animal, collum small and oval, the 2^{nd} of tergite is very broad; the 13^{th} ring is the broadest (Figure 4.1B); no ozopores; restricted to Asia, Southeast Asia, Nepal, East India (Assam), China, Borneo, Moluccus (Indonesia) and the Philippines (Sierwald, 2007). The collected specimens of the family Zephroniidae are illustrated in Figure 4.2.

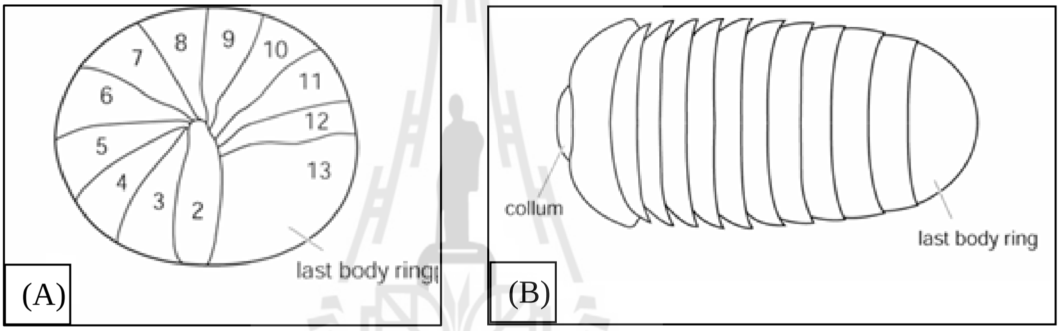

Figure 4.1 Family Zephroniidae

(A) The rolled body (B) The dorsal

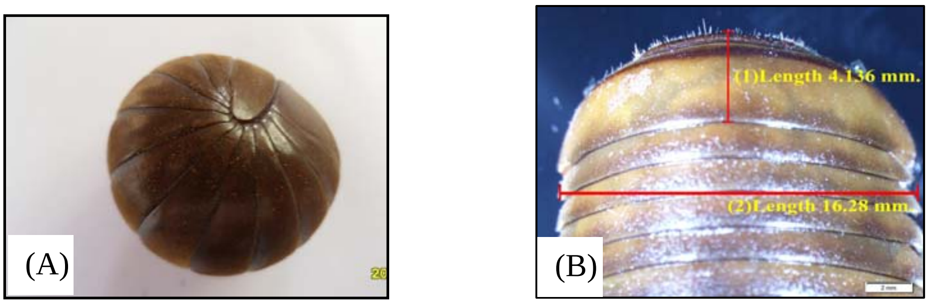

Figure 4.2 *Zephronia siamensis*

(A) The rolled body (B) The anterior

Family Paradoxosomatidae

Bodies of adults with 19 or 20 rings, there are not any eyes or ocelli; with or without paranota. The first pair of legs in the 7th ring adult males modified as gonopods, posterior pair of 7th ring normal walking leg; This family is far more diverse and numerous. They are distributed natively to all continents except North America (Sierwald, 2007). The examples of millipedes in the family Paradoxosomatidae are shown in Figure 4.3-4.7.

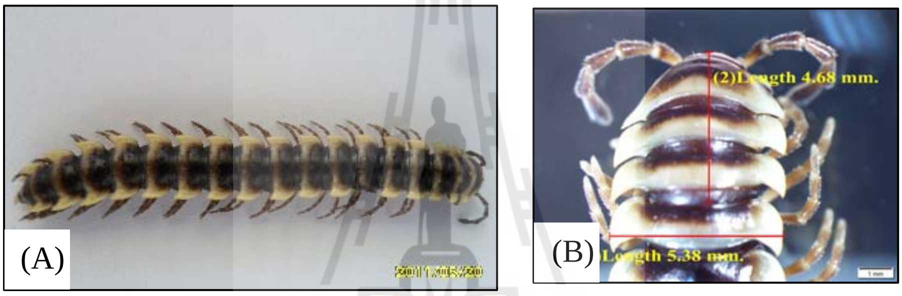

Figure 4.3 *Orthomorpha variegata*

(A) The dorsal (B) The anterior

Figure 4.4 *Orthomorpha* sp.

(A) The dorsal (B) The segmented body

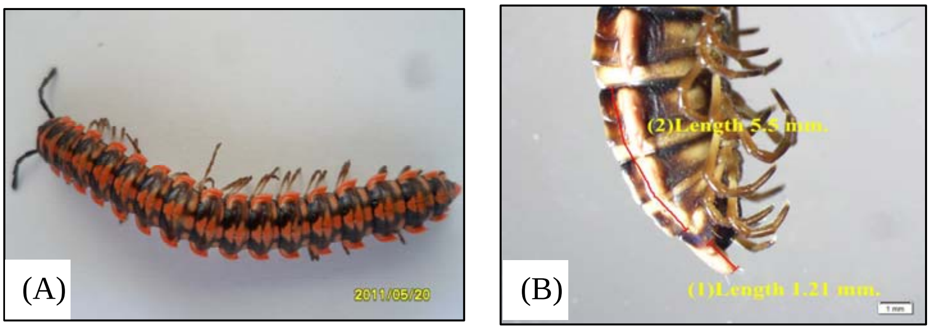

Figure 4.5 *Antheromorpha festiva*

(A) The dorsal (B) The posterior

Figure 4.6 *Antheromorpha* sp.

(A) The dorsal (B) The posterior

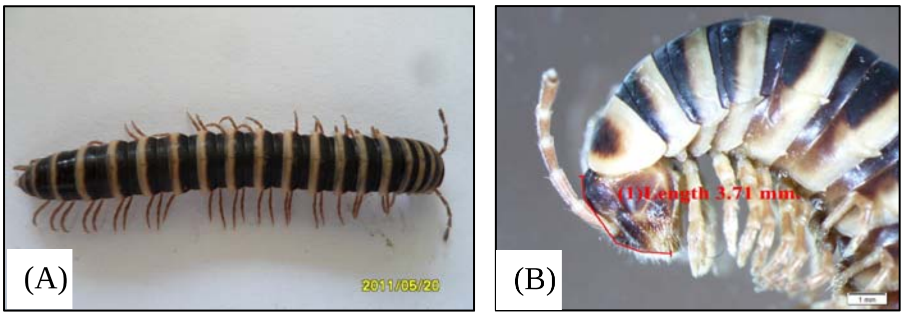

Figure 4.7 *Anoplodesmus* sp.

(A) The dorsal (B) The anterior

Family Pachybolidae

Body smooth, without longitudinal crests or ridges; labrum with distinct median suture line; 40 to 60 rings in adults; eyes with many ocelli; at most a fine pale suture line along the dorsal midline of the body; They were found in central South Africa, Madagascar, India, and Sri Lanka to Borneo (Sierwald, 2007).The species in the family Pachybolidae are featured in Figures 4.8-4.10.

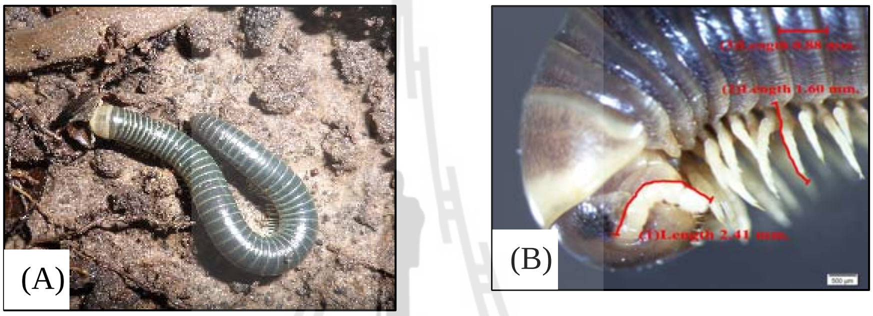

Figure 4.8 Pachybolidae 1

(A) The dorsal (B) The anterior

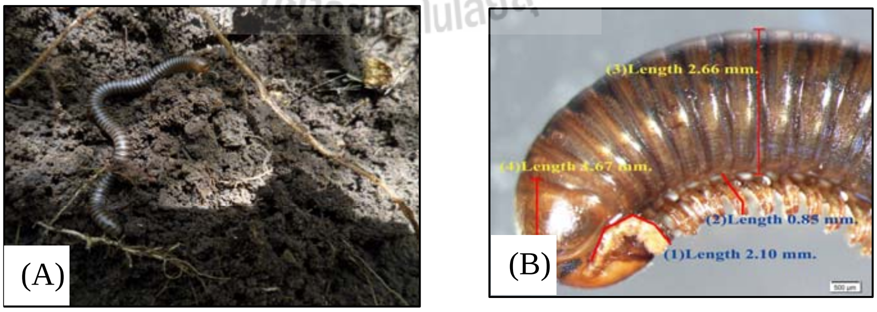

Figure 4.9 Pachybolidae 2

(A) The dorsal (B) The anterior

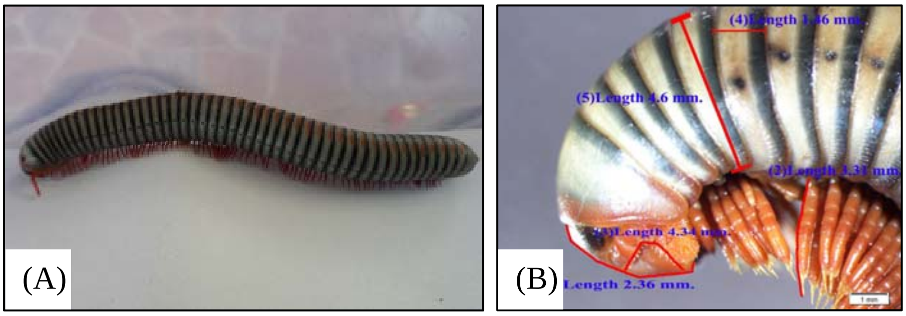

Figure 4.10 *Lithostrophus segregatus*

(A) The dorsal (B) The anterior

Family Harpagophoridae

The Harpagophoridae family is “probably the most characteristic and conspicuous element in the millipede fauna of the Oriental Region” (Hoffman, 1975). Harpagophorids are certainly very prominent members of the Oriental fauna, reaching up to 25 cm in length. The genus *Thyropygus* Pocock, 1894, is the largest genus of Harpagophoridae in Southeast Asia. It has had a complicated history but, mainly due to the work of Hoffman (1975), the genus is now quite well circumscribed. The genus is broadly distributed in Southeast Asia: Thailand, Myanmar, Vietnam, Laos, Cambodia, continental Malaysia, Sumatra, Java, and Borneo (Jeekel, 2006; Enghoff, 2005). The species in the family Harpagophoridae are featured in Figures 4.11-4.17.

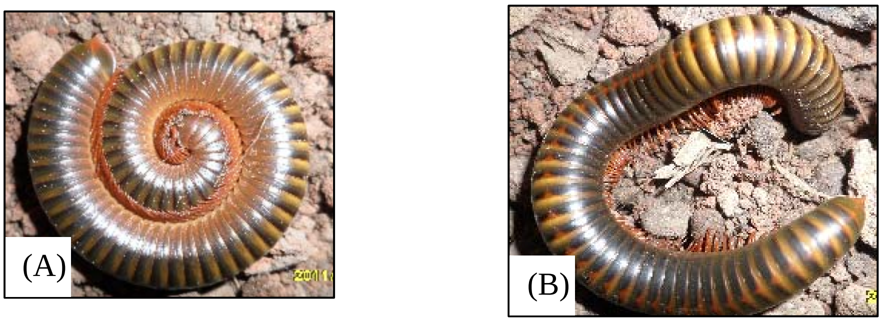

Figure 4.11 Harpagophoridae 1

(A) The side view (B) The dorsal

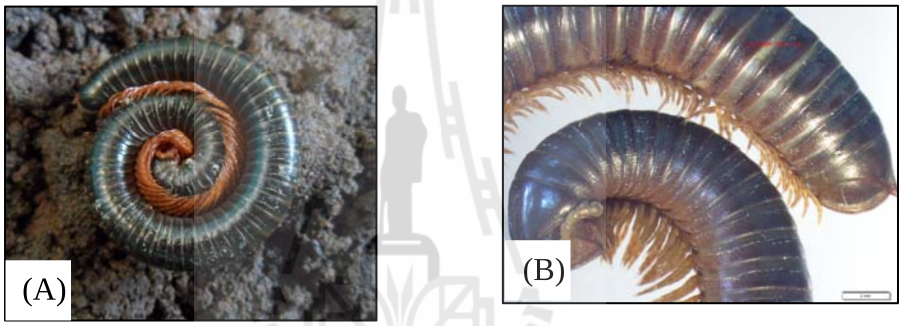

Figure 4.12 Harpagophoridae 2

(A) The side view (B) The anterior and posterior

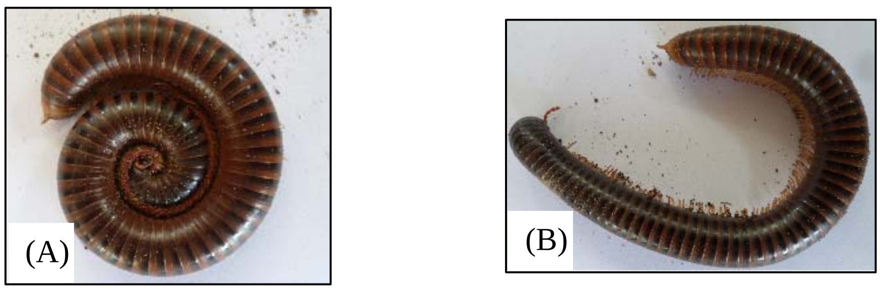

Figure 4.13 *Thyropygus* sp.1

(A) The side view (B) The dorsal

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Figure 4.14 *Thyropygus allevatus*

(A) The side view (B) The anterior

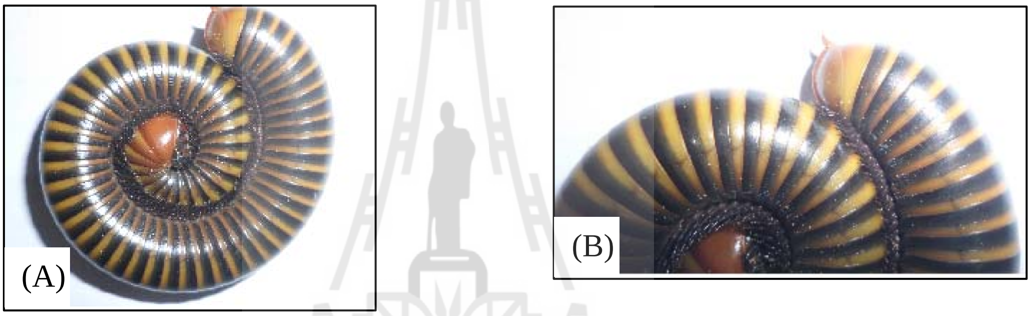

Figure 4.15 *Thyropygus induratus*

(A) The side view (B) The posterior

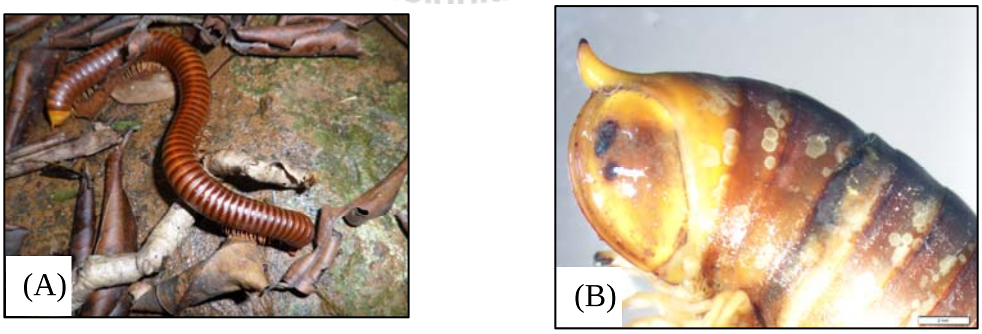

Figure 4.16 *Thyropygus* sp.2

(A) The dorsal (B) The posterior

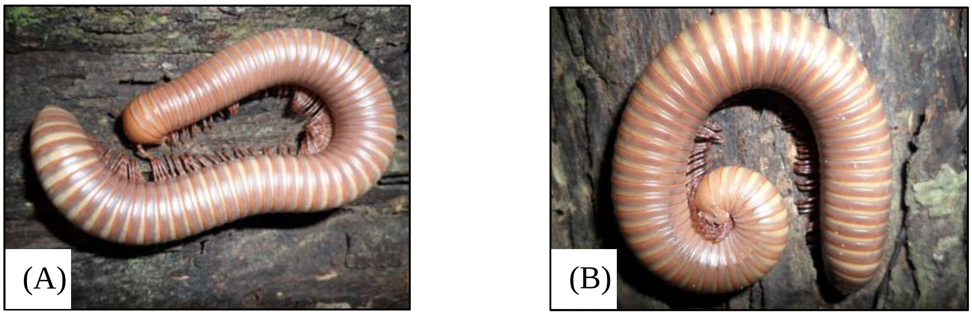

Figure 4.17 *Anurostreptus sculptus*

(A) The dorsal (B) The side viewed

Family Julidae

Side pieces of gnathochilarium were found at the midline; it may be necessary to detach the head from the trunk. The first pair of legs in males is short and hook-like, or enormously enlarged as claspers; fresh specimens with “whorl or fringe of setae” at the hind margins of body rings. They are distributed throughout the Palearchic region from the Pacific to the Atlantic and the Mediterranean Region of Africa (Sierwald, 2007). The species in the family Julidae is featured in Figure 4.18.

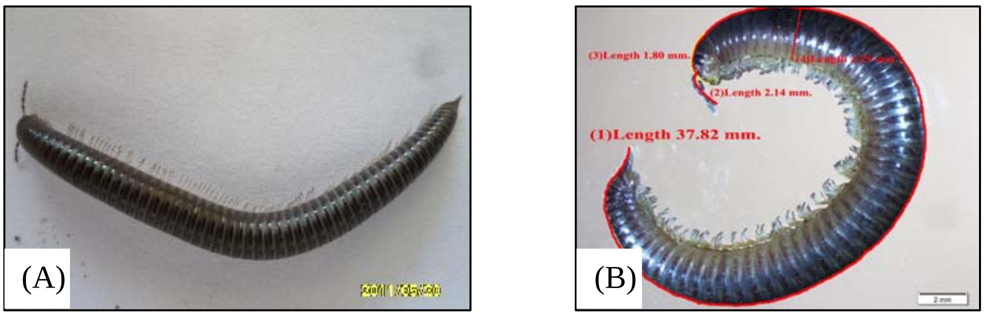

Figure 4.18 *Nepalmatoiulus* sp.

(A) The dorsal (B) The side viewed

4.1.2 Millipede species and distribution

A total of 893 millipedes were collected in all studied areas. The 893 individuals were identified to species though 82 were unidentifiable (juveniles). The highest number of specimens was *Zephronia siamensis* (263) which belongs to the family Zephroniidaes, followed by Pachybolibae 2 (151) in the family Pachybolidae and *Orthomorpha variegata* (125) in the family Paradoxosomatidae. The lowest number of specimens (3) were Harpagophoridae 1 and *Thyropygus induratus* in the family Harpagophoridae. Among these 6 families, Julidae found the least number (69). The occurrence of species and number of millipedes collected in sampling areas are listed in Table 4.2. Interestingly, the *Zephronia siamensis* is the only species of Zephroniidae distributed all over the areas and it had the highest number of individuals (263 individuals). It was a species known only in Thailand and thus, for the time being, regarded as a Thai endemic species. It occurrs in Thailand (Enghoff, 2005). Many millipede species were presented in various places. Six millipedes (*Zephronia siamensis*, *Orthomorpha variegate, Orthomopha* sp., *Antheromorpha festiva*, *Lithostrophus segregates* and *Nepalmatoiulus* sp.) were found in four forests. Whereas, three species (Harpagophoridae 2, *Thyropygus* sp.1 and *Thyropygus* sp.2) were presented in three forests. Furthermore, six species (*Anoplodesmus* sp., Harpagophoridae 1, Pachybolibae 2, and *Anurostreptus sculptus*) were distributed in DEF and ECO, as well as *Thyropygus induratus* was distributed in DDF and ECO but *Thyropygus allevatus* was found in DEF and PTF. In contrast, two millipedes were very site-specific species such as *Platyrhacus* sp.1 and Pachybolibae 1 in dry evergreen forests. The distributions of these 17 millipede species in studied areas were as follows:

1. The *Zephronia siamensis* was the common millipede in DEF, DDF, ECO and PTF. A total of 263 individuals were collected at studied areas. The highest number was in the PTF (116 individuals) and the lowest was in the DEF (31 individuals). This species was the first recorded species in Thailand and it was the Thai endemic species (Enghoff, 2005).

2. *Orthomorpha variegata* was found in DEF, DDF, ECO and PTF. A total of 125 individuals were collected at studied areas. It was found the highest number in the DEF (48 individuals) and the lowest was in the ECO (11 individuals).

3. *Orthomopha* sp. was found in the DEF, DDF, ECO and PTF. A total of 61 individuals was collected at studied areas. It was found highest in the DEF (31 individuals) and the lowest was in the ECO (7 individuals).

4. *Antheromorpha festiva* was found in the DEF, DDF, ECO and PTF. A total of 19 individuals was collected at studied areas. The highest was in the DDF (8 individuals) and the lowest was in the PTF (1 individual).

5. *Antheromorpha* sp. was found only in the DEF. A total of 15 individuals was collected at studied areas.

6. *Anoplodesmus* sp. was found in the DEF and ECO. A total of 11 individuals was collected at studied areas.

7. Pachybolidae 1 was found only in the DEF. A total of 5 individuals was collected at studied areas.

8. Pachybolidae 2 was found in the DEF and ECO. A total of 151 individuals was collected at studied areas. The highest was in the ECO (116 individuals)

9. *Lithostrophus segregates* was found in the DEF, DDF, ECO and PTF. A total of 22 individuals was collected at studied areas. The highest was in the ECO (16 individuals) and the lowest was in the PTF (1 individual).

10. Harpagophoridae 1 was found in the DEF and ECO. A total of 3 individuals was collected at studied areas.

11. Harpagophoridae 2 was found in the DDF, ECO and PTF. A total of 21 individuals was collected at studied areas.

12. *Thyropygus* sp.1 was found in the DEF, ECO and PTF. A total of 6 individuals was collected at studied areas.

13. *Thyropygus allevatus* was found in the DEF and PTF. A total of 11 individuals was collected at studied areas.

14. *Thyropygus induratus* was found in the DDF and ECO. A total of 3 individuals was collected at studied areas.

15. *Thyropygus* sp.2 was found in the DEF, ECO, and PTF. A total of 33 individuals was collected at studied areas.

16. *Anurostreptus sculptus* was found in the DEF and ECO. A total of 75 individuals was collected at studied areas. The highest was in the DEF (74 individuals)

17. *Nepalmatoiulus* sp. was found in the DEF, DDF, ECO and PTF. A total of 69 individuals was collected at studied areas. The highest was in the DEF (44 individuals) and the lowest was in the DDF (2 individuals).

Table 4.2 Occurrence of species and numbers of millipedes collected in Sakaerat Environmental Research Station.

Millipede Family/Species	**Forest types**				**Total**
	DEF	**DDF**	**ECO**	**PTF**	
Zephroniidae					
1. *Zephronia siamensis*	31	55	61	116	**263**
Paradoxosomatidae					
2. Orthomorpha variegata	48	44	11	22	**125**
3. *Orthomopha* sp.	31	9	7	14	**61**
4. *Antheromorpha festiva*	6	8	4	1	**19**
5. *Antheromorpha* sp.	15	-	-	-	**15**
6. *Anoplodesmus* sp.	7	-	4	-	**11**
Pachybolidae					
7. Pachybolidae 1	5	-	-	-	**5**
8. Pachybolidae 2	35	-	116	-	**151**
9. *Lithostrophus segregatus*	3	2	16	1	**22**
Harpagophoridae					
10. Harpagophoridae 1	2	-	1	-	**3**
11. Harpagophoridae 2	-	17	1	3	**21**
12. *Thyropygus* sp.1	3	-	2	1	**6**
13. *Thyropygus allevatus*	8	-	-	3	**11**
14. *Thyropygus induratus*	-	1	2	-	**3**
15. *Thyropygus* sp.2	17	-	3	13	**33**
16. *Anurostreptus sculptus*	74	-	1	-	**75**
Julidae					
17. *Nepalmatoiulus* sp.	44	2	10	13	**69**
Total	329	138	239	187	**893**

- = data not found
DEF = dry evergreen forest
DDF = dry dipterocarp forest
ECO = ecotone
PTF = plantation forest

4.1.3 Millipedes abundance

Average of adult millipede abundance in a year (June 2010-May 2011) was 52.53 ind/m^2 (Table 4.3). The abundance of millipedes was a minimum of 0.06 ind/m^2 in January and a maximum of 14.41 ind/m^2 in June (Table 4.3). The seasonal fluctuations in soil moisture responding to rainfall events may affect the millipede species and millipede abundance. When the soil moisture levels decrease during December to February, the most millipedes' burrows are deeper into the soil. This result is supported by Karamaouna (1987) and Karamaouna and Geoffroy (1985) who reported that the activity periods of some Mediterranean species were very pronounced and only active in wet period (winter and spring). No millipedes were found between May and October when it was very dry. During this period, they burrowed into the soil.

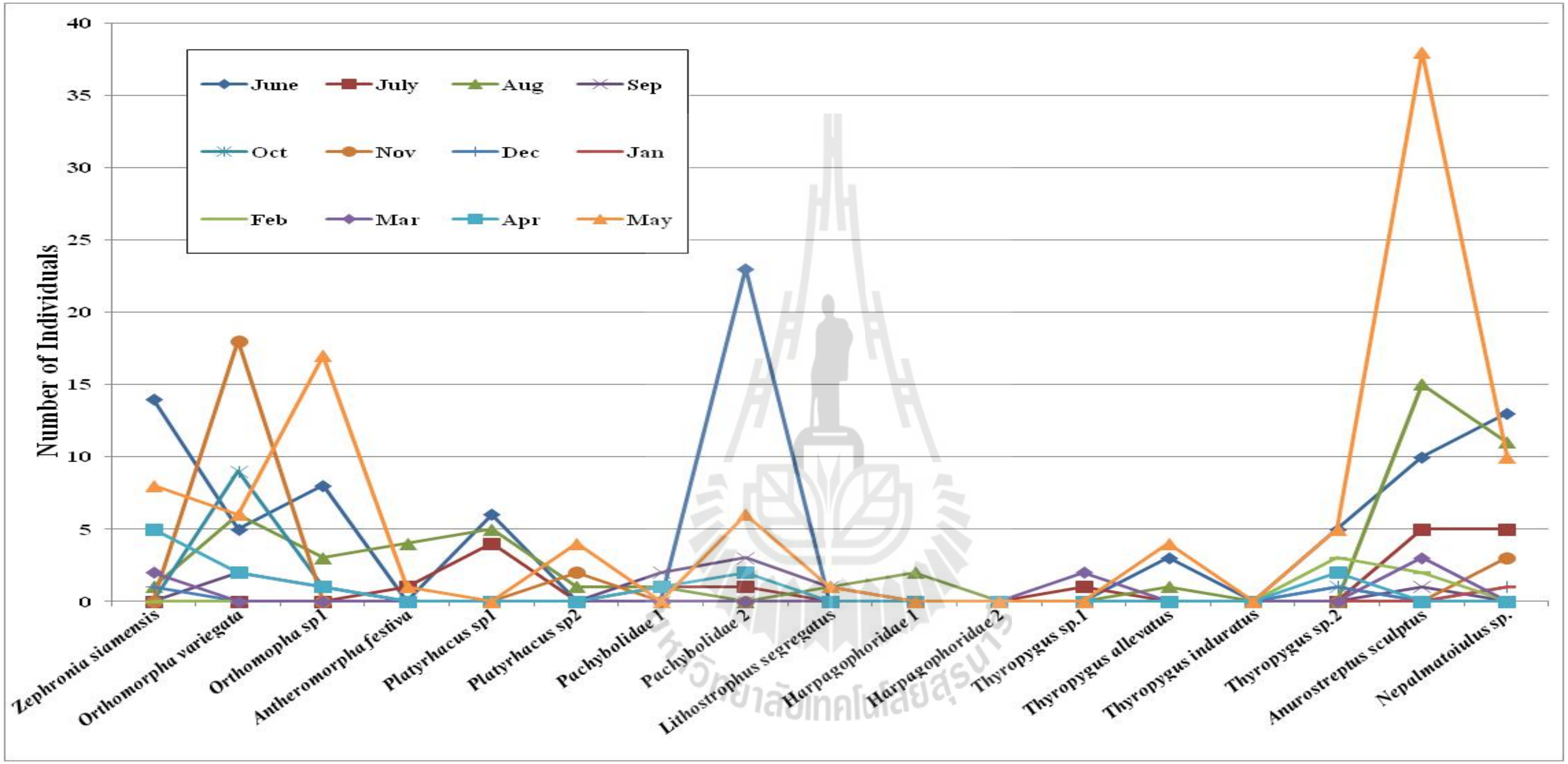

Figure 4.19 The abundance of adult millipede species in DEF**.**

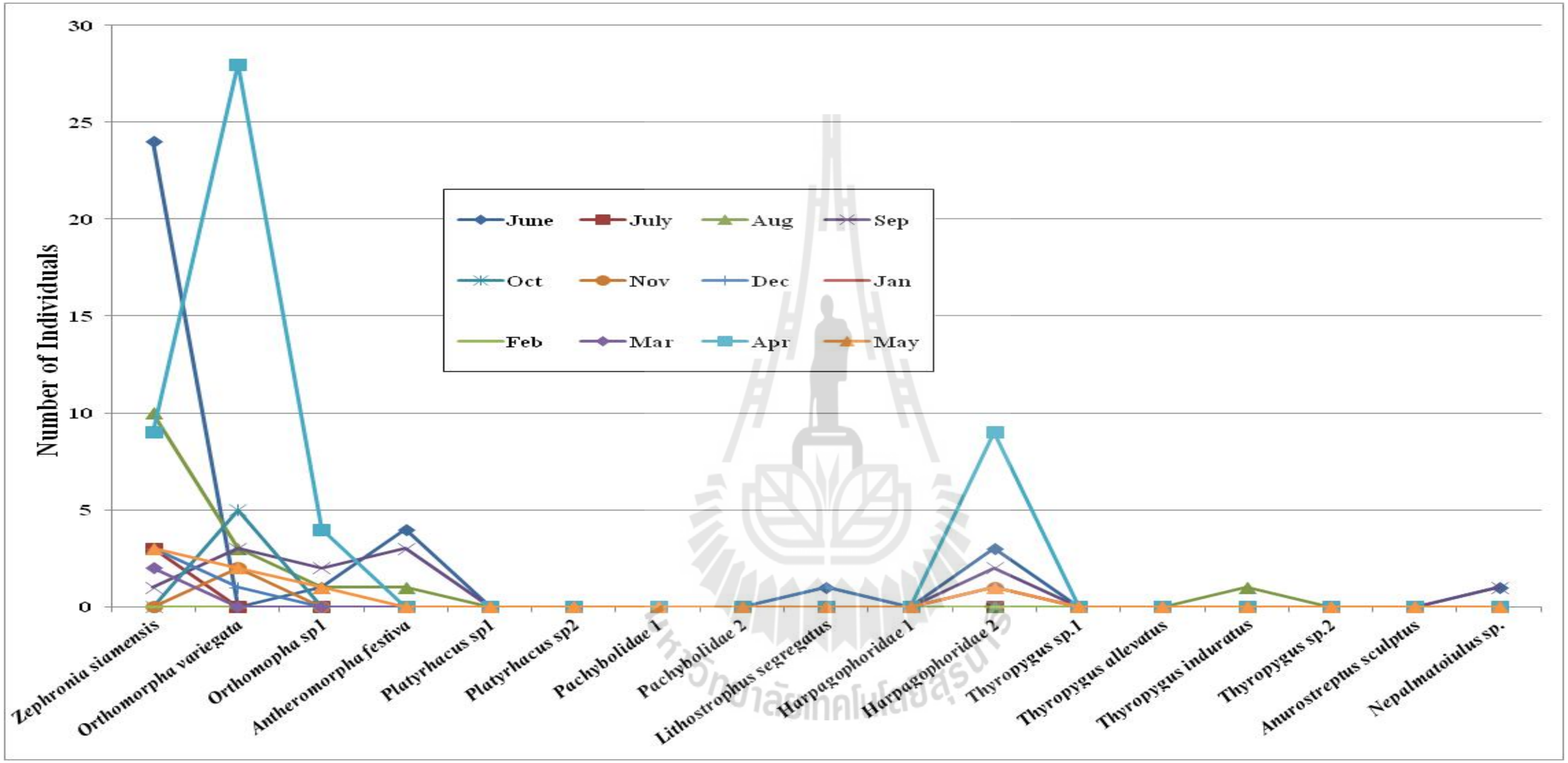

Figure 4.20 The abundance of adult millipede species in DDF.

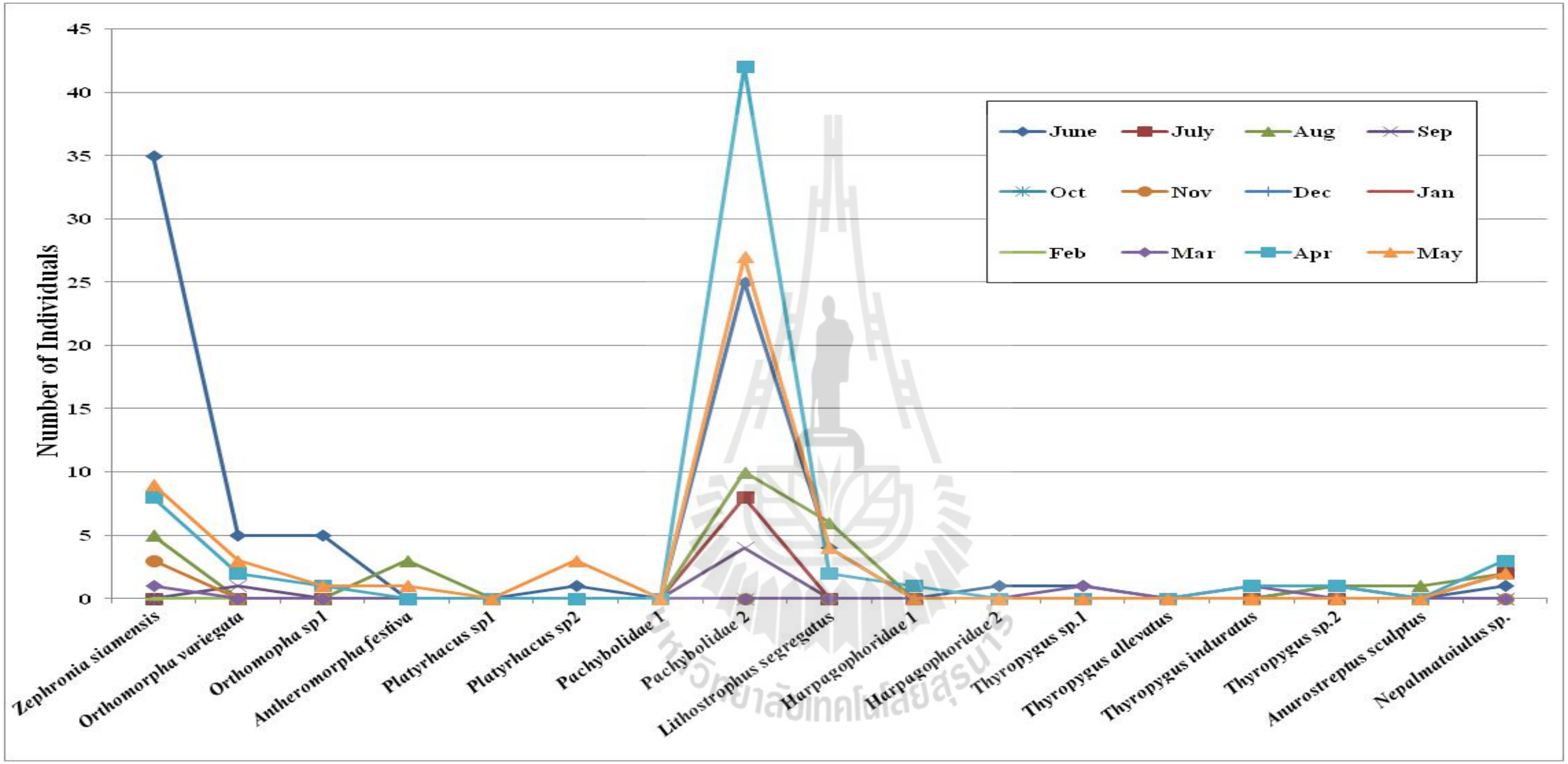

Figure 4.21 The abundance of adult millipede species in ECO.

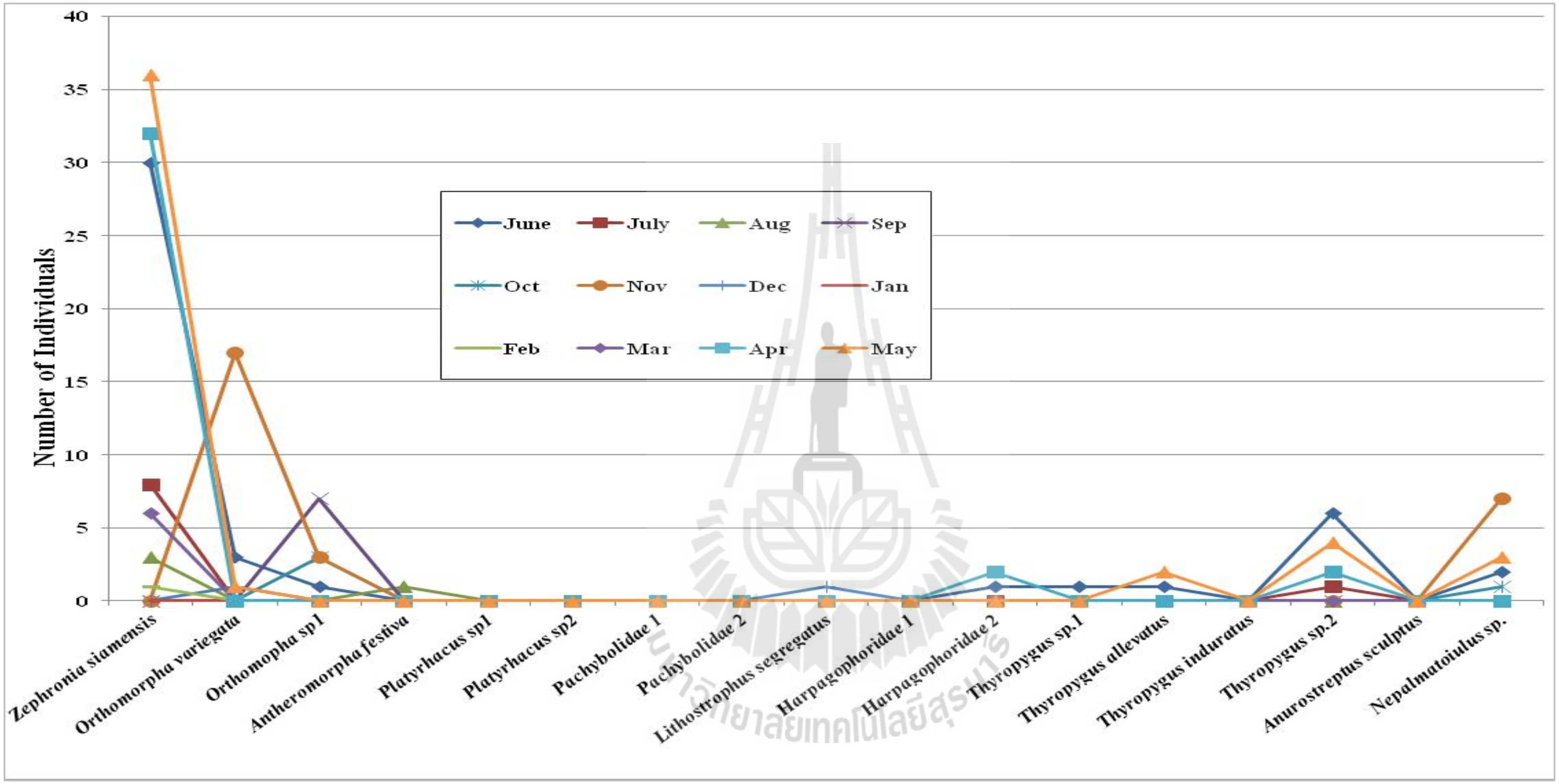

Figure 4.22 The abundance of adult millipede species in PTF.

4.1.4 Seasonal change and abundance of millipede species

The numbers of millipedes were highest in June (14.41 ind/m^2) followed by May (11.94 ind/m^2) and April (9.41 ind/m^2), respectively (Table 4.3).This result is similar to Bhakat (1987) who estimated the density and biomass of *Streptogonus phipsoni* (Polydesmida) in grassland over a year by sampling with quadrats. There were considerable differences between months. In general, the mean population density for each month was correlated positively with mean monthly rainfall. Banerjee (1967) recorded that peak activity of *Cylindroiulus punctatus* occurred during the breeding season when adults were searching actively for mates.

The *Zephronia siamensis* was only one species of family Zephroniidae. The abundance of this species was 21.92 ind/m^2 or 29.45 % of the total abundance (Table 4.4). The highest millipede abundance was present during April to June and rapidly decreased from September to February (Figure 4.23). Two genera of family Paradoxosomatidae were found in this study, *Orthomorpha* and *Antheromorpha*. The abundance two species of *Orthomorpha* was 15.50 ind/m^2 or 21.18% of the total abundance. For the occurrence, *Orthomorpha variegata*, 10.42 ind/m^2 and *Orthomopha* sp., 5.08 ind/m^2 were the common species in all studied areas (Table 4.4). The abundance of *Antheromorpha* was 2.83 ind/m^2 or 2.68% of the total abundance. The abundance of genus *Anoplodesmus* sp. was 2.17 ind/m^2 or 2.91% of the total abundance.

In temperate regions, most species are less active in the winter. The main exceptions are the Chordeumatida which are adult during the winter months. Species of *Polydesmus* are active in spring and summer (occasionally autumn too) whereas those of *Cylindroiulus* usually have two regular peaks of activity in spring and autumn (Hopkin and Read, 1992).

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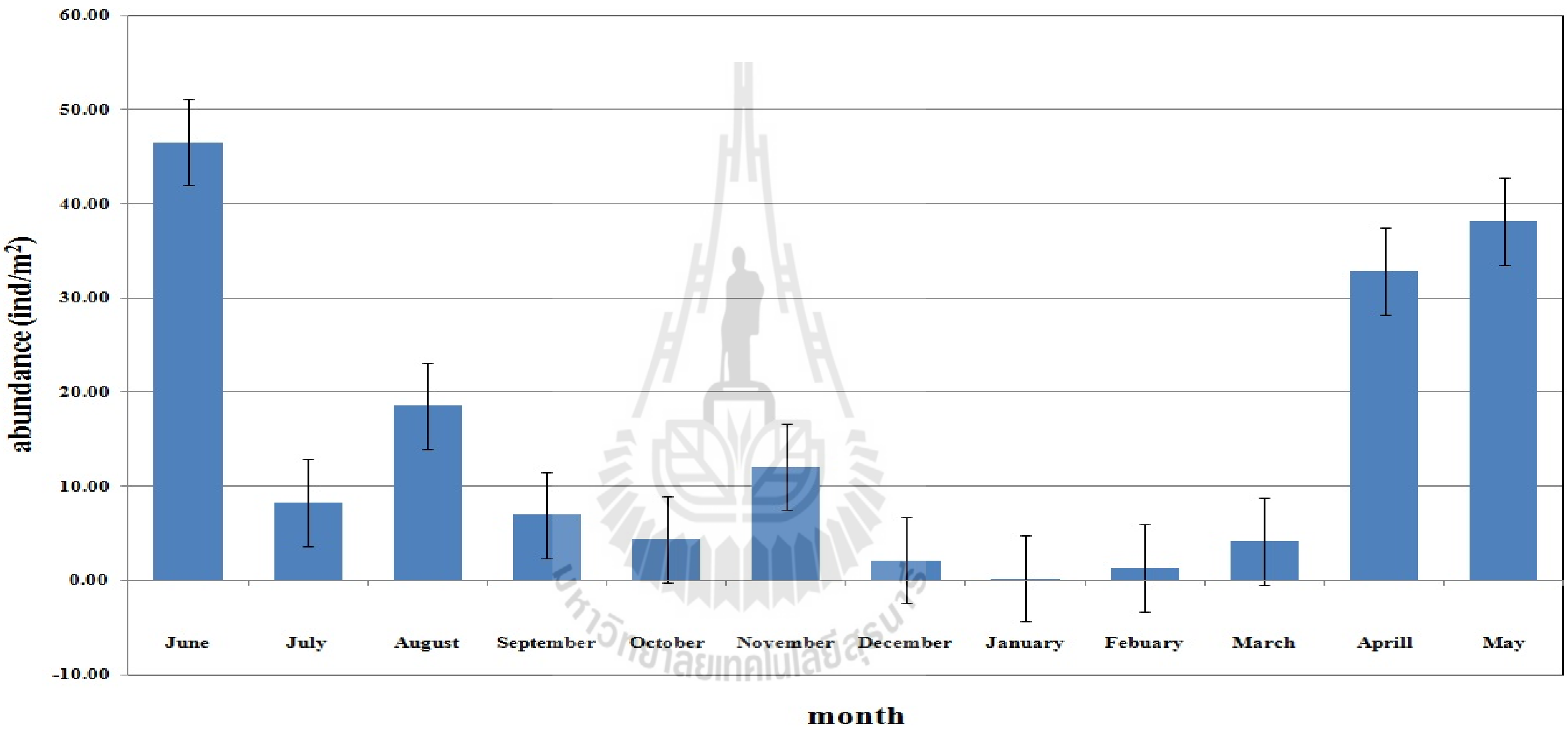

Figure 4.23 The abundance of adult millipedes, in June 2010 -May 2011 in sampling areas at Sakaerat Environmental Research Station.

Table 4.3 The abundance of adult millipede species in each month at Sakaerat Environmental Research Statiopn.

Month	Forest type								**Total**
	DEF		DDF		ECO		PTF		
	Ind/m^2	S.E	Ind/m^2	S.E	Ind/m^2	S.E	Ind/m^2	S.E	
June	5.12	5.09	2.00	2.94	4.65	6.05	2.65	3.65	**14.41**
July	0.88	1.09	0.18	0.33	0.59	1.04	0.53	0.93	**2.35**
August	3.00	3.06	0.94	1.33	1.65	2.09	0.24	0.42	**5.82**
September	0.59	0.76	0.71	0.91	0.29	0.52	0.41	0.78	**2.00**
October	0.65	1.07	0.29	0.55	0.00	0.00	0.24	0.42	**1.18**
November	1.35	2.23	0.18	0.31	0.18	0.33	1.59	2.62	**3.29**
December	0.18	0.29	0.29	0.48	-	-	0.12	0.21	**0.59**
January	0.06	0.11	-	-	-	-	-	-	**0.06**
February	0.29	0.52	-	-	-	-	0.06	0.11	**0.35**
March	0.41	0.68	0.18	0.31	0.18	0.29	0.35	0.66	**1.12**
April	0.76	0.99	2.94	4.50	3.59	5.04	2.12	3.52	**9.41**
May	5.88	5.85	0.41	0.63	2.94	3.68	2.71	4.10	**11.94**
Average	**19.12**	**17.45**	**8.12**	**10.89**	**14.06**	**17.74**	**11.00**	**14.47**	**52.53**

- = data not found

DEF = dry evergreen forest DDF = dry dipterocarp forest

ECO = ecotone PTF = plantation forest

4.1.5 Abundance of adult millipedes in different forest types

The highest total abundance of millipedes was 27.42 ind/m^2 in DEF and declined to 19.92 ind/m^2 in ECO, 15.58 ind/m^2 in PTF, and 11.50 ind/m^2 in DDF (Table 4.4). Abundance of millipedes of all forest types ranged from 11.50 ind/m^2 to 27.42 ind/m^2. Kime (1992) quoted 0-1000 m^{-2}, although densities higher than this can occur in 'swarms'. In a survey by Iatrou and Stamou (1989) of macroarthropods in Mediterranean ecosystem, millipedes were found to be the most numerous saprophage. They occurred at a density of 114 m^{-2}, i.e. 38 % of the total.

4.1.6 Density of millipedes

A total of 893 millipedes were collected in this studied. The highest millipede density was *Zephronia siamensis* (average 21.92 ind/m^2) followed by Pachybolidae 2 (average 12.58 ind/m^2), and *Orthomorpha variegata* (average 10.42 ind/m^2). The lowest density millipedes were Harpagophoridae 1 and *Thyropygus induratus* (average 0.25 ind/m^2). The density of millipede species in each forest type was shown in Table 4.4 and were described as the followings:

In DEF, the fifteen millipede species were *Zephronia siamensis*, *Orthomorpha variegata*, *Orthomorpha* sp., *Antheromorpha festiva*, *Antheromorpha* sp., *Anoplodesmus* sp., Harpagophoridae 1, *Lithostrophus segregatus*, Pachybolidae 1, Pachybolidae 2, *Thyropygus* sp.1, *Thyropygus allevatus*, *Thyropygus* sp.2, *Anurostreptus sculptus* and *Nepalmatoiulus* sp. *Anurostreptus sculptus* had the highest density 6.17 ind/m^2 followed by *Orthomorpha variegata* 4.00 ind/m^2 and *Nepalmatoiulus* sp. 3.67 ind/m^2 whereas Harpagophoridae 1 had 2 individuals calculated at 0.17 ind/m^2 (Table 4.4).

In DDF, the eight millipede species were *Zephronia siamensis*, *Orthomorpha variegata*, *Orthomorpha* sp., *Antheromorpha festiva*, Harpagophoridae 2, *Lithostrophus segregatus*, *Thyropygus induratus* and *Nepalmatoiulus* sp., *Zephronia siamensis* had the highest density 4.58 ind/m^2 followed by *Orthomorpha variegata* 3.67 ind/m^2 and Harpagophoridae 2 1.42 ind/m^2 whereas *Thyropygus induratus* had 1 individual calculated at 0.08 ind/m^2 (Table 4.4).

In ECO, the thirteen species of millipedes were *Zephronia siamensis*, *Orthomorpha variegata*, *Orthomorpha* sp., *Antheromorpha festiva*, Harpagophoridae 1, Harpagophoridae 2, *Lithostrophus segregatus*, *Anoplodesmus* sp., *Thyropygus* sp.1, *Thyropygus induratus*, *Thyropygus* sp.2, *Anurostreptus sculptus* and *Nepalmatoiulus* sp., Pachybolidae 2 had the highest density 9.67 ind/m^2 followed by *Zephronia siamensis* 5.08 ind/m^2 and other were rare species (Table 4.4).

In PTF, the ten species of millipedes were *Zephronia siamensis*, *Orthomorpha variegata*, *Orthomorpha* sp., *Antheromorpha festiva*, Harpagophoridae 2, *Lithostrophus segregatus*, *Thyropygus* sp.1, *Thyropygus allevatus*, *Thyropygus* sp.2 and *Nepalmatoiulus* sp. *Zephronia siamensis* had the highest density 9.67 ind/m^2 followed by *Orthomorpha variegate* (1.83 ind/m^2), *Orthomopha* sp.(1.17 ind/m^2) and other rare species (Table 4.4).

To compare DEF and PTF, the result found that 9 millipede species (*Zephronia siamensis*, *Orthomorpha variegata*, *Orthomorpha* sp.1, *Antheromorpha festiva*, *Lithostrophus segregatus*, *Thyropygus* sp.1, *Thyropygus allevatus*, *Thyropygus* sp.2 and *Nepalmatoiulus* sp. were found in both DEF and PTF. The results were indicated that these millipedes distributed from DEF to PTF. This may be because to the similar ecological factors and habitat structure of them.

Six millipede species (*Antheromorpha* sp., *Anoplodesmus* sp., Pachybolidae 1, Pachybolidae 2, Harpagophoridae 1 and *Anurostreptus sculptus*) were found only in DEF but not found in PTF. This may be because to the difference of ecological factors and habitat structure of them.

Interestingly, Harpagophoridae 2 was found only in PTF but not found in DEF. The results indicated that tendency of this species was introduce from other habitat to PTF.

Table 4.4 The density of adult millipede species in DEF, DDF, ECO and PTF.

Species	Density (ind/m^2)				Total
	DEF	DDF	ECO	PTF	
Zephroniidae					
Zephronia siamensis	2.58	4.58	5.08	9.67	21.92
Paradoxosomatidae					
Orthomorpha variegata	4.00	3.67	0.92	1.83	10.42
Orthomopha sp.	2.58	0.75	0.58	1.17	5.08
Antheromorpha festiva	0.50	0.67	0.33	0.08	1.58
Antheromorpha sp.	1.25	-	-	-	1.25
Anoplodesmus sp.	0.58	-	-	-	0.92
Pachybolidae					
Pachybolidae 1	0.42	-	-	-	0.42
Pachybolidae 2	2.92	-	9.67	-	12.58
Lithostrophus segregatus	0.25	0.17	0.33	0.08	1.83
Harpagophoridae					
Harpagophoridae 1	0.17	-	0.18	-	0.25
Harpagophoridae 2	-	1.42	0.08	0.25	1.75
Thyropygus sp.1	0.25	-	0.17	0.08	0.50
Thyropygus allevatus	0.67	-	-	0.25	0.92
Thyropygus induratus	-	0.08	0.17	-	0.25
Thyropygus sp.2	1.42	-	0.25	1.08	2.75
Anurostreptus sculptus	6.17	-	0.08	-	6.25
Julidae					
Nepalmatoiulus sp.	3.67	0.17	0.83	1.08	5.75
Total	**27.42**	**11.50**	**19.92**	**15.58**	**74.42**

DEF = dry evergreen forest

DDF = dry dipterocarp forest

ECO = ecotone

PTF = plantation forest

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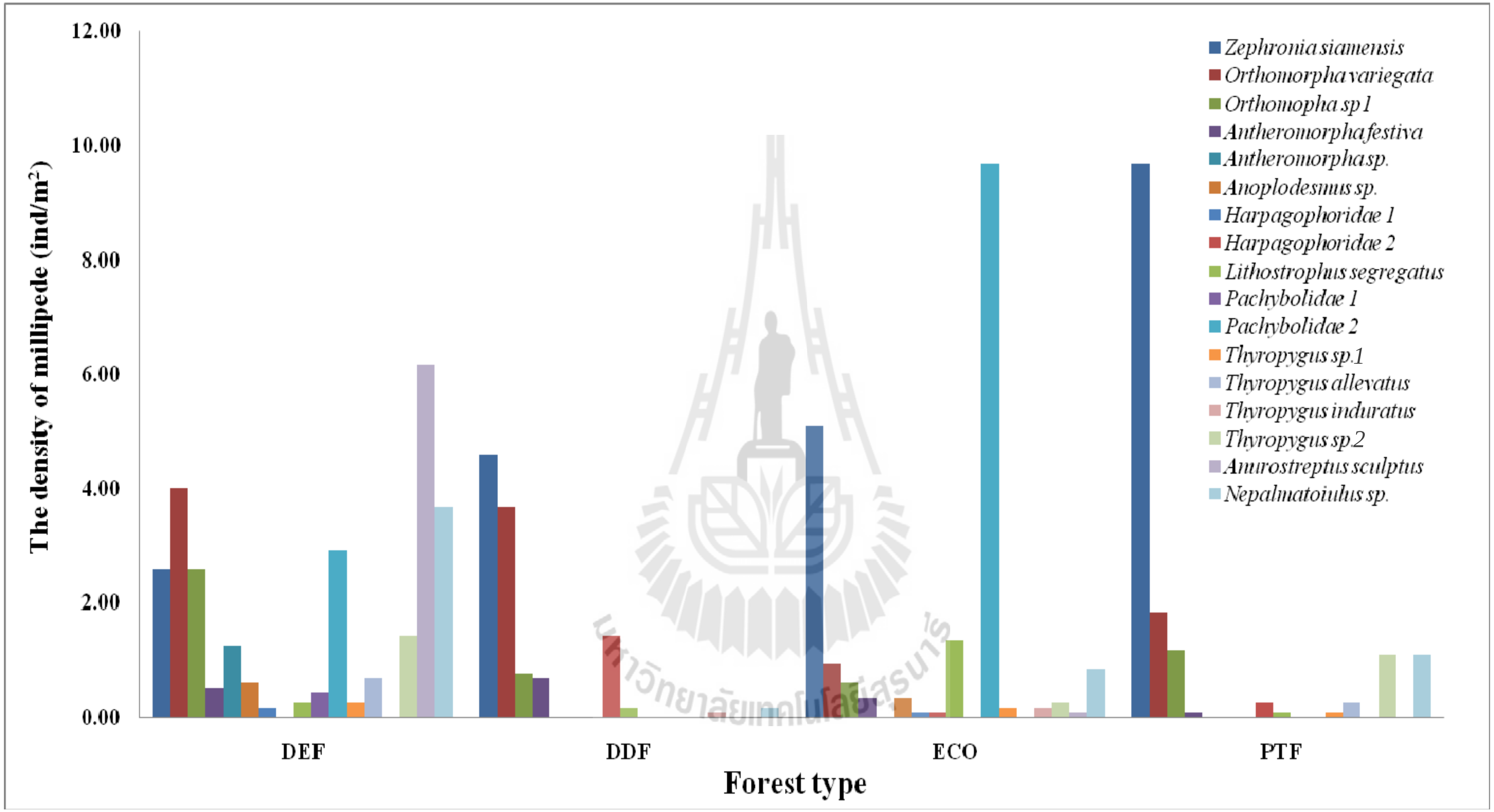

Figure 4.24 The abundance of adult millipedes in four forest types at Sakaerat Environmental Research Station.

4.1.7 Species richness

The species richness of each forest types was shown in Table 4.5. The results showed that the highest species richness was 15 in DEF and decreased to 14, and 10 in ECO and PTF, respectively. The lowest species richness was 8 in DDF. Species richness of DEF was higher than ECO, PTF and DDF. It may be dued to humidity, tree species and density of trees.

4.1.8 Shannon - Wiener index and Evenness

Species diversity was investigated by Shannon - Wiener index (H'). There was difference between each forest types (Table 4.5). The results showed that the highest index of diversity was 2.29 in DEF and index was lower to 1.59 and 1.49 in ECO and DDF, respectively. The lowest species diversity index was 1.33 in PTF. The species evenness was calculated from species diversity index and the result was shown in Table 4.5. The greatest of species evenness was 0.84 in DEF, and declined to 0.72 in DDF, 0.60 in ECO and 0.58 in PTF. The highest species diversity index and evenness index of DEF showed that DEF had more millipede species than other forest types.

However, value of the index usually lies between 1.33-2.90, thus the Shannon’s index of the whole habitat types at the SERS indicated a high diversity of millipede species. In addition, the correlation of diversity and evenness had the same tendency. As a result, DEF, ECO and DDF had higher diversity index than PTF. It can be explained that the overall of millipedes increased due to the dominance of millipede species. Furthermore, many factors such as soil moisture, depth of litter, density of tree and soil type determine the spawning, survival and feeding behavior.

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DDF and ECO had close index of diversity. It can be explained that ecological factors of them were similar.

Table 4.5 Species diversity index and evenness index of millipedes in forest types.

Index	Forest type			
	DEF	DDF	ECO	PTF
Species richness	15	8	14	10
Eveness	0.84	0.72	0.60	0.58
Species Diversity (‘H)	2.29	1.49	1.59	1.33

DEF = dry evergreen forest
DDF = dry dipterocarp forest
ECO = ecotone
PTF = plantation forest

4.1.9 Similarity index of millipede species

Similarity index was calculated from species number of millipedes composition in Sakaerat Environmental Research Station. Sørensen; Dice equation was used to compare the similarity index of each forest type, the results were shown in Table 4.6.

Table 4.6 Similarity index of millipedes in Sakaerat Environmental Research Station.

Forest type	DEF	DDF	ECO
DDF	0.57	-	-
ECO	0.89	0.84	-
PTF	0.72	0.67	0.72

DEF = dry evergreen forest DDF = dry dipterocarp forest

ECO = ecotone PTF = plantation forest

The result revealed that DEF and ECO showed the highest of similarity index (88.90%) followed by DDF and ECO (84.20%), DEF and PTF (72.00%) and ECO and PTF (72.00%) respectively. The highest similarity index of DEF and ECO might be explained by the similarity of environmental factors between them. In contrast DEF and DDF had the lowest similarity index (57.00%). It could be explained that environment factors of them were less similar leading to low similarity index. It might be concluded that environmental factors are the main factors affecting the similarity. The results indicated that the similarity index of millipedes was moderate similarity. This may be due to the different of ecological factors and habitat structure.

From the results above, it can be concluded that ecological factors were the main factors affecting to similarity of millipede abundance. Furthermore, anather reason that is relative to similarity of millipede species is density of trees. Similarity index of DEF and ECO, DDF and ECO, PTF and ECO, DEF and PTF were higher than DDF and PTF, it may be caused by covering trees and density of trees. DDF have dense trees while PTF was dominated by tall trees such as *Acacia mangium* and *Acacia auriculiformis*. This result is similar to Lavelle and Kohlmann (1984) who reported that millipede densities found in the semi-evergreen forest of Guadeloupe were particularly high, reaching 83 individuals per square meter, 77 millipedes per square meter in a tropical humid forest of Mexico, and 27 millipedes per square meter in a secondary forest of Yurimagas, Peruvian Amazonia (Lavelle and Pashanasi, 1989).

4.2 Environmental factors

4.2.1 Climatic factors

Climatic factors are composed of air temperature, relative humidity (RH), light intensity and rainfall. The results indicated that mean of temperature was the highest (27.56±1.05°C) in DDF, and the lowest (24.25±0.56°C) in DEF. Mean of relative humidity was the highest (87.09±2.25%) in DEF, followed closely by PTF and ECO had the mean of 84.51 (±1.64) % and 72.68 (±2.10) % respectively, and the lowest (70.53±1.39%) was in DDF. Regarding light intensity, DDF had the highest of 1,999.39 (±244.82) lux while DEF had the lowest of 649.28 (±57.24) lux. The mean and standard error of these factors in four forest types are shown in Table 4.7 and Figure 4.25. The One-way ANOVA of climatic factors of all forest types indicated significant differences at $p < 0.05$ and the comparison among mean values of climatic factors verified by Duncan's multiple range test are also shown in Table 4.8

Table 4.7 Mean (±SE) of climatic factors in four forest types.

Forest type	Temperature (°C)	RH (%)	Light intensity (lux)
DEF	24.25 (±0.56)	87.09 (±2.25)	649.28 (±57.24)
DDF	27.56 (±1.05)	70.53 (±1.39)	1999.39(±244.82)
ECO	27.10 (±0.84)	72.68 (±2.10)	902.88 (±111.57)
PTE	25.12 (±0.82)	84.51 (±1.64)	657.53 (±89.98)

DEF = dry evergreen forest DDF = dry dipterocarp forest

ECO = ecotone PTF = plantation forest

Generally, the temperature of all forest types vary in place and time with significant variation in plants cover. As shown in Figure 4.25, the mean temperature of all forest types was significantly different. The lowest recorded mean temperature was 24.25 (±0.56) °C in DEF, while the highest mean temperature of 27.56 (±1.05) °C was recorded in DDF (Table 4.8 and Figure 4.25). This might be caused by plant cover. Because DEF has high density of crown canopy and moisture content, it can reduce light and radiation from the sun. The modification of temperature by plant cover is both significant and complex. Shaded ground is cooler during the day than open area. Vegetation interrupts the laminar flow of air, impeding heat exchange by convection.

The results showed that the mean relative humidity of all forest types was significantly different. DEF of presented study had higher relative humidity than PTF, ECO and DDF because to it had higher tree density and more crown cover than orther forest types. It can be argued that the relative humidity is relevant to water vapor content in the air. Water vapor gets into the air by evaporation from moist surfaces and from evapotranspiration by plants. This supported the results studied by Dajoz (2000) who reported that relative humidity is generally higher in forest than open area, especially in summer when transpiration from trees is at its height. Furthermore, temperatures also influence relative humidity. Relative humidity is generally higher at night and early morning when the air temperature is lower; it is lower during the day when temperature increases. Thus, DEF had higher relative humidity than PTF, ECO, and DDF because it had lower temperature than them (Table 4.8 and Figure 4.25).

With respect to light intensity, the mean of all forest types had significant differences. Light intensity of DDF was the highest (1,999.39±244.82 lux), while that of DEF was the lowest (649.28±57.24 lux). This might be caused by crown density, stands density and canopy gap. DEF consists of densed crown, densed stands and low canopy gap. This factors influence the reduction of light intensity on the forest floor. The open area such as DDF is an area dominated by *Shorea obtusa* Wall. and *Shorea siamensis* Miq with some small shrubs and grass species of *Arundinaria pusilla* Chevel. Thus, this area will receive full sunlight. This result agreed with Smith (1996) that the light intensity varied according to average light conditions in the stand and the canopy. A crown dominant will receive full sunlight, while co-dominant, sub-dominant, suppressed and understory plants will generally receive progressively less light.

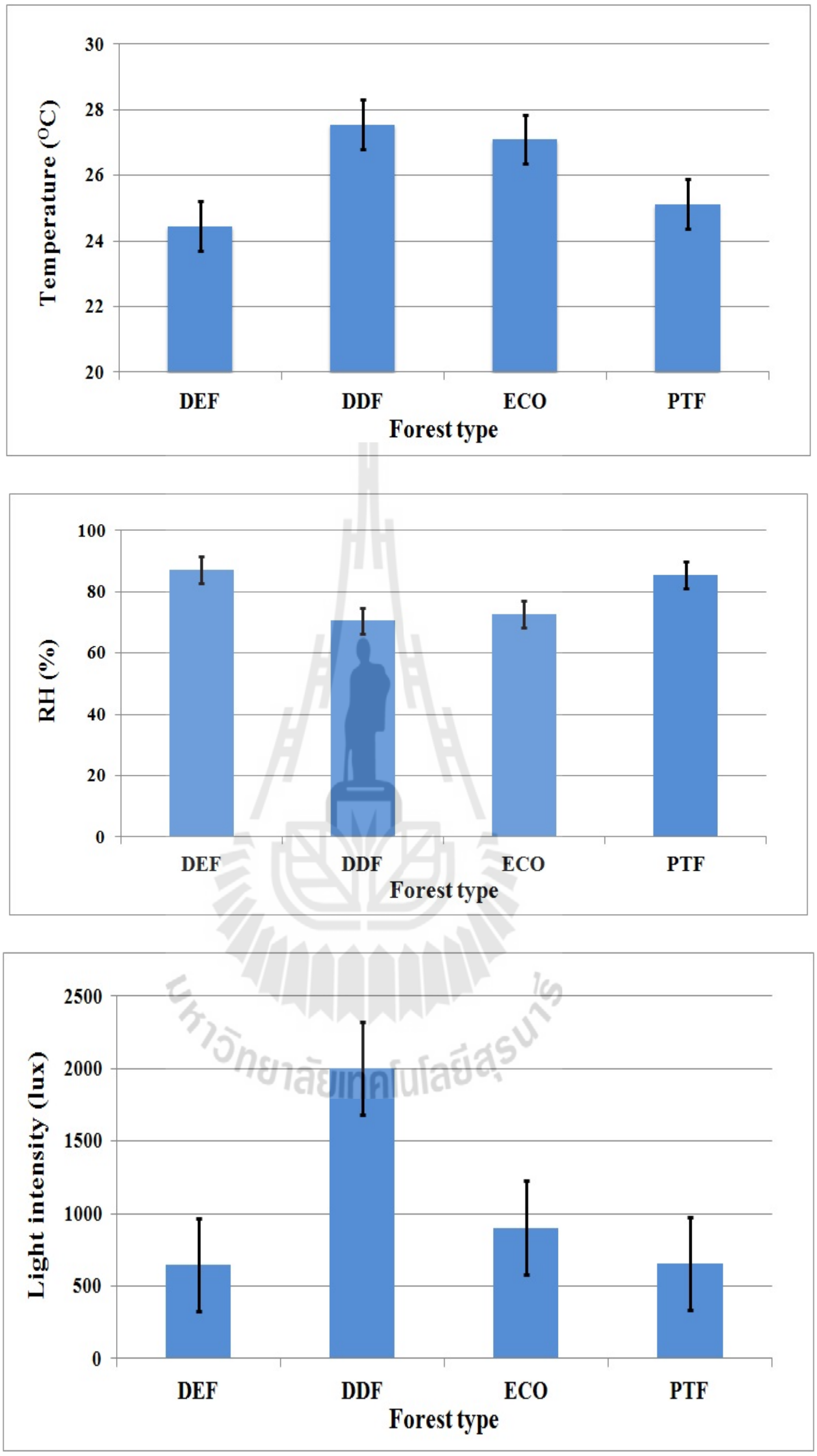

Figure 4.25 The mean (±SE) of climatic factors in four forest types.

Table 4.8 The mean (±SE) of climatic factors, litter and soil properties of four forest types.

Factor	Forest type			
	DEF	DDF	ECO	PTF
Light intensity (lux)	649.28±57.24[a]	1999.39±244.82[ab]	902.88±111.57[c]	657.53±89.98[b]
Soil temperature (ºC)	22.83±0.42[a]	24.15±0.38[ab]	23.91±0.35[c]	23.23±0.36[b]
Litter moisture (%)	31.40±2.75[c]	25.05±2.77[a]	32.18±2.86[ab]	29.08±3.00[b]
Soil moisture (%)	17.18±1.51[ab]	13.16±1.35[b]	12.50±1.11[a]	13.40±1.46[c]
Air temperature (ºC)	24.25±0.56[a]	27.56±1.05[b]	27.10±0.84[b]	25.12±0.82[b]
Relative humidity (%)	87.09±2.25[a]	70.50±1.39[b]	72.68±2.10[b]	84.51±1.64[b]
Phosphorus (ppm)	10.95±1.11[a]	9.93±2.42[b]	10.97±1.54[b]	4.57±0.63[a]
Potassium (ppm)	176.50±6.26[b]	171.25±18.34[a]	193.00±18.14[b]	225.50±18.54[a]
Total nitrogen (%)	0.29±0.01[b]	0.19±0.01[a]	0.28±0.01[b]	0.23±0.02[b]
Organic carbon (%)	3.33±0.16[b]	1.80±0.05[a]	2.73±0.13[b]	2.29±0.23[b]
Organic matter (%)	5.72±0.28[b]	3.10±0.09[a]	4.69±0.22[b]	3.94±0.39[b]
C:N ratio	11.41±0.44[b]	10.08±0.73[b]	9.69±0.33[a]	9.97±0.30[b]
Soil pH	4.44±0.09[a]	5.27±0.06[ab]	5.26±0.07[c]	5.03±0.05[b]

Remark: Significant difference is indicated by different small letter at $p < 0.05$ for Oneway ANOVA

In average, amount of rainfall per month was quite low, from November to April, and high from May to October (Figure 4.26). The maximum amount of rainfall was 319.90 mm in October, and the minimum was 0.00 mm in December (Table 4.9 and Figure 4.26).

Table 4.9 Average of rainfall per month in June 2010 to May 2011.

Month	Rainfall (mm)
June 2010	136.50
July 2010	96.50
August 2010	190.80
September 2010	149.30
October 2010	319.90
November 2010	14.50
December 2010	0.00
January 2011	0.40
February 2011	27.30
March 2011	46.00
April 2011	65.80
May 2011	88.30
Total	1,135.30

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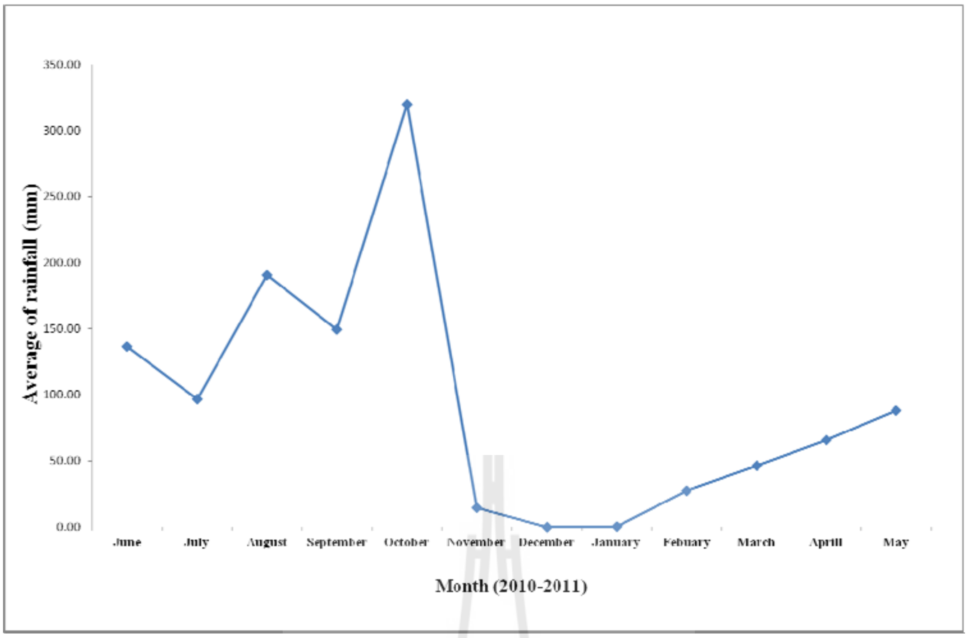

Figure 4.26 Average of rainfall (mm) from June 2010 to May 2011 at Sakaerat Environmental Research Station.

Millipede density fluctuated over a studied year. Generally, millipedes were highest in wet season and lowest in summer. The millipedes started to increase in April, reached the peak in June and declined in November (Figure 4.27).

This result is similar to Bhakat (1987), who estimated that the density and biomass of *Streptogonus phipsoni* (Polydesmida) in grassland over a year by sampling with quadrats. There were considerable differences between months. In general, the mean density for each month was correlated positively with mean monthly rainfall. The studies of David in France have dealt mainly with populations of diplopods and their effects on forests soil. In one such study, David (1984) considered just one species. The maximum density in May corresponded with the recruitments from the new generation, the minimum in February/March represented the end of the old generation. Seasonal activity is also governed by various factors.

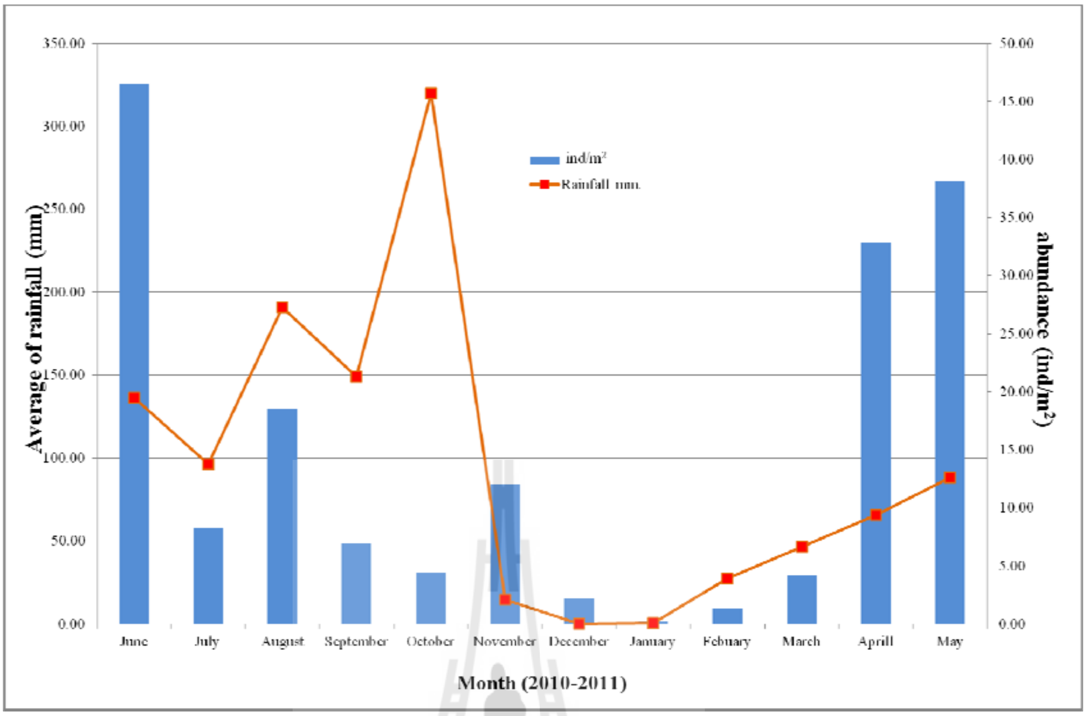

Figure 4.27 Millipede density and environmental factors in June 2010 to May 2011 at Sakaerat Environmental Research Station.

Climate was also the critical factor in determining the activity time of the millipedes in Senegal studied by Gillon and Gillon (1976). Here, animals only appeared after the onset of the rains. However activity ceased before the end of the rain in anticipation of the coming dry season.

4.2.2 Water content of litter

As shown in Table 4.10 and Figure 4.28, ECO yielded the highest water content of litter (32.18±2.86%), while DEF and PTF showed inferior results, and DDF accounted the lowest (25.05±2.75%) (Table 4.10).

Table 4.10 Mean and standard error of water content of litter of all forest types.

Forest type	Water content of litter (%)
DEF	31.40 (±2.75)
DDF	25.05 (±2.77)
ECO	32.18 (±2.86)
PTF	29.08 (±3.00)

DEF = dry evergreen forest DDF = dry dipterocarp forest

ECO = ecotone PTF = plantation forest

The results indicated that ECO, DEF, and PTF had higher water content of litter than DDF. This might be due to thickness of litter on the forest floor and cover vegetation. A layer of litter in DEF accumulated on the forest floor at an average thickness of 1 to 3 centimeters and includes leaves, twigs, fruit, bark and decomposed animals. All litter absorbed amount of water, hence, DDF had lowest water content of litter due to lower amount of litter.

Furthermore, dense vegetation, dense crown and thick canopy of DEF had influence water content of litter. From the comparison between DEF and ECO, it was found that water content of litter had close value, because ECO had amount of litter, dense vegetation and dense crown similar to that of DEF.

Besides DDF and PTF had lower dense vegetation and dense crown than ECO and DEF. Therefore the water content of litter were lower than that of ECO and DEF.

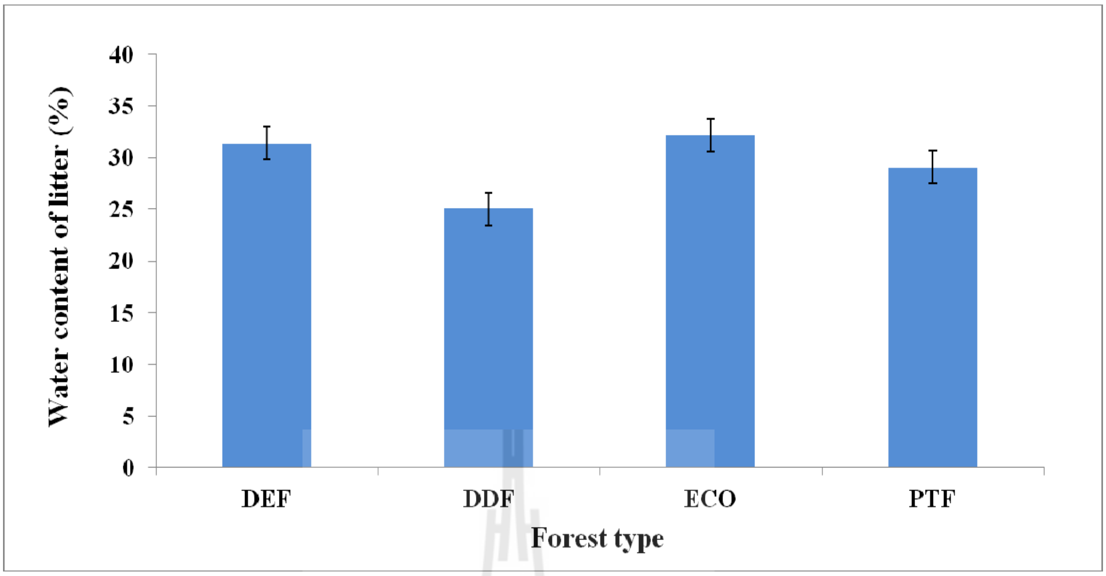

Figure 4.28 The mean and standard error water content of litter in four forest types.

4.2.3 Soil properties

The properties of soil in each forest type were analyzed from June 2010 to May 2011, totally twelve months. The soil properties of all forest types are summarized in Appendix C. The soil factors consisted of soil moisture, soil pH, soil temperature, organic matter, total nitrogen, phosphorus, potassium, organic carbon and C:N ratio. The results of the mentioned properties can be described as follows:

4.2.3.1 Soil moisture

Soil moisture of all forest types ranged from 12.50±1.11% to 17.18±1.51%. The highest was in the DEF (17.18±1.51 %) and the lowest was in the ECO (12.50±1.11 %). The DDF and PTF were about 13.16±1.35% and 13.40±1.46 %, respectively (Table 4.8). The higher soil moisture of the DEF could be attributed to lower rate of evaporation of moisture from soil due to thick canopy of the DEF in comparision with that DDF, ECO and PTF.

4.2.3.2 Soil pH

Soil of forest types showed acidic pH ranged from 4.44±0.09 in DEF to 5.27±0.06 in DDF, with differences between the forest types (Table 4.8). The mean pH of DEF was significantly ($p < 0.05$) lower than those of DDF, ECO and PTF. This may be caused by organic matter. In DEF, surface soil was always covered by vegetation and leaf litter all year, pH of soil would be affected by the organic matter supplied from the vegetation. This leaded to the soil acidification by decomposition of organic residues of microorganisms in soil (Wacharinrat, 2000).

4.2.3.3 Soil temperature

The soil temperatures were significantly different among forest types. The soil temperatures were higher in DDF (24.15±0.38°C) followed by ECO (23.91±0.35°C) and PTF (23.23±0.36°C), respectively. In contrast, the lowest soil temperature was in DEF (22.83±0.42°C).

4.2.3.4 Organic matter

Organic matter of all forest types are shown in Table 4.8 and Figure 4.29. The highest was that of the DEF (5.72±0.28%) followed by those of ECO and PTF which accounted for 4.69±0.22% and 3.94±0.28%, respectively while the lowest was that of the DDF (3.103±0.09%). The analysis of variance on organic matter of all forest types were tested for significant difference at $p < 0.05$, and the comparisons among mean value of organic matter verified by Duncan's multiple range test as shown in Table 4.8.

The results showed that the soil of DEF were richer in organic matter in comparison with the others due to the higher amount of litter produced in DEF. In natural vegetation community there is always an accumulation of plant materials at the soil surface which undergo decomposition. The results obtained in this study confirmed this statement. Because plant residues are the 80 principal material undergoing decomposition in soils hence, they are the primary source of soil organic matter. Therefore, it can be said that, in general the soils of the DEF are richer in nutrients than that of DDF. This result corresponds with the results revealed by David (1987b) who noted that there was a relationship between the size of millipede population and quality of the humus. The better the quality, the greater the population and consequently, the shallower the litter layer.

The most detailed work relating distribution of millipedes to their environment has been conducted by Kime and co-workers in Belgium. It was concluded in a study of soil-dwelling species that dritributions were a function of edaphic and climatic factors (Kime et al., 1992). The most important of millipede distributed were soil texture, soil water content, temperature, mineral content (especially calcium and magnesium), humidity and humus type (Kime, 1992). Ordination procedures have been used to illustrate the relative importance of these factors to a range of species (Kime and Wauthy, 1984; Kime et al., 1992).

4.2.3.5 Total nitrogen

Nitrogen content of all forest types were slightly different ranging from 0.19±0.01% to 0.29±0.01%. The highest was that of DEF and the lowest was that of DDF. Nitrogen content of ECO and PTF were about 0.28±0.01% and 0.23±0.02%, respectively. The analysis of variance on nitrogen of all forest types are tested non-significant difference at $p < 0.05$ and the comparisons among mean value of nitrogen verified by Duncan's multiple range test are shown in Table 4.8. As seen from this result, the mean nitrogen of DEF was higher than those of the others.

4.2.3.6 Phosphorus

As can be seen in the Table 4.8 and Figure 4.29, it was indicated that the mean of phosphorus of all forest types were slightly different ranging from 4.57±0.63 ppm to 10.97±1.54 ppm. The highest was that of ECO, followed by those of DEF, DDF and PTF which accounted about 10.97±1.54 ppm, 10.95±1.11 ppm, 9.93 ±2.42 ppm and 4.57±0.63 ppm, respectively, while mean phosphorus of PTF was the lowest. However, analysis of variance tested by One-way ANOVA on phosphorus of all forest types showed significant differences at $p > 0.05$ among them.

4.2.3.7 Potassium

Potassium content of all forest types ranged from 171.25±18.34 ppm to 225.50±18.54 ppm. The highest was that of PTF, followed by those of ECO, DEF and DDF which comprised about 225.50±18.54 ppm, 193.00±18.14 ppm, 176.50±6.26 ppm and 171.25±18.34 ppm respectively while the lowest was that of DDF. When statistically tested, they indicated non-significant differences among them. To compare DEF and DDF, the potassium content was higher in DEF than DDF. It may be caused by decomposition of leaf litter. Higher litter production in DEF contributed to higher contents of the mineral as a result of litter decomposition (Chostexs, 1960).

4.2.3.8 Organic carbon

Organic carbon contents of all forest types are shown in Table 4.8. The highest was of the DEF (3.33±0.16%) followed by ECO and PTF which were 2.73±0.13% and 2.29±0.23%, respectively. Whereas the lowest was of the DDF (1.80±0.05%). The analysis of variance on organic carbon of all habitat types were tested. They indicated non-significant difference among them.

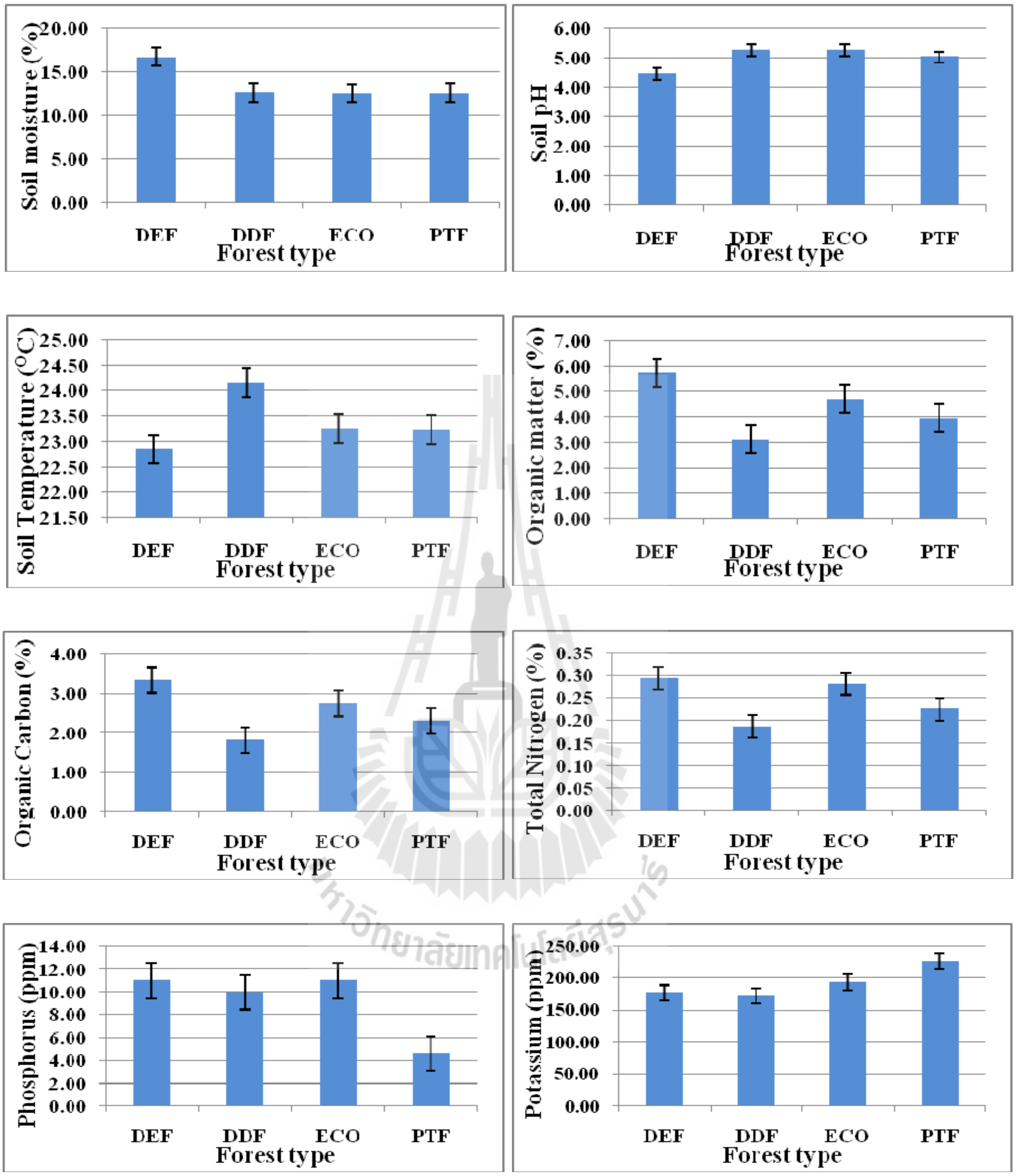

Figure 4.29 The mean of soil properties in four forest types.

4.2.4 Relationship of millipedes and environmental factors

The millipede densities were positively significantly correlated ($p < 0.05$) with soil moisture, air temperature, phosphorus, organic carbon (OC) and organic matter (OM) (Table 4.11). However, they were negatively correlated with soil temperature, litter moisture, soil pH, rainfall, relative humidity, potassium and nitrogen. These results supported by Ashwini and Sridhar (2006). They reported that millipede abundance as well as biomass of plantation were positively correlated ($p = 0.001$) with soil moisture and soil temperature. Abundance was positively correlated with soil phosphate ($p = 0.01$) and biomass with calcium ($p = 0.01$). Biomass of millipedes in plantation was negatively correlated with soil pH ($p = 0.01$) and potassium ($p = 0.05$). In the forest, a significant positive correlation ($p = 0.01$) was observed between millipedes (abundance and biomass) and rainfall. In forest, abundance was negatively correlated with soil magnesium ($p = 0.05$). Paired t-test revealed significant difference in soil edaphic features between plantation and forest ($p < 0.001$).

Zimmer et al. (2000) showed that the distribution of diplopod species was mainly influenced by temperature. However, moisture conditions also influenced the distribution pattern of many diplopods. For example, *Polyzonium germanicum* can be found in high abundances in thick litter layers which contain a high humidity around the year (David and Vannier, 1995).

Barlow (1960) determined that *Polydesmus denticulatus*n was active over a wide range of temperature (9-20°C) whereas the two activity periods of *Cylindroiulus frisius* corresponded much more closely to temperature and rainfall. In the three species examined in Barlow’s study, activity could be related most clearly to temperature rather than precipitation.

The availability of organic matter is one of the most important factors influencing millipede abundance. Millipedes feed on dead and decaying plant, the primary source of food for them. A significant correlation was found between biomass of *Arthrosphaera* and soil organic carbon among several edaphic features (organic carbon, pH, phosphate, calcium and magnesium) of the above biomes (Ashwini and Sridhar, 2008). Moreover, Loranger et al. (2008). showed that the quality of organic matter was an important factor determining millipede feeding preferences and thus, accounting for local variations of population abundance and species richness. Nitrogen content of litter is, therefore, a main ecological factor controlling the distribution of millipede populations at local level.

Tables 4.11 The correlations among millipede density and environmental factors.

	Millipede density	Light intensity	Soil temperature	Litter moisture	Soil moisture	Rainfall	Air temperature	Relative humidity	P	K	N	Soil OC	Soil OM	Soil C:N Ratio
Soil Temperature	0.003	0.225**												
Litter moisture	0.171	-0.045	0.407											
Soil moisture	0.970**	-0.077	0.274**	0.638**										
Rainfall	0.066	0.098	0.445**	0.561**	0.739**									
Air temperature	0.887**	0.131	0.505**	0.297**	0.003	0.165*								
Relative humidity	0.058	0.140	0.629**	0.699**	0.706**	0.873**	0.480**							
P	0.265**	-0.005	0.314**	0.247**	0.070	0.034	0.409**	0.215**						
K	0.000	-0.250**	0.010	0.096	-0.096	-0.183*	0.306**	-0.048	0.467**					
N	0.000	-0.416**	-0.477**	-0.150	-0.067	-0.247**	-0.208*	-0.335**	-0.077	0.098				
Soil OC	0.324**	-0.444**	-0.496**	-0.182*	-0.118	-0.345**	-0.198*	-0.416**	0.091	0.203*	0.860**			
Soil OM	0.453**	-0.443**	-0.497**	-0.183*	-0.120	-0.347**	-0.198*	-0.418**	0.091	0.204*	0.859**	1.000**		
Soil C:N Ratio	0.196	-0.185*	-0.141	-0.078	-0.088	-0.255**	-0.033	-0.239**	0.431**	0.318**	0.051	0.542**	0.543**	
pH	0.031	0.284**	0.127	-0.018	-0.349**	-0.147	0.122	-0.106	-0.003	0.234**	-0.420**	-0.472**	-0.470**	-0.211*

Pearson correlation coefficient: *, ** significant at p < 0.05 and p < 0.01, respectively

4.3 The food consumption processes of *Thyropygus cuisinieri*

The food consumption processes on leaf litter of *Thyropygus cuisinieri* was analyzed from June - November 2011, totally six months. The food consumption processes of *T. cuisinieri* consisted of consumption rate, growth rate and food conversion efficiency (AD, ECI, ECD %). The results of the mentioned properties are summarized in Table 4.2 and can be described as follows:

Tables 4.12 The leaf litter consumption, body weight gain and faecal production of millipedes during June -November 2011.

Month	**Leaf litter eaten ($g/day^{-1}/ind$)**	**Body weight gain ($g/day^{-1}/ind$)**	**Faecal pellet ($g/day^{-1}/ind$)**
June (1^{st})	24.67±2.77**	0.19±0.09	20.60±2.35**
July (2^{nd})	17.57±1.95**	0.23±0.05**	11.15±2.11**
August (3^{rd})	33.34±2.38**	0.485±0.23	18.69±3.60**
September (4^{th})	25.03±7.74*	0.21±0.10	9.24±2.23**
October (5^{th})	16.78±2.05**	0.29±0.10*	8.08±1.84**
November (6^{th})	7.12±2.92	0.14±0.07	3.58±2.86**
Total	124.51±45.38	1.54±0.81	71.34±6.43
Average	**20.75±4.28**	**0.26± 0.05**	**11.89±1.48**

*Data with different symbols across the rows are significantly different (*p < 0.05; ** p < 0.01)*

4.3.1 Litter ingestion

The results showed that leaf litter eaten by millipedes during six months was 124.51±45.38 g/day^{-1}/ind. Leaf litter eaten by millipedes range between 7.12±2.92 - 33.34±2.38 g/day^{-1}/ind. The highest was in the third month (33.34±2.38 g/day^{-1}/ind) followed by the fourth month, the first month, the second month and the fifth month which accounted for 25.03±7.74, 24.67±2.77, 17.57±1.95 and 16.78±2.05 g/day^{-1}/ind respectively, while the lowest was that in the sixth month (7.127.12±2.92 g/day^{-1}/ind) (Table 4.12). However, the faecal pellets were produced by individuals with a range of 3.58±2.86-20.60±2.35 g/day^{-1}/ind. The highest was in the first month (20.60±2.35 g/day^{-1}/ind) followed by the third month, the second month, the fourth month and the fifth month which accounted for 18.69±3.60, 11.15±2.11, 9.24±2.23 and 8.08±1.84 g/day^{-1}/ind respectively while the lowest was that in the sixth month (3.58±2.86 g/day^{-1}/ind) (Table 4.12 and Figure 4.30).

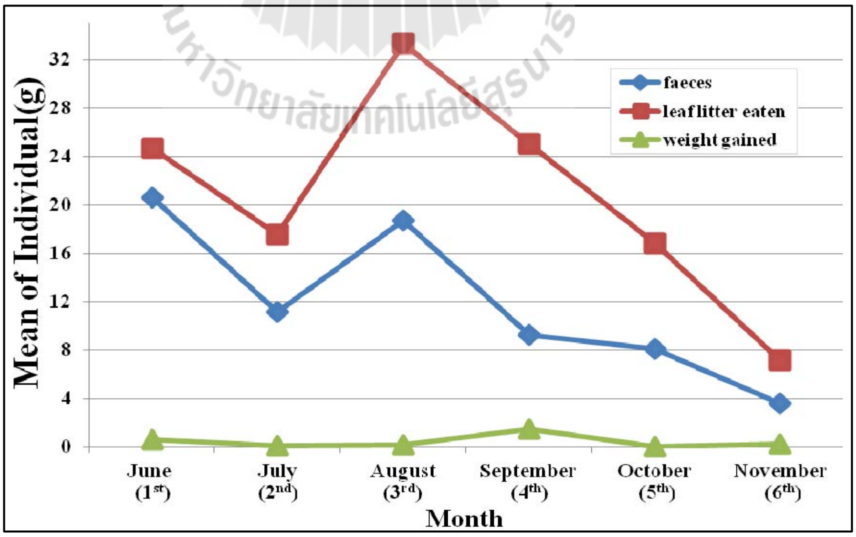

Figure 4.30 The total amount of leaf litter ingested by millipedes, weight gained and faecal pellets during June -November 2011.

At the end of the feeding experiments the weights of leaf litter eaten offered to the millipedes had decreased, suggesting millipede feeding activity. A result, the third month showed higher leaf litter eaten than the other months. It can be explained that they were in need of energy-rich diets because they laid eggs in this period. However, the results indicated that faecal pellets in the third month were higher than the fourth month, the fifth month, the sixth month and the second month probably because they used the faecal pellets for producing egg capsules (Figure 4.32) when they laid eggs.

Figure 4.31 The faecal pellets.

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Figure 4.32 Egg capsules.

Estimates of litter ingestion by millipedes vary considerably (Neuhauser and Hartenstein, 1978; Striganova, 1972). These differences are mainly a result of body size effects although other factors such as food type (Pobozsny, 1986) and temperature (Iatrou and Stamou, 1989; Wooten and Crawford, 1975) also play a role, with larger individuals consuming more food than smaller ones (Dangerfield and Milner, 1993). Individuals ingested litter at rates between 20 and 240 mg day^{-1}, with a mean rate of 157±28.1 mg/day^{-1} (n=45). Faecal pellets were produced by individuals at rates between 20 and 180 mg/day^{1}, with a mean rate of 111±12.8 mg day^{-1} (n=45).

Litter ingestion in the Seychelles giant millipede (20-240 mg /day^{-1}) represents between 0.28 and 3.37% of the mean Seychelles giant millipede dry body mass. These estimates are lower than the 2.60 and 7.60% calculated for various southern African millipedes (Dangerfield and Milner, 1993). Typical rates of daily food ingestion generally vary between 5 and 10% of the body weight (Bocock, 1963; Hopkin and Read, 1992; Reichle, 1968).

Nevertheless, the results here are similar to those of Gere (1956), who estimated the daily mass specific ingestion of various temperate diplopods to range between 0.5 and 4%. However, in assessing the role of the millipedes in litter breakdown, it is the actual quantities that are important and, owing to its large size, the Seychelles giant millipede consumes more than other tropical and temperate millipede species recorded. Temperate species rarely consume over 10% of the annual litter fall (Bocock, 1963; David, 1987; Lyford, 1943). On the other hand, there is some evidence that tropical species consume far more than temperate species. For example, Dangerfield and Milner (1996) calculated that southern African millipedes in certain habitats may consume up to ca. 40% of the total litter standing crop and up to 16% of the annual litter fall. Here, the Seychelles giant millipede alone ingested 4.55% of the litter standing crop and 17.19% of the daily litter fall every 24 hour. Using the data of Pobozsny (1985, 1986), Dangerfield and Milner (1996) calculated the total faecal production by temperate millipedes in an oak-hornbeam woodland to range between 0.6 and 2.1% of the total annual litter fall. These values are lower than the figures of 8-13% estimated for southern African millipedes and that for the Seychelles giant millipede of 2.90% of the total litter standing crop and 10.96% of the daily litter fall.

4.3.2 Consumption rate (CR)

Individuals ingested leaf litter at rates between 60.12±19.83-181.03±42.14 mg/ day. Food intake increased during the first 3 months of the experiment up to the feeding peaks (Figure 4.31). Food consumption dropped during the 5^{th} to 6^{th} months (Table 4.12). The monthly increase in consumption rate reached its peak by the 3^{rd} month (Figure 4.31) and gradually declined after to the end of the experiment.

The consumption rate of individual millipedes increased in the third month (181.03±42.14 mg/day^{-1}/ind) and decreased in the fourth month (117.62±37.75 mg/day^{-1}/ind) followed by the fifth month (92.71±34.81 mg/day^{-1}/ind) and was lowest in the sixth month (60.12±19.83 mg/day^{-1}/ind) (Table 4.12).

Table 4.13 Consumption rate of leaf litter by *T. cuisinieri* during June -November 2011.

Treatment	**June (1st)**	**July (2nd)**	**August (3rd)**	**September (4th)**	**October (5th)**	**November (6th)**
			(mg/day^{-1}/ind)			
Without millipedes	1.71±0.24	0.54±013	0.98±0.11	1.14±0.18	1.16±0.19	1.61±0.31
With millipedes	100.19±31.93*	85.55±21.04**	181.03±42.14**	117.62±37.75**	92.71±34.81**	60.12±19.83*

*Data with different letters across the rows are significantly different (*p < 0.05; **p < 0.01)*

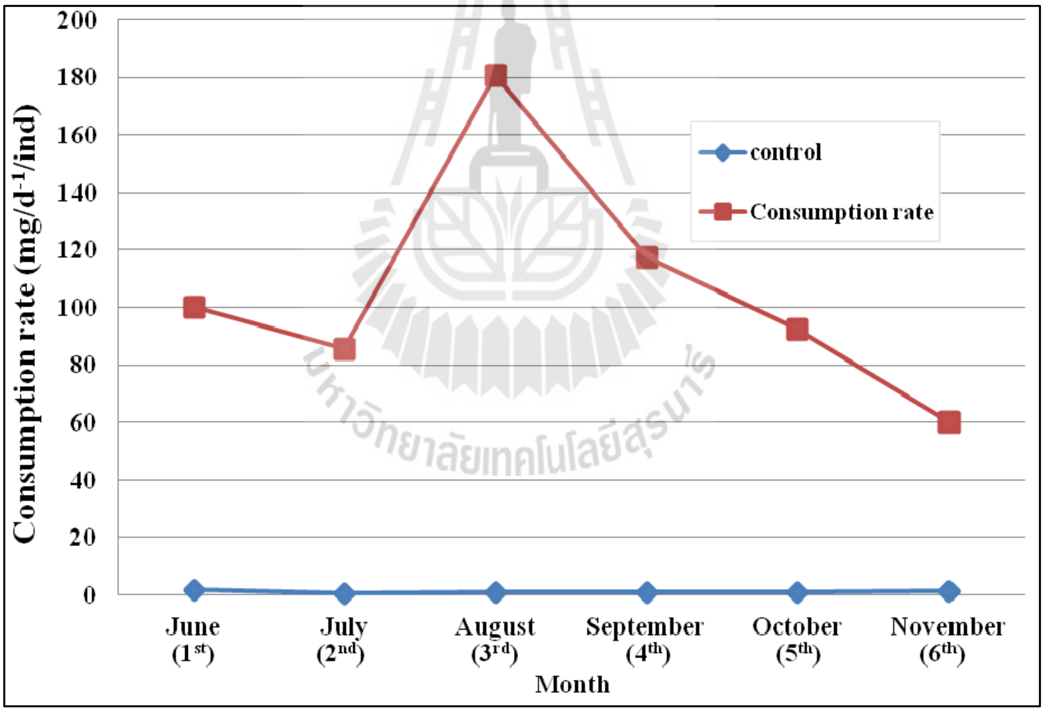

Figure 4.33 Consumption rate of *T. cuisinieri*.

Lawrence and Samways (2003) stated that individuals ingested litter at rates between 20 and 240 mg/day^{-1}, with a mean rate of 157 ±28.1 mg/day^{-1} (n=45).

Clearly, some tropical species consume more litter than temperate species, but this is due principally to their generally larger size. When figures are corrected for mass, they are very similar for both tropical and temperate species. Litter consumption combined with millipede surface abundance suggest that the total population of Seychelles giant millipede on Cousine Island consumed ca. 73.57 kg of litter per day. This is equivalent to ca. 4.55% of the total litter standing crop, and 17.19% of the daily litter fall.

4.3.3 Growth rate (GR)

The rate of increase in body weight fluctuated from the beginning of the experiment until it was terminated at 6 months (Figure 4.33). The development of body weight indicated that the millipedes attained sexual maturity in the third month when they laid eggs during the period of the experiment.

The mean body weight gain of the millipedes after terminating the experiment varied from 0.14±0.07 to 0.485±0.23 mg/day^{-1}/ind (Table 4.12). The growth rate was the highest in the third month (17.13±8.22 mg/day^{-1}/ind) followed by the fifth month, the second month, the fourth month, the first month, and the sixth month (Table 4.13).

Table 4.14 Growth rate of *T. cuisinieri* during June -November 2011.

Month	June (1^{st})	July (2^{nd})	August (3^{rd})	September (4^{th})	October (5^{th})	November (6^{th})
			(mg/day^{-1}/ind)			
Growth rate	5.44±2.49	8.07±1.82**	17.13±8.22	6.06±2.83	10.33±3.66*	5.15±2.41

*Data with different symbols across the rows are significantly different (*p < 0.05; **p < 0.01)*

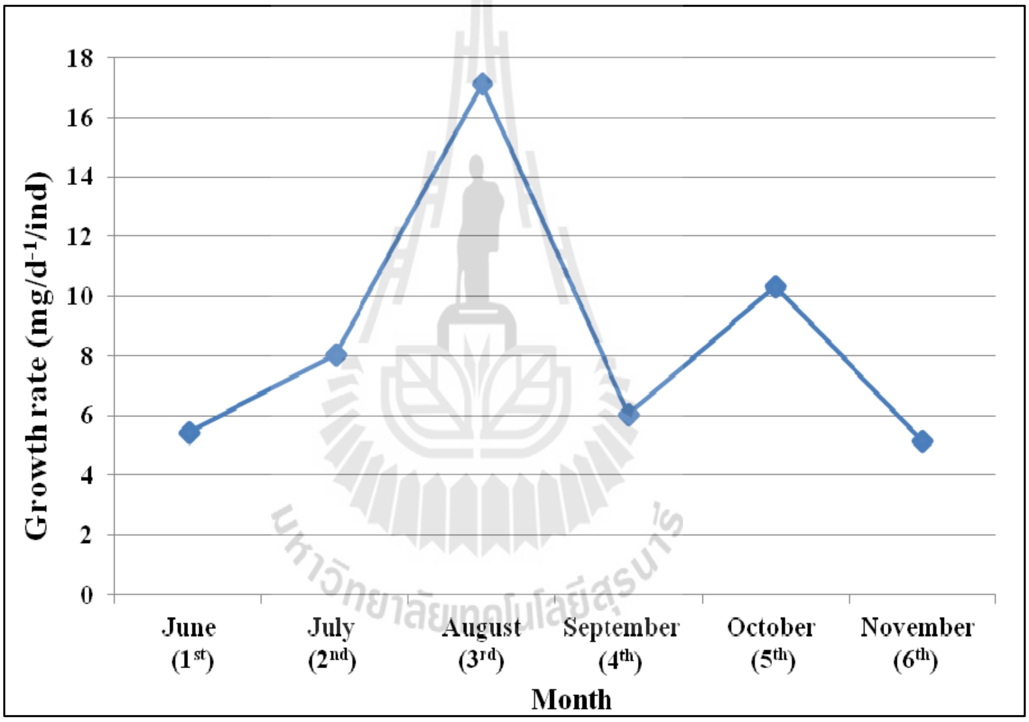

Figure 4.34 Growth rate of *T. cuisinieri*.

4.3.4 Food conversion efficiency

The food conversion efficiency of the millipedes of each month consisted of three parts. First, efficiency of conversion of ingested food to biomass (ECI), second, efficiency of conversion of digested food to biomass (ECD) and the last approximate digestibility (AD). The results were summarized in Table 4.14.

Table 4.15 Food conversion efficiency of *T. cuisinieri* during June -November 2011.

Month	Food conversion efficiency		
	ECI(%)	ECD(%)	AD(%)
June (1st)	1.72±0.72	1.10±0.43	7.00±3.12
July (2nd)	2.48±0.58**	1.14±0.28*	11.36±3.08*
August (3rd)	3.13±2.01	1.18±0.55	12.61±3.07**
September (4th)	1.37±0.58	0.90±0.60	14.14±2.85**
October (5th)	4.07±2.28	0.87±0.29*	15.12±1.89**
November (6th)	6.85±5.42	0.57±0.40	3.72±14.09
Average	**3.27±1.43**	**0.96±0.31**	**10.66±3.74**

*Data with different symbols across the rows are significantly different (*p < 0.05; ** p < 0.01)*

4.3.4.1 Efficiency of conversion of ingested food to biomass (ECI)

The efficiency of the conversion of ingested food (ECI) of the leaf litter varied from 1.37±0.58% to 6.85±5.42% (Table 4.14). ECI was highest in the sixth month followed by the fifth month, the third month, the second month and the first month, while the lowest was in the fourth month (Figure 4.34). The data on the efficiency of the conversion of ingested food (ECI) suggest that *Thyropygus* efficiently utilized the leaf litter for its growth. Although large bodied tropical millipedes showed high ingestion and throughput rates, they do not have high assimilation efficiency as they rely on low-quality diets (Striganova and Prishutova, 1990; Dangerfield and Milner, 1993; 1996).

4.3.4.2 Efficiency of conversion of digested food to biomass (ECD)

The efficiency of conversion of digested food to biomass varied from 0.57±0.40% to 1.18±0.55% (Table 4.14). Efficiency of conversion of digested food to biomass was highest in the third month (1.18±0.55%) followed by the second month (1.14±0.28%), the first month (1.10±0.43%) the fourth month (0.90±0.60%) and the fifth month (0.87±0.29%) respectively, while the lowest was in the sixth month (0.57±0.40%) (Table 4.14 and Figure 4.34).

4.3.4.3 Approximate digestibility (AD)

The approximate digestibility varied from 3.72±14.09% to 15.12±1.89% (Table 4.14). Approximate digestibility was highest in the fifth month (15.12±1.89%) followed by the fourth month (14.14±2.85%), the third month (12.61±3.07%), the second month (11.36±3.08%) and the first month (7.00±3.12%), while the lowest was in the sixth month (3.72±14.09%) (Table 4.14 and Figure 4.34).

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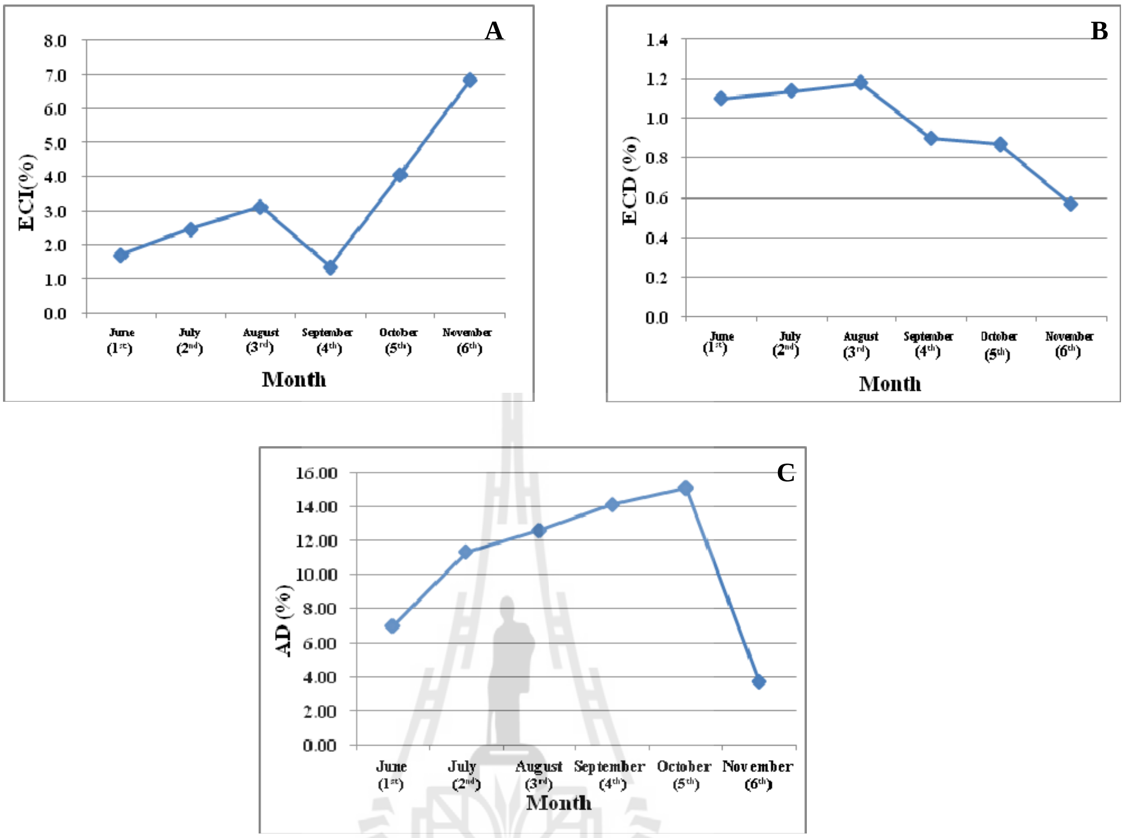

Figure 4.35 Monthly variations in the food conversion efficiency of *T. cuisinieri*.

(A) Efficiency of conversion of ingested food into biomass (ECI)

(B) Efficiency of conversion of digested food to biomass (ECD)

(C) Approximate digestibility (AD)

CHAPTER V

CONCLUSION

5.1 Conclusion

Millipede samplings were conducted in Sakaerat Environmental Research Station during June 2010-May 2011. The sampling areas were selected from different forest types: dry evergreen forest (DEF), the dry dipterocarp forest (DDF), the ecotone (ECO) and the plantation forest (PTF). The objective of this research were to investigate species diversity of millipedes and relationships between millipede species and environmental factors in the sampling areas and, to conduct the food consumption processes of cylindrical millipedes (*Thyropygus cuisinieri*). The study demonstrated that a total of seventeen species of millipedes found in this study belongs to family Zephroniidae, Paradoxosomatidae, Platyrhacidae, Pachybolidae, Harpagophoridae and Julidae. Seventeen millipede species were found in the sampling areas i.e. The *Zephronia siamensis*, *Orthomorpha variegate, Orthomopha* sp., *Antheromorpha festiva, Antheromorpha* sp., *Anoplodesmus* sp., Pachybolidae 1, Pachybolidae 2, *Lithostrophus segregates,* Harpagophoridae 1, Harpagophoridae 2, *Thyropygus* sp1., *Thyropygus allevatus*, *Thyropygus induratus*,. *Thyropygus* sp2., *Anurostreptus sculptus* and *Nepalmatoiulus* sp.

The most abundant species was *Zephronia siamensis* which presented in every forest type. The rarest species were Harpagophoridae 1 and *Thyropygus induratus* that they distributed only 0.33% of all. Population density was highest in June followed by in May and in August. The millipede density was highest in DEF followed by ECO, DDF and PTF. The millipede density was significantly different among sites in June. The highest species diversity (2.29), species richness (15.00) and the evenness of millipede were found in DEF. Total abundance of millipedes in DEF (27.42 ind/m^2) was the highest followed by ECO (19.92 ind/m^2), PTF (15.58 ind/m^2) and DDF (11.50 ind/m^2), respectively. The highest species diversity and species richness of millipedes were found in DEF, while the highest evenness was found in DEE followed by DDF.

The highest density was found in June (14.41 ind/m^2). Millipede number was low in January and February. Millipede density was positively correlated with soil moisture, air temperature, phosphorus, organic carbon and organic matter, but negatively correlated with soil temperature, litter moisture, soil pH, rainfall relative humidity, potassium and nitrogen.

The study of ingestion and assimilation of leaf litter by cylindrical millipedes (*Thyropygus cuisinieri*) was conducted under laboratory conditions during June-November 2011. The result showed that the amount of leaf litter consumed during for six months was 124.51±45.38 g/day^{-1}/ind. The highest consumption rate (181.03 mg/day^{-1}/ind) and growth rate (17.13±8.22 mg/day^{-1}/ind) were in the third month while, the lowest in both were in the sixth month. Cylindrical millipedes have high assimilation efficiency as they play an important role in leaf litter in Northeast of Thailand. Data on litter production, litter decomposition rates provide precise data on the roles of saprophagous fauna such as millipedes. These estimates serve as useful index for comparison among different species.

5.2 Recommendation

For this study, the millipede identification was based upon external and internal morphology, further studies should use molecular methods e.g. DNA or protein sequences that the reliability significant results could be obtained. Moreover, the study of competition, predation, parasitism and diseases should be included in the future research to investigate biotic interaction within the species diversity of millipedes.

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APPENDICES

APPENDIX A

NUMBER AND SPECIES OF MILLIPEDS IN FOUR FOREST TYPES

Table 1 Number and species of millipedes in dry evergreen forest (DEF).

Month	Quadrats	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Jun	1	4	3	1	0	0	0	0	18	0	0	0	0	0	0	1	2	8
	2	1	0	2	0	6	0	0	5	0	0	0	0	3	0	3	8	4
	3	9	2	5	0	0	0	0	0	0	0	0	0	0	0	1	0	1
Jul	1	0	0	0	1	4	0	1	1	0	0	0	1	0	0	0	0	1
	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	4
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aug	1	1	3	2	3	5	1	1	0	0	0	0	0	1	0	0	10	2
	2	0	1	0	1	0	0	0	0	0	2	0	0	0	0	0	5	7
	3	0	2	1	0	0	0	0	0	1	0	0	0	0	0	0	0	2
Sep	1	0	2	1	0	0	0	0	3	1	0	0	0	0	0	0	1	0
	2	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oct	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	8	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nov	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3
	3	0	17	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0

1 = *Zephronia siamensis* , 2 = *Orthomorpha variegata* , 3 = *Orthomopha* sp., 4 = *Antheromorpha festiva,* 5 = *Platyrhacus* sp1. , 6 = *Platyrhacus* sp2. , 7 = Pachybolidae 1 , 8 = Pachybolidae 2, 9 = *Lithostrophus segregates,* 10 = Harpagophoridae 1, 11 = Harpagophoridae 2, 12 = *Thyropygus* sp. , 13 = *Thyropygus allevatus* , 14 = *Thyropygus induratus* , 15 = *Thyropygus* sp2., 16 = *Anurostreptus sculptus* , 17 = *Nepalmatoiulus* sp.

Table 1 (continued) Number and species of millipedes in dry evergreen forest (DEF).

Month	Quadrats	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Dec	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jan	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Feb	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0
	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Mar	1	2	0	0	0	0	0	0	0	0	0	0	2	0	0	0	2	0
	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Apr	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	1	1	1	0	0	0	1	2	0	0	0	0	0	0	2	0	0
	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
May	1	2	3	13	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	2	1	2	4	0	0	4	0	6	0	0	0	0	0	0	0	37	9
	3	5	1	0	1	0	0	0	0	1	0	0	0	4	0	5	1	0

1 = *Zephronia siamensis* , 2 = *Orthomorpha variegata* , 3 = *Orthomopha* sp., 4 = *Antheromorpha festiva,* 5 = *Platyrhacus* sp1. , 6 = *Platyrhacus* sp2. , 7 = Pachybolidae 1 , 8 = Pachybolidae 2, 9 = *Lithostrophus segregates,* 10 = Harpagophoridae 1, 11 = Harpagophoridae 2, 12 = *Thyropygus* sp. , 13 = *Thyropygus allevatus* , 14 = *Thyropygus induratus* , 15 = *Thyropygus* sp2., 16 = *Anurostreptus sculptus* , 17 = *Nepalmatoiulus* sp.

Table 2 Number and species of millipedes in dry dipterocarp forest (DDF).

Month	Quadrats	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Jun	1	8	0	1	0	0	0	0	0	0	0	3	0	0	0	0	0	0
	2	9	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
	3	7	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	1
Jul	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aug	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	2	3	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	6	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Sep	1	1	3	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
	2	0	0	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Oct	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nov	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

1 = *Zephronia siamensis* , 2 = *Orthomorpha variegata* , 3 = *Orthomopha* sp., 4 = *Antheromorpha festiva,* 5 = *Platyrhacus* sp1. ,
6 = *Platyrhacus* sp2. , 7 = Pachybolidae 1 , 8 = Pachybolidae 2, 9 = *Lithostrophus segregates,* 10 = Harpagophoridae 1,
11 = Harpagophoridae 2, 12 = *Thyropygus* sp. , 13 = *Thyropygus allevatus* , 14 = *Thyropygus induratus* , 15 = *Thyropygus* sp2.,
16 = *Anurostreptus sculptus* , 17 = *Nepalmatoiulus* sp.

Table 2 (continued) Number and species of millipedes in dry dipterocarp forest (DDF).

Month	**Quadrats**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Dec	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	2	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jan	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Feb	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mar	1	2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Apr	1	9	22	2	0	0	0	0	0	0	0	8	0	0	0	0	0	0
	2	0	4	2	0	0	0	0	0	0	0	1	0	0	0	0	0	0
	3	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
May	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

1 = *Zephronia siamensis* , 2 = *Orthomorpha variegata* , 3 = *Orthomopha* sp., 4 = *Antheromorpha festiva,* 5 = *Platyrhacus* sp1. , 6 = *Platyrhacus* sp2. , 7 = Pachybolidae 1 , 8 = Pachybolidae 2, 9 = *Lithostrophus segregates,* 10 = Harpagophoridae 1, 11 = Harpagophoridae 2, 12 = *Thyropygus* sp. , 13 = *Thyropygus allevatus* , 14 = *Thyropygus induratus* , 15 = *Thyropygus* sp2., 16 = *Anurostreptus sculptus* , 17 = *Nepalmatoiulus* sp.

Table 3 Number and species of millipedes in ecotone (ECO).

Month	Quadrats	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Jun	1	11	2	3	0	0	1	0	13	4	0	0	1	0	0	1	0	1
	2	10	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
	3	14	3	1	0	0	0	0	11	0	0	1	0	0	0	0	0	0
Jul	1	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	2
	2	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aug	1	0	0	0	1	0	0	0	4	0	0	0	0	0	0	1	0	2
	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	5	0	0	2	0	0	0	6	6	0	0	0	0	0	0	1	0
Sep	1	0	1	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oct	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nov	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

1 = *Zephronia siamensis* , 2 = *Orthomorpha variegata* , 3 = *Orthomopha* sp., 4 = *Antheromorpha festiva*, 5 = *Platyrhacus* sp1. ,
6 = *Platyrhacus* sp2. , 7 = Pachybolidae 1 , 8 = Pachybolidae 2, 9 = *Lithostrophus segregates*, 10 = Harpagophoridae 1,
11 = Harpagophoridae 2, 12 = *Thyropygus* sp. , 13 = *Thyropygus allevatus* , 14 = *Thyropygus induratus* , 15 = *Thyropygus* sp2.,
16 = *Anurostreptus sculptus* , 17 = *Nepalmatoiulus* sp.

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Table 3 (continued) Number and species of millipedes in ecotone (ECO).

Month	Quadrats	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Dec	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jan	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Feb	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mar	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	3	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Apr	1	7	0	0	0	0	0	0	0	1	1	0	0	0	1	1	0	1
	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	1	0	1	0	0	0	0	42	1	0	0	0	0	0	0	0	2
May	1	0	1	0	0	0	0	0	5	0	0	0	0	0	0	0	0	1
	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	5	2	1	1	0	3	0	22	4	0	0	0	0	0	0	0	1

1 = *Zephronia siamensis* , 2 = *Orthomorpha variegata* , 3 = *Orthomopha* sp., 4 = *Antheromorpha festiva*, 5 = *Platyrhacus* sp1. ,
6 = *Platyrhacus* sp2. , 7 = Pachybolidae 1 , 8 = Pachybolidae 2, 9 = *Lithostrophus segregates*, 10 = Harpagophoridae 1,
11 = Harpagophoridae 2, 12 = *Thyropygus* sp. , 13 = *Thyropygus allevatus* , 14 = *Thyropygus induratus* , 15 = *Thyropygus* sp2.,
16 = *Anurostreptus sculptus* , 17 = *Nepalmatoiulus* sp.

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Table 4 Number and species of millipedes in plantation forest (PTF).

Month	Quadrats	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Jun	1	5	2	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0
	2	4	0	1	0	0	0	0	0	0	0	0	0	1	0	5	0	1
	3	21	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Jul	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	8	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Aug	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sep	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oct	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Nov	1	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	5
	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2

1 = *Zephronia siamensis* , 2 = *Orthomorpha variegata* , 3 = *Orthomopha* sp., 4 = *Antheromorpha festiva,* 5 = *Platyrhacus* sp1. ,
6 = *Platyrhacus* sp2. , 7 = Pachybolidae 1 , 8 = Pachybolidae 2, 9 = *Lithostrophus segregates*, 10 = Harpagophoridae 1,
11 = Harpagophoridae 2, 12 = *Thyropygus* sp. , 13 = *Thyropygus allevatus* , 14 = *Thyropygus induratus* , 15 = *Thyropygus* sp2.,
16 = *Anurostreptus sculptus* , 17 = *Nepalmatoiulus* sp.

Table 4 (continued) Number and species of millipedes in plantation forest (PTF).

Month	Quadrats	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Dec	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Jan	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Feb	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mar	1	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Apr	1	23	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	2	9	0	0	0	0	0	0	0	0	0	2	0	0	0	1	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
May	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	18	1	0	0	0	0	0	0	0	0	0	0	2	0	4	0	3

1 = *Zephronia siamensis* , 2 = *Orthomorpha variegata* , 3 = *Orthomopha* sp., 4 = *Antheromorpha festiva,* 5 = *Platyrhacus* sp1. ,
6 = *Platyrhacus* sp2. , 7 = Pachybolidae 1 , 8 = Pachybolidae 2, 9 = *Lithostrophus segregates,* 10 = Harpagophoridae 1,
11 = Harpagophoridae 2, 12 = *Thyropygus* sp. , 13 = *Thyropygus allevatus* , 14 = *Thyropygus induratus* , 15 = *Thyropygus* sp2.,
16 = *Anurostreptus sculptus* , 17 = *Nepalmatoiulus* sp.

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APPENDIX B

ENVIRONMENTAL FACTORS IN FOUR FOREST TYPES

Table 1 Environmental factors of dry evergreen forest (DEF).

Month	Light (lux)	Soil Temp (ºC)	Litter	Soil Moisture (%)	Rainfall (mm.)	Air Temp (ºC)	Humidity (%)	P (ppm)	K (ppm)	Total Nitrogen (%)	Organic Carbon (%)	Organic matter (%)	C:N Ratio	Soil pH
June	2373.67	25.47	16.19	15.72	136.50	29.70	85.00	9.26	173.00	0.22	1.58	2.71	7.18	5.14
July	1995.67	25.17	16.19	11.91	96.50	29.20	84.00	9.26	173.00	0.22	1.58	2.71	7.18	5.14
August	356.67	25.67	34.75	18.08	190.80	26.90	86.00	5.48	122.00	0.17	1.82	3.13	10.71	5.17
September	3876.67	25.00	55.75	22.46	149.30	27.40	88.00	5.48	122.00	0.17	1.82	3.13	10.71	5.17
October	2062.33	24.00	40.87	25.85	319.90	23.15	89.00	5.48	122.00	0.17	1.82	3.13	10.71	5.17
November	1144.33	25.67	22.97	5.70	14.50	22.20	78.00	5.48	122.00	0.17	1.82	3.13	10.71	5.17
December	1360.33	20.33	13.37	4.52	0.00	25.80	78.00	1.89	120.00	0.20	1.75	3.02	8.75	5.60
January	3493.33	20.67	11.26	3.60	0.40	21.60	75.00	1.89	120.00	0.20	1.75	3.02	8.75	5.60
February	2522.67	22.33	9.36	3.65	27.30	24.70	74.00	1.89	120.00	0.20	1.75	3.02	8.75	5.60
March	1873.67	22.33	16.30	14.07	46.40	25.65	80.00	23.08	270.00	0.15	2.05	3.53	13.67	5.15
April	203.67	25.17	52.97	19.93	65.80	27.30	82.00	23.08	270.00	0.15	2.05	3.53	13.67	5.15
May	2729.67	28.00	10.69	6.03	88.30	29.25	83.00	23.08	270.00	0.15	2.05	3.53	13.67	5.15

Table 2 Environmental factors of dry dipterocarp forest (DDF).

Month	Light (lux)	Soil Temp (ºC)	Litter	Soil Moisture (%)	Rainfall (mm.)	Air Temp (ºC)	Humidity (%)	P (ppm)	K (ppm)	Total Nitrogen (%)	Organic Carbon (%)	Organic matter (%)	C:N Ratio	Soil pH
June	536.00	23.67	45.76	13.97	136.50	29.70	85.00	12.75	181.00	0.25	2.61	4.49	10.44	4.86
July	1386.00	25.50	45.76	12.22	96.50	29.20	84.00	12.75	181.00	0.25	2.61	4.49	10.44	4.86
August	1306.00	26.00	36.94	21.61	190.80	26.90	86.00	7.19	168.00	0.29	3.01	5.17	10.38	4.30
September	612.00	24.00	53.69	26.67	149.30	27.40	88.00	7.19	168.00	0.29	3.01	5.17	10.38	4.30
October	645.33	23.00	50.47	34.24	319.90	23.15	89.00	7.19	168.00	0.29	3.01	5.17	10.38	4.30
November	406.00	23.67	20.47	21.95	14.50	22.20	78.00	7.19	168.00	0.29	3.01	5.17	10.38	4.30
December	378.67	18.67	14.11	10.67	0.00	25.80	78.00	7.74	150.00	0.36	3.92	6.74	10.89	4.02
January	517.33	19.33	14.59	9.03	0.40	21.60	75.00	7.74	150.00	0.36	3.92	6.74	10.89	4.02
February	473.33	20.00	4.34	10.04	27.30	24.70	74.00	7.74	150.00	0.36	3.92	6.74	10.89	4.02
March	411.00	20.67	31.84	10.87	46.40	25.65	80.00	16.13	207.00	0.27	3.76	6.46	13.93	4.59
April	545.00	24.50	40.33	17.00	65.80	27.30	82.00	16.13	207.00	0.27	3.76	6.46	13.93	4.59
May	574.67	25.00	18.51	12.63	88.30	29.25	83.00	16.13	207.00	0.27	3.76	6.46	13.93	4.59

Table 3 Environmental factors of ecotone (ECO).

Month	Light (lux)	Soil Temp (ºC)	Litter	Soil Moisture (%)	Rainfall (mm.)	Air Temp (ºC)	Humidity (%)	P (ppm)	K (ppm)	Total Nitrogen (%)	Organi Carbon (%)	Organic matter (%)	C:N Ratio	Soil pH
June	1348.67	24.00	30.14	14.87	136.50	29.70	85.00	14.57	229.00	0.27	2.43	4.18	9.00	5.25
July	1891.56	24.84	30.14	12.94	96.50	29.20	84.00	14.57	229.00	0.27	2.43	4.18	9.00	5.25
August	453.33	26.93	30.16	16.08	190.80	26.90	86.00	7.94	140.00	0.26	2.26	3.88	8.69	4.93
September	916.00	25.17	45.45	20.21	149.30	27.40	88.00	7.94	140.00	0.26	2.26	3.88	8.69	4.93
October	984.33	24.00	50.08	26.48	319.90	23.15	89.00	7.94	140.00	0.26	2.26	3.88	8.69	4.93
November	664.33	24.67	17.00	10.79	14.50	22.20	78.00	7.94	140.00	0.26	2.26	3.88	8.69	4.93
December	1124.33	22.33	18.02	6.04	0.00	25.80	78.00	4.30	130.00	0.29	3.33	5.73	11.48	5.29
January	813.33	14.67	10.65	5.03	0.40	21.60	75.00	4.30	130.00	0.29	3.33	5.73	11.48	5.29
February	174.67	21.33	10.86	5.33	27.30	24.70	74.00	4.30	130.00	0.29	3.33	5.73	11.48	5.29
March	242.33	20.00	49.16	9.78	46.40	25.65	80.00	17.07	273.00	0.30	2.88	4.95	9.60	5.55
April	640.67	25.00	57.04	13.16	65.80	27.30	82.00	17.07	273.00	0.30	2.88	4.95	9.60	5.55
May	1280.00	26.00	37.41	9.69	88.30	29.25	83.00	17.07	273.00	0.30	2.88	4.95	9.60	5.55

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Table 4 Environmental factors of plantation forest (PTF).

Month	Light (lux)	Soil Temp (ºC)	Litter	Soil Moisture (%)	Rainfall (mm.)	Air Temp (ºC)	Humidity (%)	P (ppm)	K (ppm)	Total Nitrogen (%)	Organic Carbon (%)	Organic matter (%)	C:N Ratio	Soil pH
June	2040.67	24.70	38.72	11.59	136.50	29.70	85.00	3.80	152.00	0.15	1.38	2.38	9.20	4.86
July	774.33	24.76	34.69	9.98	96.50	29.20	84.00	3.80	152.00	0.15	1.38	2.38	9.20	4.86
August	728.00	26.00	21.79	12.07	190.80	26.90	86.00	7.20	180.00	0.21	1.87	3.21	8.90	4.86
September	1277.00	24.00	50.02	21.40	149.30	27.40	88.00	7.20	180.00	0.21	1.87	3.21	8.90	4.86
October	741.67	23.33	49.33	28.88	319.90	23.15	89.00	7.20	180.00	0.21	1.87	3.21	8.90	4.86
November	323.33	24.00	20.97	12.23	14.50	22.20	78.00	7.20	180.00	0.21	1.87	3.21	8.90	4.86
December	485.33	20.33	15.20	9.37	0.00	25.80	78.00	1.58	268.00	0.30	3.41	5.86	11.37	5.10
January	311.33	20.00	14.52	7.50	0.40	21.60	75.00	1.58	268.00	0.30	3.41	5.86	11.37	5.10
February	269.67	20.00	4.57	3.36	27.30	24.70	74.00	1.58	268.00	0.30	3.41	5.86	11.37	5.10
March	250.33	21.27	4.57	6.34	46.40	25.65	80.00	5.68	302.00	0.24	2.50	4.31	10.42	5.29
April	402.67	25.33	54.43	18.99	65.80	27.30	82.00	5.68	302.00	0.24	2.50	4.31	10.42	5.29
May	286.00	25.00	40.13	9.51	88.30	29.25	83.00	5.68	302.00	0.24	2.50	4.31	10.42	5.29

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