THE POPULATION DYNAMICS AND DISTRIBUTION OF TERRESTRIAL EARTHWORMS AT SAKAERAT ENVIRONMENTAL RESEARCH STATION AND ADJACENT AREAS, NAKHON RATCHASIMA PROVINCE

Pattana Somniyam

A Thesis Submitted in Partial Fulfillment of the Requirements for the

Degree of Doctor of Philosophy in Environmental Biology

Suranaree University of Technology

Academic Year 2008

การกระจายตัวและการเปลี่ยนแปลงประชากรของไส้เดือนดินในสถานีวิจัยสิ่งแวดล้อมสะแกราชและพื้นที่ใกล้เคียง จังหวัดนครราชสีมา

นายพัฒนา สมนิยาม

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต
สาขาวิชาชีววิทยาสิ่งแวดล้อม
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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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พัฒนา สมนิยาม : การกระจายตัวและการเปลี่ยนแปลงประชากรของไส้เดือนดินในสถานีวิจัยสิ่งแวดล้อมสะแกราชและพื้นที่ใกล้เคียง จังหวัดนครราชสีมา (THE POPULATION DYNAMICS AND DISTRIBUTION OF TERRESTRIAL EARTHWORMS AT SAKAERAT ENVIRONMENTAL RESEARCH STATION AND ADJACENT AREAS, NAKHON RATCHASIMA PROVINCE) อาจารย์ที่ปรึกษา : ดร.พงศ์เทพ สุวรรณวารี, 215 หน้า.

การศึกษาการกระจายตัวของไส้เดือนดินในสถานีวิจัยสิ่งแวดล้อมสะแกราชและพื้นที่ใกล้เคียง จังหวัดนครราชสีมา พบไส้เดือน จำนวน 21 ชนิด 5 วงศ์ โดยพบในพื้นที่ป่าธรรมชาติ 14 ชนิด พื้นที่เกษตรกรรม 14 ชนิด และบริเวณพื้นที่บ้านพักอาศัย 13 ชนิด ทุ่งหญ้า 8 ชนิด และป่าปลูก 5 ชนิด ไส้เดือนที่พบสามารถจำแนกได้ดังนี้ วงศ์ Megascolecidae มี 13 ชนิด ได้แก่ *Amynthas alexandri*, *A. defecta*, *A. sieboldi*-group, *Amynthas* sp.1, *Amynthas* sp.2, *Amynthas* sp.3, *Amynthas* sp.4, *Metaphire bahli*, *M. houlleti*, *M. peguana*, *M. planata*, *M. posthuma* และ *Polypheretima elongata* วงศ์ Moniligastridae มี 3 ชนิด ได้แก่ *Drawida beddardi*, *Drawida* sp.1 และ *Drawida* sp.2 วงศ์ Octochaetidae มี 3 ชนิด ได้แก่ *Dichogaster affinis*, *Di. bolaui* และ *Di. modiglianii* วงศ์ Glossoscolecidae มี 1 ชนิด คือ *Pontoscolex corethrurus* และ ในวงศ์ Ocnerodrilidae อีก 1 ชนิดคือ *Gordiodrilus elegans* ความหนาแน่นของประชากรไส้เดือนดินมีมากที่สุดในบริเวณพื้นที่บ้านพักอาศัย หนาแน่นมากในฤดูฝน ลดน้อยลงในฤดูหนาวและพบได้ยากในฤดูร้อน จากการศึกษาครั้งนี้อาจสรุปได้ว่า ประเภทของการใช้ที่ดินที่ต่างกันมีผลต่อชนิด การกระจายตัว และความหนาแน่นของไส้เดือน ขณะที่ฤดูกาลมีอิทธิพลต่อการเปลี่ยนแปลงของประชากรไส้เดือนดิน ส่วนปัจจัยสิ่งแวดล้อม เช่น ปริมาณน้ำฝน ความชื้นสัมพัทธ์ ความชื้นในดิน ปริมาณไนโตรเจน แคลเซียมและอินทรียวัตถุ ที่เพิ่มขึ้นทำให้ความหนาแน่นของไส้เดือนดินเพิ่มขึ้น ขณะที่อุณหภูมิที่สูงขึ้นทำให้ความหนาแน่นของไส้เดือนดินลดลง

สาขาวิชาชีววิทยา	ลายมือชื่อนักศึกษา____________________
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	ลายมือชื่ออาจารย์ที่ปรึกษาร่วม____________________

PATTANA SOMNIYAM : THE POPULATION DYNAMICS AND DISTRIBUTION OF TERRESTRIAL EARTHWORMS AT SAKAERAT ENVIRONMENTAL RESEARCH STATION AND ADJACENT AREAS, NAKHON RATCHASIMA PROVINCE. THESIS ADVISOR : PONGTHEP SUWANWAREE, Ph.D. 215 PP.

TERRESTRIAL EARTHWORM SPECIES DIVERSITY DYNAMICS, DISTRIBUTION SAKAERAT ENVIRONMENTAL RESEARCH STATION

Twenty one earthworm species in five families were found in these areas. Natural forests and agricultural areas had 14 species followed by residential areas (13), grassland (8), and forest plantation (5). Earthworm species consists of thirteen species of Megascolecidae, (*Amynthas alexandri*, *A. defecta*, *A. sieboldi*-group, *Amynthas* sp.1, *Amynthas* sp.2, *Amynthas* sp.3, *Amynthas* sp.4, *Metaphire bahli*, *M. houlleti*, *M. peguana*, *M. planata*, *M. posthuma*, and *Polypheretima elongata)*, three species of Moniligastridae (*Drawida beddardi*, *Drawida* sp.1, and *Drawida* sp.2), three species of Octochaetidae (*Dichogaster affinis*, *Di. bolaui*, and *Di. modiglianii*), one species of Glossoscolecidae (*Pontoscolex corethrurus*) and one species of Ocnerodrilidae (*Gordiodrilus elegans*).

The highest population densities were found in residential areas. The earthworm density increased in rainy season then declined in winter season, and disappeared in summer season. *P. corethrurus* was dominant in these areas. Different in land use types greatly influenced earthworm diversity, density and distribution. While seasonal changes definitely affected earthworm dynamics. The earthworm

density was also positively correlated with environmental factors such as rainfall, relative humidity, soil moisture, nitrogen content, and soil calcium. In contrast, it was negatively correlated with soil temperature.

School of Biology | Student's Signature ________________

Academic Year 2008 | Advisor's Signature ________________

Co-advisor's Signature ______________

Co-advisor's Signature ______________

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Pattana Somniyam

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CHAPTER I

INTRODUCTION

1.1 The importance of problem

Earthworms are soil invertebrates appeared on Earth 600 million years ago (Lavelle *et al.*, 1999). They belong to class Oligochaeta of phylum Annelida (Edwards and Bohlen, 1996). Earthworms play the important roles in soil physical, chemical, and biological characters (Edwards, 2004). For example, some earthworm species create the vertical burrows that improve soil aeration, porosity and permeability (Edwards, 2004; Edwards and Bohlen, 1996). Earthworms consume litter, and leave more available plant nutrients in their casts into the soil surface. Depending on earthworm species, the casts contain neutral pH, higher available nitrogen, phosphorus, potassium, and calcium contents than surrounding soil, as well as a higher cation-exchange capacity (Brow *et al.*, 2004; Edwards, 2004; Trelo-ges, 2002). Earthworms also stimulate microbial populations such as nitrogen bacteria in their gut and casts that encourage soil fertility. These results can increase plant growth and yield of crops (Edwards and Bohlen, 1996).

In addition, some earthworms predate harmful nematodes and suppress insect biopest, hence, decreasing the concentration of harmful organisms in soil (Arancon *et al.*, 2005; Marhan and Scheu, 2005). Nevertheless, earthworms are beneficial to human in many ways. They are widely used for vermicompost, bait for fish, and human food. Moreover, they can also alleviate or cure human illness such as stones in the bladder, jaundice, pile, fever and small pox (Edwards and Bohlen, 1996, Satchell, 1983).

Although earthworms are beneficial for soil, plant and human, few earthworm studies have been done in Thailand. Only three earthworm diversity studies have been conducted so far. Gates (1972) was the first researcher who studied earthworm in Burmar and adjacent regions. He described 27 earthworm species from Thailand. Thirty four years later, Skawsang (2003) discovered only two genera belonging to the family Megascolecide in Ong Chu-Na Suan subwatershed, Kanchanaburi. Whereas Kosavititkul (2005) found 16 species in Khao Yai National Park (in mixed deciduous, dry evergreen, moist evergreen, hill evergreen forest and grass land); among them, three species had never been discovered in Thailand before.

Therefore, this study will provide new information of earthworm diversity in Thailand, and will be a valuable resource for basic and applied research, and also increasing knowledge in use various aspects earthworms for people who work in the field of ecological, agricultural, and environmental sciences.

1.2 Research objectives

This thesis has two main objectives as follows:

1. to study the species richness, population dynamics and population distributions of terrestrial earthworms in different forest types, agricultural land use and residence areas near to Sakaerat Environmental Research Station (SERS).

2. to investigate the relationship between terrestrial earthworms and their environmental factors.

1.3 Research hypotheses

1. The abundance of earthworm species varies in different areas such as forest types, agricultural lands and residence areas.

2. The population dynamics and distribution of earthworms depend on environmental factor changes.

1.4 Scope and limitations

1.4.1 Study area

This study was conducted at Sakaerat Environmental Research Station and adjacent areas. Total of twelve land use types were selected for this research, consisting of four forest types, namely dry evergreen forest, dry dipterocarp forest, forest plantation, and grass land, four types of agricultural land, including mango plantation, sugarcane plantation, cassava plantation, and rice paddy, and three types of residential areas, including household areas, SERS building area, and Silvicultural Research Station area. The environmental factors including precipitation, ambient temperature, soil temperature, soil moisture, soil pH, N, P, K, Ca, and organic matter were also studied.

1.4.2 Sampling time

Four replicates of earthworm, soil and plant litter were collected from dry evergreen and dry dipterocarp forest once a month in 2006 to determine the species diversity, and population dynamic of earthworms. While samples from twelve land use types were collected only in rainy season (June, August, and October) in 2006 to determine earthworm diversity in these areas.

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CHAPTER II

LITERATURE REVIEW

Earthworms are among the most visible fauna of soil organisms. They have numerous beneficial effects on soil fertility and structure. This chapter deals with an overview of earthworm benefits, earthworm morphology, earthworm biology, earthworm diversity and geographical distribution, earthworm ecology, the influence of environmental factors on earthworms, effects of agricultural practices and chemical on earthworms, the role of earthworms in organic matter and nutrient cycles, and finally, the information about Sakaerat Environmental Research Station

2.1 Earthworm benefits

Earthworms are beneficial in many ways. They provide bait for fishing, a source of protein for animal food and, most importantly, they play a unique and important role in conditioning the soil. Earthworm improves the physical structure of the soil, improves soil fertility, plant growth and health, but suppresses weed growth, and help clean up dangerous chemicals in the environment.

Earthworms can be used for human food. They are regarded as a delicacy by the Maoris in New Zealand. In Japan earthworm pies have been made, and have been reported from South Africa of fried earthworms being eaten. Primitive natives from New Guinea and parts of Africa have been reported to eat raw earthworms and earthworms are believed to be a source of human food in South America. There have been many reports of earthworms being eaten or applied to humans to alleviate or cure such as stones in bladder, jaundice, piles, fever and smallpox. Earthworm ashes have been used as a tooth powder in primitive societies or applied to the head to make hair grow, and they have been used in testing pregnancy (Edwards and Bohlen, 1996).

The high protein content of earthworms has been reported by many researchers. The amounts of essential amino acids recorded are very adequate for a good animal feed. Earthworms have excellent range of vitamins and are rich in niacin, and vitamin B_{12}. The over all nutrient spectrum of worm tissues has excellent potential as a feed for fish, poultry, pigs or domestic animals (Edwards and Bohlen, 1996).

Earthworms improve the physical structure of the soil. For example: the tunneling activity of earthworm improves soil aeration, porosity, and permeability. Earthworm cast absorb water faster than soil. Therefore, they could increase moisture absorption and moisture available to plants. (Edwards and Bohlen, 1996; Lavelle *et al.,* 1999; Lee, 1985).

Earthworms improve soil fertility in many ways. For instance; earthworm activity counteracts leaching by bringing up nutrients from deep in the soil and depositing them on the soil surface as castings. Earthworms eat the litter and leave the nutrients in their castings for plants to use, help compost residues and waste products. Bacteria in a worm's gut help destroy harmful chemicals and breakdown organic wastes. Plant growth stimulants such as auxins are produced in the castings; these hormones stimulate roots to grow faster and deeper. Earthworm casts have higher nitrogenase activity, meaning greater rates of nitrogen fixation are found in casts as compared to surrounding soil (Edwards and Bohlen, 1996; Ranch, 2006).

Earthworms improve plant growth and health. Crops grown in earthworm-inhabited soil increase yields from 25% to over 300% than in earthworm-free soil. They help eliminate thatch in lawns and grassy areas by eating and digesting the plant debris and discourage populations of soil organisms such as insects, nematodes and others that are harmful to plants. They can produced compost (vermicompost) which dramatically increases germination and growth in many plants. Earthworm castings speeds up the sprouting of germinate seeds following a one hour soaking (Edward, 2004). A large earthworm population suppresses weed growth. They often eat weed seeds and either destroy them or reduce their ability to germinate. Earthworm relationship with plant roots and help plants grow better hence shading out weeds and out competing them for water and nutrients (Edwards and Bohlen, 1996; Ranch, 2006).

Earthworms often help clean up dangerous chemicals in the environment. Researchers have found that bacteria living in the guts of worms breakdown (detoxify) many hazardous chemicals such as hexachlorocyclohexane (HCH). Most recently they are being used as a diagnostic tool since they have the ability to hyper accumulate toxins and environmental pollutants found in the soil (since they ingest soil). As a result they are often collected and their tissue analyzed for chemical contaminants. (Edwards and Bohlen, 1996; Ranch, 2006).

2.2 Earthworm morphology

Earthworms are bilaterally symmetrical, externally segmented, with a corresponding internal segmentation. They have no skeleton and a thinly pigmented cuticle, bearing setae on all segments except the first two; with an outer layer of circular muscles. They are hermaphrodite and have relatively few gonads, which are situated in definite segmental position. When mature, a swollen area of the epidermis called a clitellum, located in particular segments. The eggs are usually fertilized and the young develop within the eggs, the newly hatched worms resembling adults. The external and internal characters of earthworms are described as follow (Edwards and Bohlen, 1996).

2.2.1 The external characters

2.2.1.1 Segmentation

Earthworms are divided externally into bands or segments along the length of body by furrows or intersegmental grooves, which coincide with the position of the septa dividing the body internally. The segments vary in width, usually being widest in the anterior and clitellar regions. Segments are numbered arbitrarily form the front to the rest. The mouth opens on the first segment, or peristomium, which bears on its dorsal surface the prostomium, a lobe overhanging the mouth (Figure 2.1). The prostomium varies in size, and in some worms it may be so small that it cannot be distinguished. The way in which the peristomium and prostomium are joined differs between species and is useful systemic character. The connection is termed zygolobous, prolobous, epilobous or tanylobous, depending on the demarcation of the prostomium (Figure 2.2) (Edwards and Bohlen, 1996).

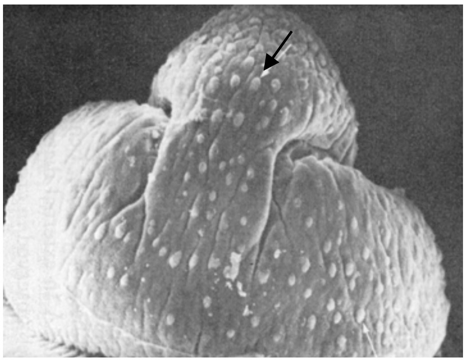

Figure 2.1 Scanning electron microscopy of an epilobous prostomium of *Eisenia fetida.* The arrow indicates a sense organ. (Jamieson, 1981).

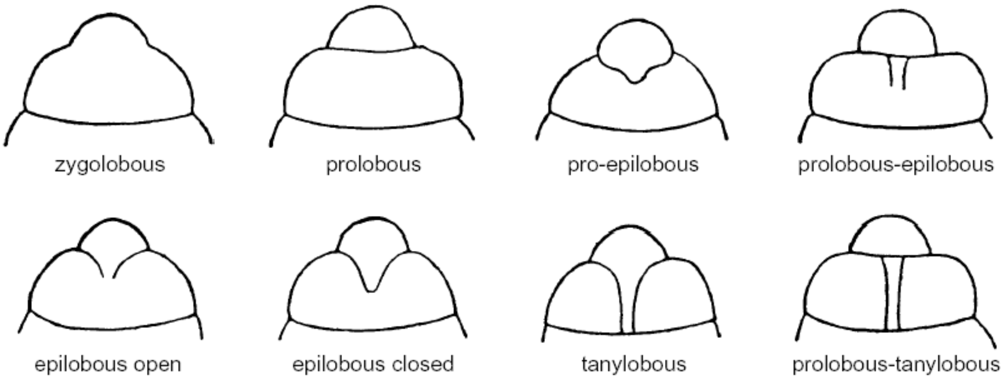

Figure 2.2 Types of prostomium in oligochaetes (Michaelsen, 1928).

2.2.1.2 Chaetotaxy

The setae, which are bristle-like structures borne in follicles on the exterior of the body wall, can be extened or retracted by means of protractor and retractor muscles which are attached to the base of the follicles and pass through the longitudinal muscle layer into the circular muscle layer below. As the setae are used to grip the substrate, their principal function is locomotory. Different species of oligochaetes have setae of varying shapes- either rod-, needle- or hair-like. The shape of setae varies with their position, the most common from being those of *Lumbricus*, which are sigmoid and about one mm long. Often setae are enlarged in both at the anterior and posterior ends; the setae in the region of genital pores (particular the male pores) are sometimes modified in size and shape, and situated on raised papillae, termed 'genital setae' (Figure 2.3). The genital setae, which can be up to seven mm long in some species. These setae assist the physiological processes which take place at copulation by providing physical stimuli to the partner. (Edwards and Bohlen, 1996; Jamieson, 2001).

The setae are arranged in a single ring around the periphery of each segment, their number and distribution being typically termed either lumbricine or perichaetine. The lumbricine arrangement, typical of the lumbricidae, consists of eight setae per segment in ventral and latero-ventral pairs. If the distance between the setae in each pair is very small, they are termed 'closed paired', if wider apart, they are termed 'widely paired', or if they are very far apart so that the pairing is not obvious, they are termed 'distant', as shown in Figure 2.4 (Edwards and Bohlen, 1996; Jamieson, 2001).

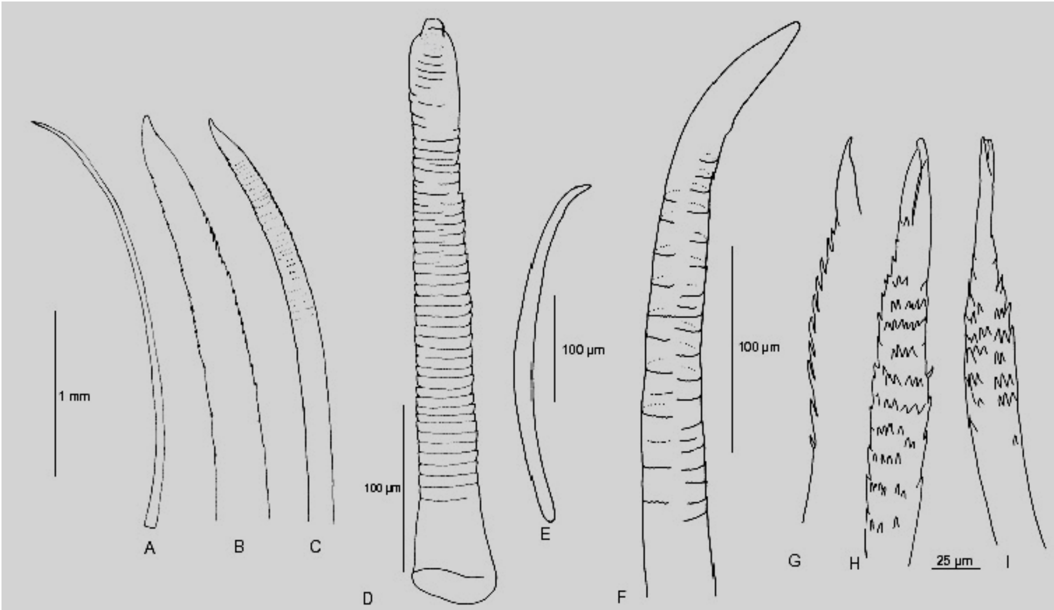

Figure 2.3 Penial setae of some Australian Megascolecinae A-C: *Heteroporodrilus mediterreus*. D: *Notoscolex camdensis*. E-F: *Cryptodrilus polynephricus*. G-I: *Digaster armifera* (Jamieson, 1972).

The distance between each pair and between neighboring paires is constant for each species. The setae are designated by letter, a, b, c and d, beginning with the most ventral setae on each side, and z, y, x, w-beginning with the most dorsal one on each side, irrespective of how many there are in between, as show in Figure 2.5 (Edwards and Bohlen, 1996; Jamieson, 2001).

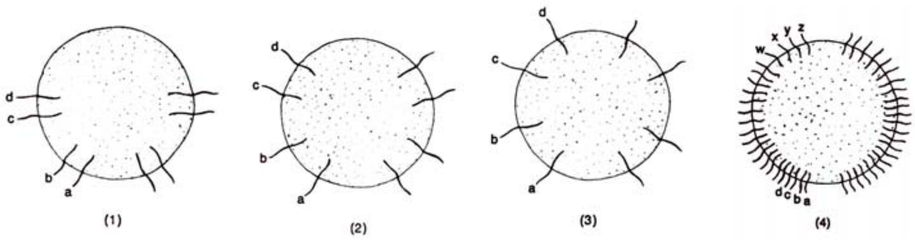

Figure 2.4 Arrangement of setae in Oligochaeta. 1, 2, 3, Lumbricine arrangement; 4, Perichaetine arrangement. 1, Closely paired; 2, widely paired; 3, distant paired (Edwards and Bohlen, 1996).

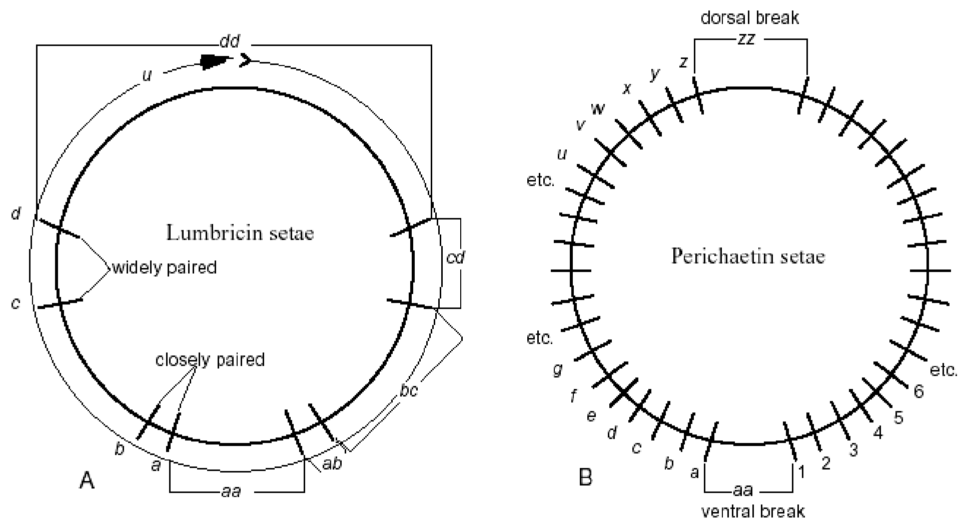

Figure 2.5 Diagrammatic cross section of an earthworm A: the lumbricin arrangementand B: the perichaetin arrangement of somatic setae (Jamieson, 2000).

2.2.1.3 Genital and other apertures

Earthworms are hermaphrodite and have both male and female genital openings to the exterior, consisting of paired pores on the ventral or ventro-laterally side of the body. In lumbricid worms, the male pores are situated ventro-laterally on the 15^{th} or occasionally on the 13^{th} segment. Megascolecidae, the male pores may be associated with one or two pairs of prostatic pores; these are openings of the ducts of accessory reproductive bodies known as prostates (Minnich, 1977).

The male and prostatic pores: The position of male and prostates pores are sometimes combined as one opening, but when separate they are usually joined by longitudinal seminal grooves, on either side of the ventral surface of the body (Minnich, 1977).

Spermathecal pores: Spermathecal pores in earthworms are generally inconspicuous, not always paired. They are usually intersegmental and are most often situated in the ventral or latero-ventral position, but sometimes they are close to the mid-dorsal line. The segmental location of spermathecal pores and their position relative to setal lines is much used for specific identification in Megascolecids. Usaully earthworms have two or more pairs of spermathecal pores, with a maximum of seven pairs in some species, but other are absent (Minnich, 1977).

Femal pores: the female pores are most commonly a single pair, situated either in an intersegmental groove or on a segment, their position often being diagnostic of a particular family. Thus, in the Enchytraeidae they are in groove 12/13, and in the Lumbricidae, Megascolecidae and Glossoscolecidae, they are on segment 14. Sometimes the female pores are united into a single median pore (Edwards and Bohlen, 1996; Jamieson, 2001).

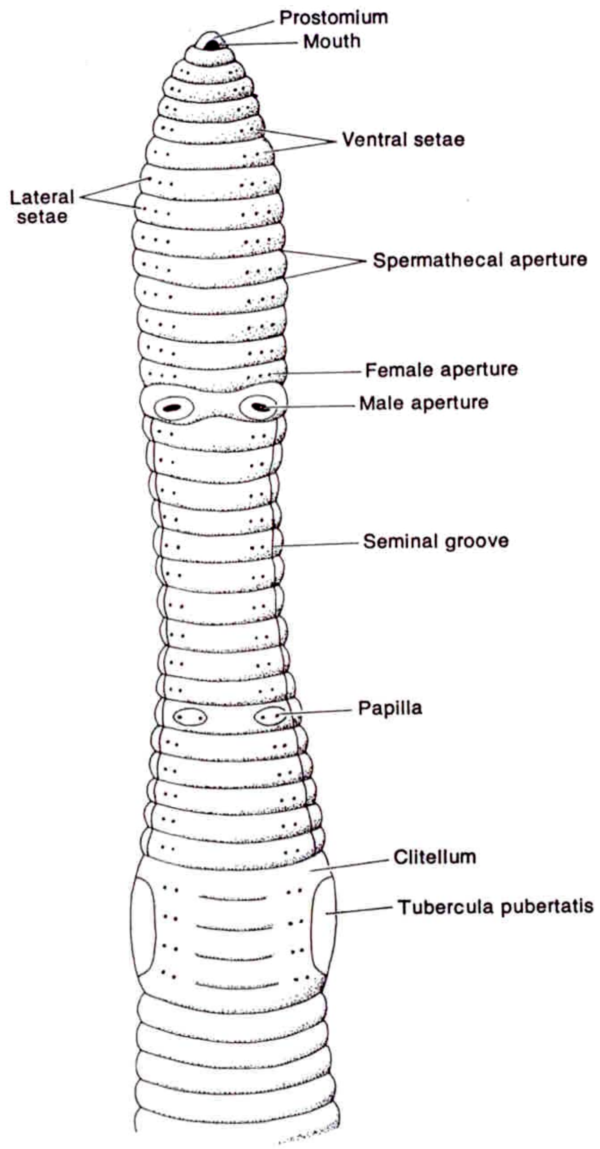

Figure 2.6 Ventral view of the anterior region of *Lumbricus terrestris* (Minnich, 1977).

Dorsal pores: The dorsal pores are small openings situated in the intersegmental grooves on the mid-dorsal line, occured in most terrestrial oligochaetes, but not in aquatic and semi-aqutic species. These pores communicated with the body cavity and the coelomic fluid. The position of the first dorsal pore is used as a systematic character at the species level, although these pores may be hard to distinguish in some worms (Edwards and Bohlen, 1996; Stephenson, 1930).

The clitellum: The clitellum is a specialization of the epidermis for secreting the cocoon, in which the eggs are deposited and into which spermatozoa received into spermathecae from the partner are exuded to bring about fertilization. It is either a saddle-shaped or annular structure. It usually appears swollen, although sometimes it can be differentiated externally only by its color. In some megascolecids it appears only as a well-defined constriction (Stephenson, 1930).

The position of clitellum and the number of segments over which it extends differ considerably among oligochaetes. Lumbricidae have clitellum on anterior part of the body, behind the genital pores, beginning between segments 22 and 38, and extending over about 4-10 segments posteriorly (Figure 2.6). Megascolecidae have the clitellum further forward, beginning at or in front of segment 14, thus including the female pore, and posteriorly it may also include the male pore (Figure 2.7).

Most earthworms possess various makings at sexual maturity, in the form of tubercles, ridges and papillae on the anterior ventral surface, and these differ greatly in number and form in different species of oligochaetes. The tubercula pubertatis usually extend over fewer segments than those occupied by the clitellum. The position of the clitellum is used as a diagnostic character, because the position and number of segments occupied by the clitellum is, with small variations, constant for each species (Edwards and Bohlen, 1996; Jamieson, 2001).

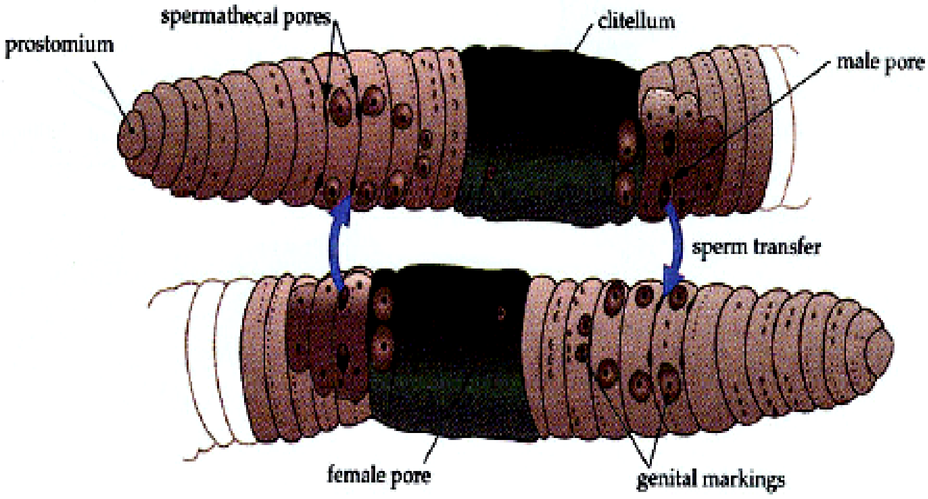

Figure 2.7 The clitellum and their associated structure (Jamieson, 2001).

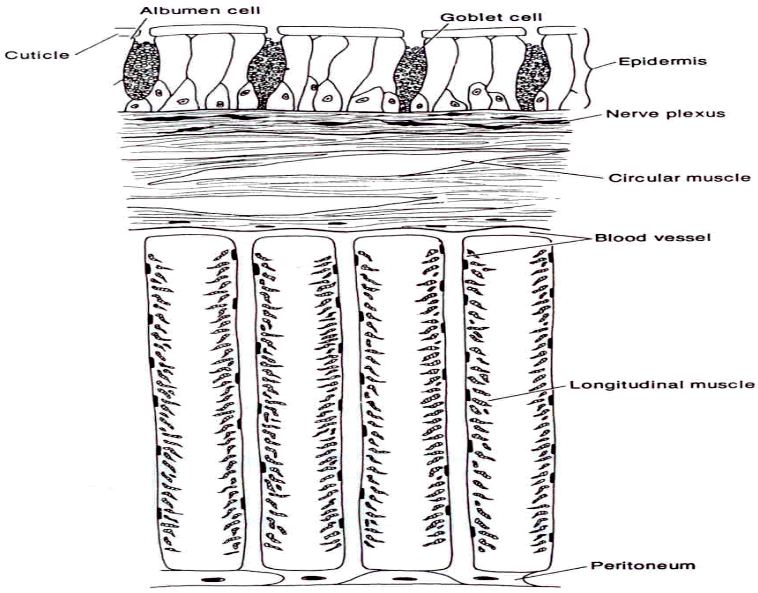

Figure 2.8 Transverse section of a portion of the body wall (Grove and Newell, 1962).

Pigmentation: Pigmental worms, such as *Lumbricus terestris*, are usually red, brown, a combination to these colors, or even grayish or greenish. The ventral surface of these worms is usually much lighter in color than the dorsal surface, although some deeply pigmented megascolecids are pigmented equally on both dorsal and ventral surfaces. The color of pigmented worms, when preserved in formalin, is fairly stable but the reds and pinks of unpigmented worms usually fade rapidly (Edwards and Bohlen, 1996).

The body wall: The body wall consists of an outer cuticle, the epidermis, a layer of nervous tissue, circular and longitudinal muscle layers, and finally the peritoneum, which separates the body wall from the coelom. The epidermis consists of a single layer of several different kind of cells (Figure 2.8).

The supporting cells, which are columnar in shape, are the main structural cells of the epidermis, and have processes which extend into the muscle at their bases. Two forms of glandular cells present are the mucous or goblet cells and albumen cells. Mucous cells secrete mucus over the surface of the cuticle to prevent desiccation and to facilitate movement through soil. The function of the albumen cells in not known. Large numbers of sensory cells, grouped together to form sense organs which respond to tactile stimuli, are scattered throughout the epidermis. These are more numerous on the ventral than on the dorsal surface (Edwards and Bohlen, 1996).

Photoreceptor cells, capable of distinguishing differences in light intensity, occur in the basal part of the epidermis, and are most numerous on the prostomium and first segment and on the middle segments. The epithelium of the buccal cavity bear groups of sensory cells which can be stimulated by chemical substances associated with taste. The prostomium contains receptors which can detect sucrose, glucose and quinine as well as many chemicals (Laverack, 1960).

2.2.2 The internal characters

2.2.2.1 The coelom

The coelom is a large cavity that extends through the length of the body, and is filled with coelomic liquid. The coelomic fluid is milky white liquid which is sometimes colored yellow by eleocytes, cells containing oil droplets. The consistency of the coelomic fluid differs between different species of earthworms, and also depends upon the humidity of the air in which the worms live; thus, it is thicker and more gelatinous in worms in dry situations than in those from wetter habitats. Coelomic fluid is also expelled through the dorsal pores at times of stress and may have several functions such as preventing desiccation, promoting coetaneous respiration or providing protection from predators (Edwards and Bohlen, 1996).

2.2.2.2 Alimentary canal

The alimentary canal or gut of earthworms is basically a tube extending from the mouth to the anus, although it is differentiated into a buccal cavity, pharynx, esophagus, crop, gizzard and intestine (Figure 2.9). The short buccal cavity flanked by a tube-like prostomium begins at the mouth and occupies only the first one or two segments, with one or two diverticula or evaginations. The pharynx, which is not always differentiated clearly from the buccal cavity, extends backwards to about the sixth body segment. All terrestrial oligochaetes have an esophagus, which opens from the pharynx as a narrow tube, modified posteriorly as a crop and gizzard. At the posterior end of the esophagus is the crop, a thin-walled storage chamber situated in front of the gizzard, which is muscular and lined with a thicker cuticle than the crop. The crop and gizzard are situated much further forward in some of the other species of earthworms than in the Lumbricidae; they are immediately behind the pharynx in

Megascolecid species which commonly have 2-10 gizzards, each occupying one segment. The rest of the elimentary canal is the intestine, which is a straight tube for most of its length, slightly constricted at each septum. Most of the digestion and absorption of food materials takes place in the intestine. The internal surface of the intestine has many small longitudinal folds and its surface area is increased by a large fold in the medial dorsal line, the typhlosole, which projects from the dorsal wall, this differs in relative size in different species (Edwards and Bohlen, 1996).

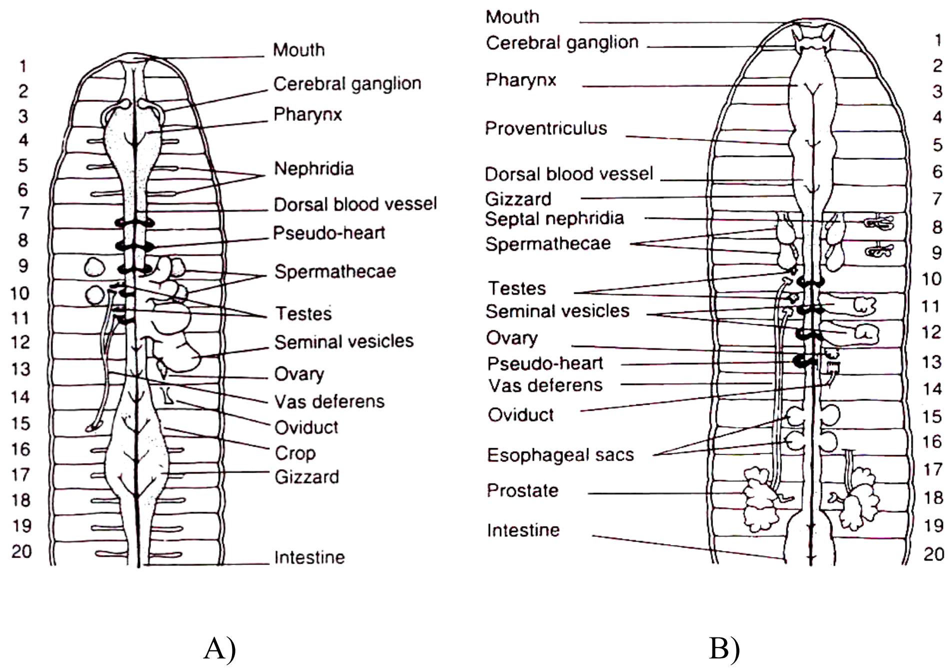

Figure 2.9 Digestive, circulatory and reproductive systems of earthworms A) *L. terrestris*, B) *Pheretima* spp. (Edwards and Bohlen, 1996).

2.2.2.3 The vascular system

Earthworms have a closed vascular system. There are three principal blood vessels, one dorsal and two ventral, that extend almost the entire length of the body, joined in each segment by blood vessels which ring the peripheral region of the coelom, and the body wall.

The largest of the longitudinal vessels, the contractile dorsal vessels, is associated closely with the gut for most of its length, except in the most anterior portion, where it is separated from the gut by a mesentery. Some species of Megascolecidae and Glossoscolecidae have paired dorsal vessels for part or all of the length of the body. The ventral vessel, which is narrower than the dorsal vessel, lies immediately below the gut, and is suspended from it by a mesentery. It conveys blood from the anterior part of the body to the posterior. The subneural vessel is even smaller than the ventral vessel, lies beneath the ventral nerve cord (Edwards and Bohlen, 1996).

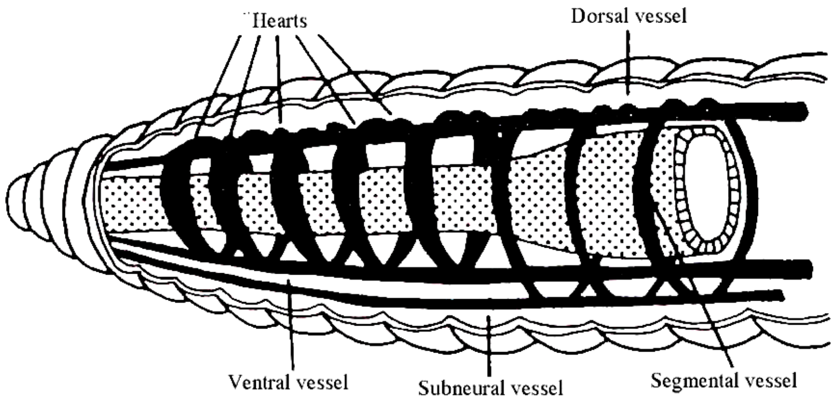

Figure 2.10 The circulatory system of a lumbricid (Wallwork, 1983).

Other longitudinal blood vessels are the extra-esophageal (or lateral – esophageal) vessels which lie along either side of the gut, from the pharynx to the first of the dorso-subneural vessels. The paired commissural vessels pass round the body in each segment from the dorsal vessel (and supra-intestinal vessel in those species which have it) to the ventral or subneural vessels. Some of the anterior commissures are enlarged, contractile, and with valves termed ‘hearts’ or ‘Pseudo-hearts’; Lumbricus has five pairs of such vessels (situated in segments 7 to 11), but some species have more and other less; Megascolecid worms have between two and five pairs of ‘hearts’. The hearts direct the flow of blood through the body by means of valves similar to those in the dorsal vessel. Sometimes the hearts are attached by mesenteric-like folds of the peritoneum to the faces of the septa. The dorsal vessel supplies blood to the typhlosole via three small typhlosolar vessels per segment (Figure 2.10) (Edwards and Bohlen, 1996).

2.2.2.4 The respiratory system

Terrestrial oligochaetes have few specialized respiratory organs. Most respiration is through the body surface which is kept moist by the mucous glands of the epidermis, the dorsal pores of which exude coelomic fluid and the nephridial excretions through the nephridiopores (Edwards and Bohlen, 1996). This method of gaseous exchange depends upon a network of small blood vessels buried in the body wall of terrestrial earthworms, so that oxygen dissolved in the surface moisture film can permeate through the cuticle and the epidermis to the thin walls of these vessels, where it is taken up by the hemoglobin in earthworms with a very high affinity for oxygen. As in other animals, carbon monoxide can block the functioning of hemoglobin in earthworms (Gardiner, 1972). The high affinity of earthworm hemoglobin for oxygen allows earthworms to live even in poorly ventilated soils. However, when soil is flooded after rain, earthworms may experience low oxygen tensions. This may cause them to leave their burrows in search of atmospheric oxygen (Wallwork, 1983).

2.2.2.5 The excretory system

The nephridia, which are the main organs of nitrogenous excretion in oligochaetes, are paired in each segment except the first three and the last. The internal opening from the coelom into each nephridium is just in front of a septum, and is a funnel- shaped nephrostome, which leads to a short pre-septal canal that penetrates the septal wall into the segment behind, where the main part of the nephridium lies. The nephridium continues as a long post-septal canal with three loops, which can be distinguished as four sections: a vary long 'narrow tube'; a shorter ciliated 'middle tube'; a 'wide tube'; and finally, the 'muscular tube' or reservoir, which opens to the exterior at the nephridiopore (Figure 2.11). Some earthworms also have micronephridia, which are much smaller and more numerous. Other kinds of nephridia end in a closed tube instead of a nephrostome; they are very small, exonephric, and attached to the body wall, with as many as 200-250 per segment. Species of *Pheretima* have this type of nephridia as well as septal michronephridia. All earthworms have nephridia of one or more of the types described above (Edwards and Bohlen, 1996; Stephenson, 1930).

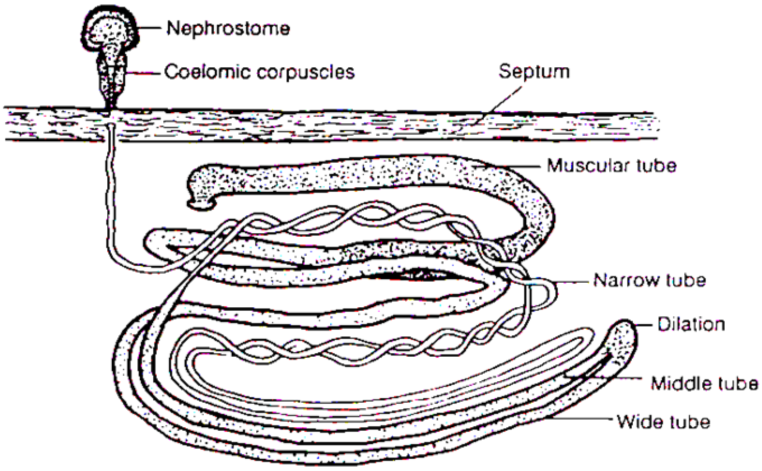

Figure 2.11 Diagram of a nephridium (Grove and Newell, 1962).

2.2.2.6 The nervous system

Earthworms are very sensitive to chemicals, to touch and to light, and react to avoid adverse conditions. These segmental nerves extend around the body wall, at first in the longitudinal muscle layer, and then in the circular muscle layer, ending near the mid-dorsal line, thus forming almost a complete ring (Figure 2.12). Each septum is supplied by a pair of nerves arising near the junction of the posterior segmental nerves and the ventral nerve cord. The distribution of the nerves in the anterior four segments of the body differs from that in the other segments. Segment 3 has the typical distribution of three pairs of segmental nerves, but they originate from segment 4, which also possesses three pairs, so that six pairs of segmental nerves come from the ventral nerve cord in segment 4. Segment 2 is supplied with two pairs of nerves which originate from the junction of the circum, pharyngeal connectives with the ventral nerve cord in segment 3, the larger posterior pair dividing, to give the normal three nerve rings in segment 2. The first segment is supplied by a pair of nerves originating in the lateral portions of the subpharyngeal connectives, which branch into two, shortly after they leave these nerves, and ramify through the first segment without forming nerve rings. A small nerve comes from the most ventral of these two branches to supply the ventral surface of the buccal cavity (Edwards and Bohlen, 1996).

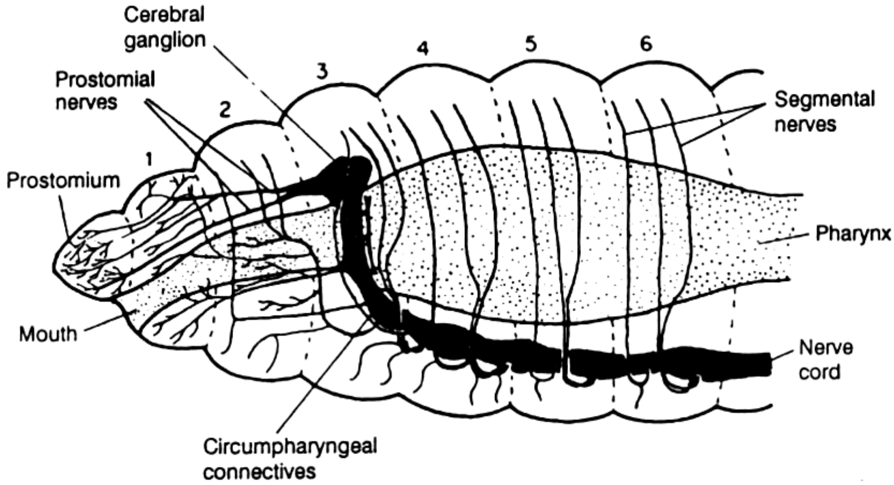

Figure 2.12 Nervous system of *Lumbricus terrestris* (Grove and Newell, 1962).

2.2.2.7 The reproductive system

Oligochaetes are hermaphrodite, and have more complicated genital systems than most unisexual animals. The productive organs, which are confined to comparatively few segments in the anterior portion of the body, include the male and female organs and associated organs, the spermathecae, the clitellum and other glandular structures (Figure 2.13). The paired ovaries, which produce oocytes, are roughly pear-shaped in Lumbricus (or fan- shaped in Pheretima), and are attached by their wider ends to the ventral part of the posterior face of septum 12/13, hanging freely in segment 13, in most terrestrial species. The ovisacs are backward-facing evaginations of the anterior face of septum immediately behind the ovaries, and open into the dorsal wall of the ovarian funnels. They narrow posteriorly to form the oviducts, which in turn open on to the ventral surface of the body, their position differing between earthworm families (Edwards and Bohlen, 1996; Stephenson, 1930).

The basic male organs are the testes. Most species of Lumbricidae, Megascolecidae and Glossoscolecidae have two pairs of testes (holoandric), but some species of Lumbricidae and also the Onerodrilidae have only a single pair (meroandric). The testes are loded organs attached to the posterior faces of septa 9/10 and 10/11 of Lumbricus and projecting from the septal wall into two median testis sacs, one in segment 10 and one in segment 11. The testis sacs are separate compartments within segments 10 and 11, laying below the ventral vessel and enclosing the ventral nerve cord. Some species, e.g. *Pheretima* spp., have much more extensive sacs which contain the hearts, dorsal vessel, esophagus and seminal vesicles. These sacs are filled with nutrient fluid in which lie the developing male cells. The testis sacs communicate with the seminal vesicles (vesiculae seminalis) which are storage sacs for the developing male cells (Stephenson, 1930).

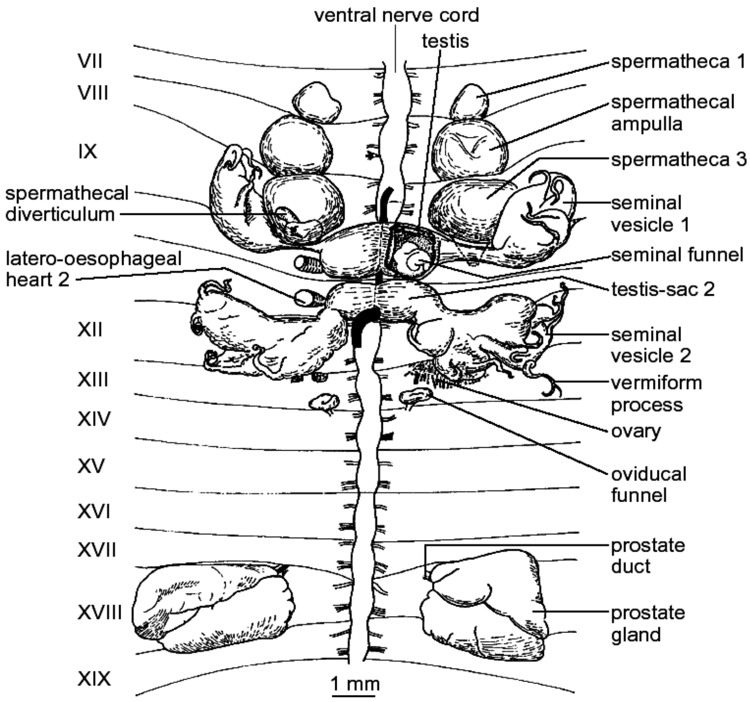

Figure 2.13 Genital organs of a megascolecine (Jamieson and Bradbury, 1972).

The seminal vesicles are the largest and most conspicuous organs of the reproductive system, and are immidaitely obvious when earthworms are dissected as white masses on either side of the alimentary canal. Lumbricus has three pairs of seminal vesicles in segments 9, 10, and 11. The Megascolecidae have from one to four pairs of seminal vesicles, *Pheretima* spp. having two pairs. Seminal vesicles are never in the same segment as the testes or the testis sacs (Edwards and Bohlen, 1996).

The prostates or prostatic glands are large glands associated with the posterior ands of the vasa deferentia. Their function is to produce a fluid in which sperm cells can be transferred between worms during copulation. In the Megascolecidae they are of two types, tubular, or racemose (as in *Pheretima*) where the glandular tissue is compact with branching canals opening into the associated ducts. Other families have prostates in the form of muscular finger-like processes, or convoluted tubes. Prostate glands are rare in the family Lumbricidae.

Most oligochaetes have spermathecae, which are almost always paired organs. The spermathecae are attached to the body wall by short stalk-like ducts. Many species of megascolecids have one or more diverticula from the spermathecal ducts (Edwards and Bohlen, 1996).

2.3 Earthworm biology

Earthworms are invertebrates composed of many segments. They also have little bristle-like organs that help them cling to slippery surfaces. Most earthworms have both male and female organs. However, they still need a partner for mating and reproduce egg called cocoons (Edward and Bohlen, 1996). Earthworm can produce from 3 to 1,000 cocoons per year, depending on species and environmental conditions. It may take from 1 to 5 months for the eggs to hatch and then take from 3 to 12 months before these worms are sexually mature. Worms typically live only a few months because of the many environmental threats they face. They have been observed to live for 10 years in a protected environment (Edward, 2004; Duiker and Stehouwer, 2007).

2.3.1 Life cycle

Earthworms are semi-continuous or continuous breeders, producing ova at most times in the year (Olive and Clark, 1978). The ova of earthworms are contained in cocoons, which differ in shape with species. Cocoon can be produced at any time in the year, but most species of earthworms produce cocoons when the temperature, soil moisture, food supplies and other environmental factors are suitable (Edwards and

Bohlen, 1996). The number of cocoons produced in a season differ greatly with both species and climate (Evans and Guild, 1948). The time cocoons take to hatch varies considerably among species, ranging from 3 weeks for *Bimastos zeteki* (Murchie, 1960) to 5 months for *Eisenia roses* (Wilcke, 1952). Clearly, the production and time for maturation of cocoons varies with species, population density, age structure, available food, moisture and temperature (Edwards and Bohlen, 1996).

2.3.2 Reproduction

Earthworms are hermaphrodites with separate testes and ovaries that function simultaneously. Most earthworm species reproduce by cross-fertilization, although some species can produce cocoons parthenogenetically. Most species mate periodically throughout the year, except when environmental conditions are unsuitable or when they are estivating or in diapause. After copulation, each clitellum produces a secretion which eventally hardens over its outer surface, and become the completely cocoon containing a nutritive albuminous fluid. The ova and the spermatozoa which were discharged into it as the tube passed the spermathecal openings. Cocoons continue to be formed until all the stored seminal fluid has been used up. Fertilization, which occurs in the cocoon, is external (Edwards and Bohlen, 1996). The number of fertilized ova in each cocoon ranges from 1 to 20 for lumbricid worms (Stephenson, 1930), but usually only one or two survive and hatch. The period from hatching to sexual maturity is affected by temperature and the type of available food, and varies with species (Julka, 1988). Some species can reproduce parthenogenetically. Many authors have demonstrated that potentially parthenogenetic polyploidy earthworm populations tend to have a much wider geographical distribution (Edwards and Bohlen, 1996).

2.3.3 Quiescence, diapause and estivation

If the soil become too dry, too cold, or too warm for earthworms to survive in it. Earthworms have several ways of surviving such adverse periods. *Diapause* is restricted to condition, when the worm stops feeding, empties the alimentary canal and constructs in the soil a spherical chamber lined with mucus, within which it rolls into a tight ball or loose knot. In *quiescence*, the worm respond directly to deteriorating environmental conditions and become active as soon as the conditions are favourable. Unlike diapause, quiescence is accompanied by severe tissue dehydration (Olive and Clark, 1978). Edwards and Lofty (1977) use the general term 'estivation' for this phenomenon of inactivity but it applies properly only to the passing of summer or dry season in a dormant state.

2.3.4 Growth

Earthworms continue to grow throughout their lives by continually adding segments proliferated from a growing zone just in front of the anus (Hyman, 1940). However, Sun and Pratt (1931) reported that earthworms emerged from the cocoon possessing the full adult number of segments and grew by enlargement of segments. Evans (1946) stated that some species possess the adult number of segments on hatching, where other species add further segments during post-emergence growth. The young worms tend to be colorless on hatching, with the circulatory system showing through the cuticle due to the presence of hemoglobin in the blood. The worms continue to grow, except for changes, until maturity is reached. There was a rapid pre-reproductive phase of growth followed by a phase of steadily decreasing growth after sexual maturity was attained. Many workers have confirmed this sigmoid growth curve for *E. fetida* and other species that can grow in organic wastes (Edwards and Neuhauser, 1988).

2.3.5 Behavior patterns

Earthworms are very sensitive to touch, the pattern and speed of their reaction varying with both the species and circumstances. For example, the behavior of *L. terrestris* when it scavenges for food on the soil surface. If the earthworm is touched, it withdraws back into its burrow, sometimes very quickly, and does not emerge again for some time. Many other kinds of stimuli applied to the soil promote activity in earthworms and cause them to come to the soil surface, such as vibrations, stamping on the surface, electrical and chemical stimuli (Edwards and Bohlen, 1996).

The feeding behavior of *Lumbricus terrestris* have been studied. Earthworms feed on leaf and other plant materials obtained from the soil surface and pull many kinds of leaves into the burrows by the tip of the laminae, leaving the nonpalatable petioles projecting from the burrow (Edwards and Bohlen, 1996). After heavy rain, individuals of the same species appear on the surface soil. The suggested cause of these migrations was that hydrogen sulfide was produced in the burrows, resulting from anaerobic conditions developing because of poor soil ventilation, and many of these die, probably due to exposure to ultraviolet light or radiation (Edwards and Bohlen, 1996).

2.4 Earthworm diversity and geographical distribution

2.4.1 Systematic affinities and evolutionary descent

Earthworms belong to class Oligochaeta and are related to the Polychaeta and the Hirudinae. Polychaetes may be considered as the older group because their larval development is more primitive than the oligochaetes, which have an embryo in a cocoon supplied with yolk or structure of their genital organs. Possibly, the Polychaeta are ancestral to the Oligochaeta, or they may both be derived from a common aquatic ancestor. The early oligochaetes probably lived in mud rather than water, becoming transiently terrestrial when the mud dried up periodically. They then became separated gradually into two groups, one purely terrestrial, the other aquatic (in fresh water) (Edwards and Bohlen, 1996).

Stephenson (1930) considered that the common ancestor of the terrestrial Oligochaeta belonged to the aquatic Lumbriculidae, which is one of the most primitive of the oligochaete families. Of the modern families that have been described, he considered the Moniligartridae to be the most primative. The Megascolecidae and Eudrillidae have more advanced characteristics. The Glossoscolecidae, Lumbricidae, Hormogastridae and Microchaetidae have fewest primitive features and may be considered to have evolved later than the other families, the Lumbricidae probably being most recent.

2.4.2 Families, genera and species

Many authors have produced classifications of the Oligochaeta. Michaelsen (1921) classified earthworms into 21 families, and Stephenson (1930) simplified this arrangement into 14 families. Of Stephenson's 14 families, seven- the Aeolosomatidae, Naididae, Tubificidae, Pheodrilidae, Enchytraeidae, Lumbricidae and Branchiobdellidae-were placed in the Microdrili group and the remaining seven families in the Megadrili. Stephenson's classifications of the megadrile families (1930) are as follows:

1. Family Alluroididae.
2. Family Haplotaxidae.
3. Family Moniligastridae (Syngenodrilinae, Moniligastrinae).
4. Family Megascolidae (Acanthodrilinae, Megascolecinsae, Octochaetinae, Ocnerodrilinae).
5. Family Eudridae (Parendrilinae, Eudrilinae).
6. Family Glossoscolecidae (Glossoscolecinae, Sparganophilinae, Microchaetinae, Homogastrinae, Criodrilinae).
7. Family Lumbricidae.

The classification of the megascolecide earthworms has always been much more controversial than that of other oligochaete families, and more recently four new systems of classification have been proposed, those of Omodeo (1958), Gates (1959), Lee (1959), and Jamieson (1971). Omodeo recorgnized the taxonomic groups by the position and numbers of the calciferous glands, and on this basis raised one group to family status. Lee used the number and position of the male pores and position of the nephridiopores as a key characteristic. Gates considered the structure of the prostatic glands and excretory system, and position of the caliciferous glands to be important and raised all the main groups to family status (reviewed in Edwards and Bohlen, 1996). Sims (1967) agreed with the diffinitions of the groupings proposed by Gates, but recognized only two families, the Megascolecidae and the Acanthodrilidae, dividing this last family between the Acanthodrilinae, Octochaetinae and Ocnerodrilinae.

Gates (1959) classified the majority of oligochaetes as follows:

1. Family Moniligastridae.
2. Family Megascolecidae.
3. Family Ocnerodrilidae.
4. Family Acanthodrilidae.
5. Family Octochaetidae.
6. Family Eudrilidae (sub family Parendrilinae and Eudrilinae).
7. Family Glossoscolecidae.
8. Family Sparganophilidae.
9. Family Microchaetidae.
10. Family Homogastridae.
11. Family Criodrilidae.
12. Family Lumbricidae.

Jamieson (1988) reviewd the overall phylogeny and higher classification of the oligochaeta base on a cladistic analysis. He placed all the megadrile families that were predominantly or wholly terrestrial into a new cohort. Cohort: Terrimegadrili was divided into 4 super families, Ocnerodriloidae (family Onerodrilidae), Eudriloidae (family Eudrilidae), Lumbricoidae (family Kynotidae, Komarekionidae, Ailoscolecidae, Microchaetidae, Homogastridae, Glossoscolecidae, and Lumbricidae) and Megascolecoidea (family Megascolecidae)

The two most ecologically important families in Europe, North America, Australia and Asia are the Megascolecidae and the Lumbricidae. The megascolecids and their close relatives comprise more than half the known species, and this group includes worms that are very widely distributed outside the Palearctic zone. However, the most important family in terms of human welfare is undoubtedly the Lumbricidae, generally considered to be the most recently evolved family. This family has followed the spread of human colonization from the more developed countries around the world. Thus, the earthworm populations in crop-growing areas in temperate regions are far more likely to consist mainly of species of the Lumbricidae than of members of any other family (Edwards and Bohlen, 1996).

Sims and Easton (1972) reviewed the genus *Pheretima* and divided it into eigth genera: *Archipheretima*, *Pithermara*, *Ephemitra*, *Metapheretima*, *Planaphertima*, *Amynthas*, *Metaphire*, and *Pheretima.*

The latest classification of terrestrial species by Reynolds and Cook (1993) had the following divisions:

Order Haplotaxidae:

Family Acanthodrilidae

Family Ailoscolecidae

Family Alluroididae

Family Almidae

Family Biwadrilidae

Family Criodrilidae

Family Diporochaetidae

Family Enchytraeidae

Family Eudrilidae

Family Glossoscolecidae

Family Hormogastridae

Family Komarekionidae

Family Kynotidae

Family Lumbricidae

Family Lutodrilidae

Family Lobatocerebridae

Family Megascolecidae

Family Microchaetidae

Family Ocnerodrilidae

Family Octochaetidae

Family Propappidae

Family Sparganophiloidae and

Family Moniligastridae.

2.4.3 Earthworm diversity and geographical distribution

Earthworms occur all over the world, but only rarely in deserts, areas under constant snow and ice, mountain ranges and areas almost entirely lacking in soil and vegetation. Nevertheless, some species of earthworms are widely distributed, and Michaelsen (1910, quoted in Edwards and Bohlen, 1996 p.40) has used the term ‘peregrine’ to describe such species, where the other species that do not seem able to spread successfully to other areas to any great extent have been termed ‘endemic’ species. Both the Megascolecidae and Lumbricidae are far-ranging in distribution. A few species belonging to the lumbricide are believed to be endemic to North America, Europe, Asia, The Caucasus, Siberia and Japan (Edwards and Bohlen, 1996). Peregrine species of the Lumbricidae are also found distributed widely throughout the rest of the world, particularly in the temperate zone of the southern hemisphere. They are found in Mexico, Central America, South America, South Africa, India, Australia and Hawaii. The agency of this spread has been mainly passive, usually by unintentional transportation by man (Edwards and Bohlen, 1996).

In Europe, species of the Sparganophillidae found in many countries, including England, and species of the Homogastridae are endemic in the southern part of the continent (Edwards and Bohlen, 1996). African continent has two groups of endemic worms, the Microchaetidae, and members of the Acanthodrilidae. The family Moniligastridae has a very large range, encompassing South-East and eastern Asia, South India, Manchuria, Japan, and Philippines. Other than the Moniligastridae, South-East Asia and Australasia are dominated by earthworms belonging to the classical Megascolecidae.

Reynolds (1994) summarized the world distribution of currently 18 families of terrestrial earthworms (Figure 2.14). The Zoogeographical regions where the earthworm families are believed to have originated are listed below, as well as the other continents to which they have been transported.

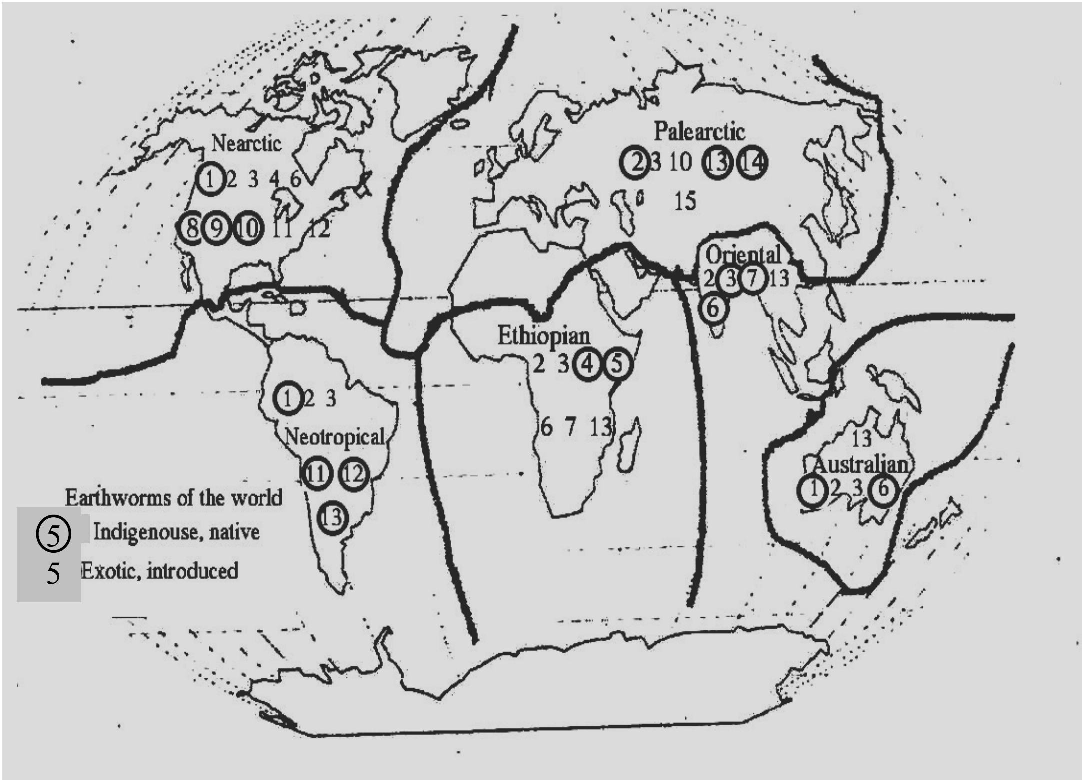

Figure 2.14 The origin and dispersal of the major terrestrial earthworm families (Reynolds, 1994).

Australian = Australia, Tasmania, New Guinea and some smaller islands of the Malayan Archipelago, The native families are Acanthodrilidae (1) and Octochaetidae (6), and exotic families are Lumbricidae (2) and Megascolecidae (3)

Ethiopian = Africa south of the Sahara Desert and Atlas Mountains, and the southern corner of Arabia. The native families are Eudrilidae (1) Microchaetidae (5), and Octochaetidae (6). The exotic families are Lumbricidae (2), Megascolecidae (3), and Moniligastridae (7).

Nearctic = Canada, United States, Greenland, and north Mexico. The native families are Acanthodrilidae (1), Komarekionidae (8), Lutodrilidae (9), and

Sparanophilidae (10). The exotic families are Eudrilidae (4), Glossoscolecidae (11), Lumbricidae (2), Megascolecidae (3), Octochaetidae (6), and Ocnerodrilidae (12).

Neotropical = South America, Central America, most of Mexico, the West Indies and New Zealand. Native families are Acanthodrilidae (1), Glossoscolecidae (11), Ocnerodrilidae (12), and Almidae (13). The exotic families are Lumbricidae (2) and Megascolecidae (3).

Oriental = India, Indochina, South china, Malaya including the westerly islands of the Malayan Archipelago. The native earthworm families are Megascolecidae (3), Moniligastridae (7), and Octochaetidae (6). The exotic families are Almidae (13), Eudrilidae (4), and Lumbricidae (2).

Palearctic = Europe to the Pacific Ocean, Africa north of the Sahara Desert, and Asia north of the himalaya Mountains. The native families are Almidae (13), Diporochaetidae (14), Homogastridae (15), and Lumbricidae (2). The exotic families are Megascolecidae (3) and Sparganophilidae (10).

In recent years, earthworm diversity and geographical distribution has been reported by many of authors. Diversity of earthworms species in some countries are showed in Table 2.1.

Table 2.1 Recent earthworm diversity of some countries.

Regions/Countries	Earthworms species	References
North America		
United Stated of America and Canada	180	Blakemore, 2006b
Hawaii and Puerto Rico	35	Blakemore, 2006b
Central America		
Cuba	200	Fragoso *et al*., 1999
Hispaniola	130	Fragoso *et al*., 1999
Mexico	95	Fragoso *et al*., 1993
Honduras	50	Fragoso *et al*., 1999
Puerto Rico	18	Fragoso *et al*., 1999
Jamaica	10	Fragoso *et al*., 1999
South America		
Amazon	105	Blakemore, 2006b
Chile	88	Blakemore, 2006b
Brazil	77	Brown and James, 2006b
Europe		
New Zealand	192	Dalby, Baker and Smith, 1998
France	180	Dalby, Baker and Smith, 1998
Italy	57	Edwards and Bohlen, 1996
British and Ireland	48	Blakemore, 2006b
Switzerland	38	Edwards and Bohlen, 1996
Czechoslovakia	37	Edwards and Bohlen, 1996
Norway	30	Edwards and Bohlen, 1996
Spain	25	Monroy *et al*., 2003
Germany	24	Edwards and Bohlen, 1996
Sweden	20	Blakemore, 2006b
Scotland	15	Butt and Lowe, 2004
Australia and Tasmania	710	Blakemore, 2006b
New Zealand	193	Blakemore, 2006b
New Guinea	110	Blakemore, 2006b
Asia		
India and Sri Lanka	505	Blakemore, 2006b
India	385	Fragoso *et al*., 1999
Vietnam, Laos and Cambodia	232	Blakemore, 2006b
Indonesia	215	Blakemore, 2006b
Myanmar	130	Blakemore, 2006b
Russia	113	Blakemore, 2006b
Malaysia	94	Blakemore, 2006b
Korea	88	Blakemore, 2006b
Japan	77	Blakemore, 2006b
Taiwan	70	Blakemore, 2006b
Vietnam	28	Blakemore, 2006b
Thailand	24	Blakemore, 2006a
Singapore	19	Shen and Yeo, 2005
Philippines	14	James, 2006
South Ocean	41	Blakemore, 2006b
South Atlantic	61	Blakemore, 2006b
Pacific Ocean	89	Blakemore, 2006b

2.4.4 Thailand earthworm

Thailand is located in the tropical region, which has high level of biological diversity due to the richness of earthworm natural food sources and suitable environment. However, the number of the study on earthworms diversity and distribution in Thailand is considered too little. There are 27 species reported by Gates (1939); then, reduced to 24 species by Blakemore (2006a). These earthworms have been placed in Glossoscolecidae (*Pontoscolex corethrurus*), 21 species in Megascolecidae (*Lampito mauritii*, *Perionyx excavatus*, and *Polypheretima elongata*), 12 species of *Amynthas* (*A. alexandrii*, *A. comptus*, *A. exiguus austrinus*, *A. exiguous exiguus*, *A. gracilis*, *A. houlleti*, *A. hupbonensis*, *A. longicauliculatus*, *A. manicatus manicatus*, *A. mekongianus*, *A. morrisi*, and *A. papulosus)*, 6 species of *Metaphire* (*M. anomala*, *M. bipora*, *M. peguana*, *M. planata*, *M. posthuma*, and *M. virgo)*, Moniligastridae (*Drawida barwelli)*, Octochaetidae (*Dichogaster affinis)*. Recenty, Kosavittikul (2005) found 13 earthworm species belonging to three families in Khao Yai National Park: There are Glossoscolecide (*Pontoscolex corethrurus*), Megascolecidae (*Amynthas alexandri*, *A. fucosus*, *A. longicauliculatus*, *Methaphire peguana*, *M. houlleti*, *Perionyx excavatus*, and *Pithermera bicincta*), and Moniligastridae *(Drawida beddardi)*, three of *Amynthas*, and *Metaphire* were supposed to be new species and *A. fucosus* was a new recorded species of Thailand.

2.5 Earthworm ecology

2.5.1 Earthworm populations

Size of populations: Populations of earthworms vary greatly in terms of numbers or biomass and diversity. The earthworm population (number) rang from only a few individual per square meter to more than 2000 per square meter (Edwards and Bohlen, 1996). The size of population depends on a wide range of factors, including soil type, pH, chemical status, moisture-holding capacity of the soil, rainfall, and ambient temperatures, but most importantly, on the ready availability of organic matter that is the major food resource for earthworms (Curry, 1998; Lavelle *et al*., 1999; Lee, 1985). The numbers of earthworms in regularly cultivated arable soil are usually very variable, and populations are intermediate in size between the more sterile habitats and those in pasture and natural grassland which can support large number of earthworms. The populations in coniferous forest tend to be lower and those in deciduous temperate forests and tropical forests rather larger than those in arable land (Edwards and Bohlen, 1996). The number of earthworms in different habitats are shown in Table 2.2.

The diversity of earthworm species varies greatly by site and habitats. Baker *et al*. (1997) surveyed the earthworm fauna of urban and agricultural soils in Australia. They found that abundance varied between habitats with highest numbers found in pastures and orchards and least in cereal crops. Species richness was least in soils used for cereal cropping and great in urban gardens. Similarity indices showed that earthworm populations of similar vegetative cover had similar earthworm density. This world be induced by the shift from high quality pasture grass roots to low quality roots of woody trees (Zou and Gonzalez, 1997).

Table 2.2 Density of earthworms in different habitats (modified after Edwards and Bohlen, 1996).

Habitats	**No./m^2**	**countries**	**Extraction method**
Fallow	18.5-33.5	USSR	Handsorting
Fallow	22.6	Wales	Handsorting
Fallow	210-460	S. Australia	Handsorting
Arable soil	146	N. Wales	Handsorting
Arable soil	287	Bardsey Island	Handsorting
Arable soil	220	Germany	Wet sieving
Arable	20-25	S. Australia	Handsorting
Arable	5-100	Rumania	Handsorting
Arable	7.4-101.8	Uganda	Handsorting
Pasture	389-470	UK	Handsorting
Pasture	390	Bardsey	Handsorting
Pasture	481-524	N. Wales	Handsorting
Pasture	260-640	Australia	Handsorting
Pasture	742-1235	New Zealand	Handsorting
Pasture	690-2020	New Zealand	Handsorting
Pasture	72-1112	S. Africa	Handsorting
Pasture	400-500	Ireland	Handsorting
Old pasture	390-470	England	Handsorting
Old pasture	646	Wales	Handsorting
Old pasture	288	France	Washing/ sieving
Natural grassland	250-750	New Zealand	Handsorting
Tropical savanna	230	Ivory Coast	Handsorting/wet sieving
Coniferous forest	14-66	Finland	Handsorting
Coniferous forest	103-167	Sweden	Handsorting
Coniferous forest	10-40	Norway	Handsorting
Coniferous forest	27-72	Japan	Handsorting
Mixed woodlands	14-142	USA	Handsorting
Mixed woodlands	157	Wales	Handsorting
Mixed woodlands	118-138	England	Handsorting
Mixed woodlands	136	USSR	Handsorting
Mixed woodlands	106	Czechoslovakia	Handsorting
Tropical forest	61.7	Nigeria	Handsorting
Tropical rainforest	80-121	Mexico	-
Tropical rainforest	280-401	Costa Rica	Handsorting
Tropical rainforest	64-166	Malaysia	Handsorting
Tropical rainforest	6-26	Sarawak	Handsorting
Tropical rainforest	68	Peru	Handsorting

Age distribution: The populations of earthworm in soil habitat tend to have pyramidal age structure, with many more young individuals than mature ones at most time of the year (Edwards, and Bohlen, 1996). After active breeding periods, the proportion of immature worms will be greatest, and at all other times relatively small (Evans and Guild, 1948).

Spatial distribution: Earthworms are by no means distributed randomly in soil. Murchie (1958) concluded that no single one of the factors was likely to be solely responsible for the horizontal and vertical distribution, but rather the interaction of several or all of the factors. The possible factors that were likely to be responsible for variability in horizontal distributions were: physico-chemical (soil temperature, moisture, pH, inorganic salts, aeration and texture), availability of food (herbage, leaf litter, dung, consolidated organic matter, and historical factors (including disturbance and colonization of new habitats). Gerard (1967) stated that the vertical distribution of each species changed considerably with the time of year. The two factors influencing movement to deeper soil, seemed to be very cold or very dry surface soil.

Seasonal populations: All species of worms seem to be quiescent in summer and mid-winter, and at both times earthworms were deeper than 7.5 cm below the soil surface. The activities of earthworms differ greatly between seasons and they active in the spring and Autumn; the two soil conditions that affected earthworm activity most are temperature and moisture (Edward, 2004). Tiwari *et al*. (1992) also found a significant correlation between earthworm populations and temperature and moisture in a pineapple field. Earthworm activity in the tropics is also limited to certain seasons. Earthworms are active mainly in the 4-6 months of the rainy season between May and October. In contrast, in the humid continental climate of the south-eastern United States, they active in the spring and autumn months (Gates, 1961). In grassland in Japan, the greatest numbers of earthworms occurred in autumn, especially in October, and the numbers were very low in winter, particularly during January and February (Nakamura, 1968). In Australia, earthworm population increased from May to July and decreased from July to October. The highest numbers occurred in winter and spring (Baker *et al*., 1993).

2.5.2 Earthworm communities

Major ecological groups: Earthworm communities may be simple or more complex but species tend to be complementary in their activities. Several schemes have been proposed to classify earthworm species into major ecological categories, which are based mainly on differences among species in the burrowing and feeding activities, and vertical stratifications in soil. Piearce (1972) divided woodland species of earthworms into three types based on their feeding habits, including pigmented litter feeders; unpigmented topsoil feeder, and unpigmented humus or compost feeders.

Bouche (1977) also recognized three major ecological group, which he termed: (1) epigeics, (2) anecics, and (3) endogeics. Epigeic earthworms are typically live on the soil surface or in the upper reaches of the mineral soil, beneath a litter layer, have relatively high reproductive rates and grow rapidly. Anecic earthworms that form permanent or semipermanent vertical burrows in the soil, which descend into the mineral horizon and open at the soil surface. The Endogeic earthworms consume more soil than do either epigeic or anecic species and derive their nourishment from more humified organic matter.

Perel (1977) separated lumbricids into two major morpho-ecological groups: humus formers and humus feeders. Humus formers feed on coarse particulate organic matter at various stages of decomposition. Humus feeders use more humified and fine particulate organic matter and consume more soil than humus formers.

Lavelle (1988) divided endogeic species into three subcategories: polyhumic endogeic earthworms ingest soil with a high organic matter content; mesohumic ones feed indiscriminately on both mineral and organic particles in the upper 10-15 cm of soil; and oligohumic earthworm, which are found in tropical ecosystems, feed on soil of the deep horizons (30-40 cm deep) that are poor in organic matter.

Species diversity: The number of earthworm species ranges from 1 to 15 species in most habitat. Most earthworm communities contain around 3-6 species, with a remarkable degree of consistency among habitats and different geographic regions. The diversity of earthworm community at a given locality is influenced by characteristics of the soil, climate and organic resources of the locality, as well as history of land use and soil disturbance. The number of species are relatively rich in deciduous woodlands and permanent pastures or meadows, and relatively poor in coniferous forest, peatlands, heathlands and cultivated fields. The species-poor communities are characterized by extreme soil conditions, such as low pH or poor fertility, low-quality litter or high degree of soil disturbance (Edwards and Bohlen, 1996). However, Fragoso and Lavelle (1992) showed that average biomass and population density of earthworms in tropical rain forests did not differ much form that in temperate woodlands. Lavelle (1983) analysed 42 earthworm communities from around the world and described eight distinct communities, falling into a latitudinalvegetational sequence, that corresponded closely to the different biomes in which they found:

1. coniferous forest;
2. heath;
3. cold grassland;
4. cold deciduous forest;
5. temperate deciduous forest;
6. temperate grassland and Mediterranean woodland;
7. moist savanna;
8. dry savanna.

Species associations: Certain earthworm species tend to be associated with one another. Usually, such associations result from some characteristic of habitat, for instance, *L. terrestris*, *A. longa*, *A. caliginisa*, and *O. cyaneum* are characteristic pasture species in England, although they are not the only species that occur in pasture. Similarly, there are rarely more than four species in peaty soils, these are usually small worms (Edwards and Bohlen, 1996).

Dispersal: Earthworms can move from one location to another either by active or passive dispersal. Active dispersal of earthworms across the soil surface, are relatively slow. Earthworms may migrate to evade unfavorable environmental conditions or to seek new habitats, but the behavioral cues leading to such dispersal are poorly understood. Passive transport of earthworms occurs as a result of incidental anthropochorous transport by humans, by being carried in streams or surface flow of water during heavy rains. Incidental transport by humans may have an important influence on the local dispersal of earthworm populations. Earthworms have been introduced purposely to new environments to improve soil fertility and plant production and ameliorate soil. The initial rate of spread (during the first 4-5 years) of earthworms was slow but increasedly, rapidly thereafter, reaching a rate of about 10 m per year, and they had colonized the whole field in 8-10 years (Edwards and Bohlen, 1996).

Predators: Earthworms are a part of the diet of hundreds of vertebrate and invertebrate animals, and can also serve as hosts for a variety of parasitic and disease organisms. The influences of predators, pathogens, and parasites on the dynamics of earthworm populations have proven difficult to determine (Edwards, 1998).

2.6 The influence of Environmental factors on earthworms

2.6.1 Temperature

The activity, metabolism, growth, respiration and reproduction of earthworms are all influenced greatly by temperature. Fecundity is affected very much by different temperatures. The optimum temperature for cocoon production by *L. terrestris* was 15°C with 25.3 cocoons produced per *annum* (Butt, 1991). Cocoons also tend to hatch sooner at higher temperature. The growth period from hatching to sexual maturity is also dependent on temperature; for instance, *A. chlorotica* took 29-42 weeks to mature in an unheated cellar (Evan and Guild, 1948) and only 13 weeks at 18°C (Michon, 1954). Viljoen *et al.* (1992) reported that *D. veneta* completed its life cycle in 107 days at 15°C and in 151 days at 25°C. Lee (1985) reported that the optimal temperature for growth of indigenous populations of Lumbricidae in Europe ranged from 10 to 15°C. Satchell (1967) concluded that the most suitable conditions for activity of earthworms on the surface were at night when soil temperatures did not exceed 10.5°C.

2.6.2 Moisture

Water constitutes 75-90% of earthworms body weight so the prevention of water loss is a major factor in earthworm survival. If soils are dry, earthworms may move to deeper soil layers, die, or revert to a hibernation condition called diapause. Earthworm activity also depends upon adequate available of soil moisture, but the moisture requirements for earthworm populations from different regions of the world can be quite different (Edward and Bohlen, 1996).

Many moisture preferences for earthworm have been reported. For example, Madge (1969) reported that *Hyperiodrilus africanus* preferred soil between 12.5 and 17.2% moisture contents, and the optimal soil moisture content for cast production was about 23.3%. Adult *Perionyx excavatus* preferred a moisture content 80-85% in organic materials (Edwards, 1988). The moisture preferences of both juvenile and clitellate specimens were 81% (Hallatt, 1992). Muyima *et al*. (1994) reported that the moisture requirements of *Dendrobena veneta* ranged between 67.4 and 84.3%. The optimum moisture content for growth and maturation of juvenile worms was 75%. Growth rates of juvenile *Aporectodia caliginosa* was affected significantly by soil moisture, temperature, and the temperature moisture interaction. Optimum growth conditions for *A. caliginosa* were -5 *kPa* water potential, and they lost weight when the soil water potential was -54 *kPa* for all temperatures (Edward and Bohlen, 1996).

2.6.3 Soil properties

The burrowing and feeding activity of earthworms, as well as their overall population, are affected by the soil environment in which they live. Earthworms are influenced by soil type and texture. Light and medium loams had greater total populations of worms than heavier clays or more open gravelly sands and alluvial soils (Edwards and Bohlen, 1996). The silt content of the soil was correlated most with earthworm abundance (Hendrix *et al.*, 1992). Baker *et al.* (1992) found weak positive correlations between clay content of the soil and the abundance of *A. trapezoids*, *A. rosea*, and *A. caliginosa*. Of these three species, *A. caliginosa* exhibited the strongest positive correlation with clay content.

Soil texture can influence earthworm populations because of its effects on other soil properties such as moisture, nutrient and cation exchange capacity (Edwards and Bohlen, 1996).

2.6.4 Soil pH

It has been demonstrated that earthworms are very sensitive to the hydrogen ion concentration of aqueous solutions, so soil pH is sometimes a factor that limits the species, numbers and distribution of earthworms that live in any particular soil. Several researchers have stated that most species of earthworms prefer soils with a neutral pH, but can tolerate a pH from 5.0 to 8.0 (Edwards and Bohlen, 1996).

2.6.5 Organic matter and food supply

Organic matter is the major food resource for endogeic earthworms. In some forests and native grasslands, earthworm populations are associated with plant species that provide the amount and quality of above-or belowground litter they produced (Marhan and Scheu, 2005; Campana *et al.*, 2002; Nachtergale *et al.*, 2002).

The quality of residue is also important. Residue with a high carbon to nitrogen (C:N) ratio is not very palatable for earthworms. Manure can help make it more palatable and produce faster growth rates (Ortiz-Ceballos *et al*., 2004). The distribution of organic matter in soil influences the distribution of earthworms greatly. Soil that are poor in organic matter do not usually support large numbers of earthworms (Edwards and Bohlen, 1996). Earthworms eat organic residue that needs to be present in sufficient quantity. Shakir and Dindal (1997) stated that earthworms depended on the type of dominant vegetative cover in the site.

The litter composition is the factor that affects earthworm abundance and biomass on the sites. Most species of earthworms can distinguish between different kinds of forest litter. Vegetation can effect earthworm populations by altering the quantity and quality of their food supply. Earthworms can use a wide variety of organic materials for food, and even in adverse conditions can extract sufficient nourishment from organic matter and micro-organisms in soil to survive. The kind and amount of food available influences not only the size of earthworm populations but also the species present, and their rate of growth and fecundity (Edwards and Bohlen, 1996).

2.7 Effects of agricultural practices and chemicals on earthworms

2.7.1 The effect of cultivation

Cultivation over a few years probably affects the environment for earthworms. Long-continued cultivation usually results in loss of aggregate structure and reduction of soil organic matter content, and these must result in lower population of soil earthworms (Edward and Bohlen, 1996).

Conventional mechanical tillage practices such as ploughing and harrowing lead to a reduction in earthworm populations and loss of the beneficial effects on soil properties. In contrast, some experiments have shown that earthworm numbers increase with cultivation (Edward and Bohlen, 1996). It has been found that lumbricid populations are generally lower in arable fields or cultivated areas than in permanent grasslands (Lee, 1985). Mechanical damage, due to tillage implements, has often been assumed to be the major cause of mortality and population decline, but the loss of surface litter and general decline in soil organic matter content that results from long-continued cultivation and cropping, and leads to a reduction in food supply for earthworms, may be more important (Duiker and Stehouwer, 2007). Earthworm populations were presence under no-tillage, minimum tillage and native forests higher than under conventional tillage. Soil disturbance thus had a negative impact on earthworm populations, and significant positive relationships were observed between earthworm abundance and of no-tillage systems, as well as with soil C content. (Brown *et al*., 2004). Jordan *et al*. (1997) stated that tillage was the single most important factor influencing the number of earthworms in the spring and fall sampling.

2.7.2 The effects of cropping

Crop rotations, which leave crop residues on the soil surface as a food source for soil biota, may encourage earthworm populations. Hendrix *et al*. (1992) reported that earthworm abundance was related to the quantity and quality of plant residues in different agroecosystems. Providing earthworms with a diverse diet is important. Crop residue of leguminous species (low C:N ratio) is more palatable to earthworms than that of mature grass and grain species (high C:N ratio). However, a legume such as soybean produces very little crop residue, which limits the quantity of food available to earthworms (Smith *et al*., 2005). Cropping are influence the numbers of earthworms in arable land considerably. Hopp and Hopkins (1946) reported that alfalfa-grass cropped plots contained more earthworms than lespedenza-grass-cropped plot, and that grass-cropped plots in orchards contained more earthworms than plots with timothy grass. The earthworm populations under continuous maize were larger than under continuous soybean, and even bigger populations under continuous winter cereals (Edwards and Bohlen, 1996).

2.7.3 The effects of fertilizers

The effects of various inorganic fertilizers on earthworms apparently vary from site to site, and have led to opposing claims that they are harmful or that they are beneficial to earthworms (Lee, 1985). Organic fertilizers increased earthworm populations more than inorganic fertilizers in arable lands for equivalent increments of N, and this was attributed to the additional food for earthworms provided by the farmyard manure and sewage products. Animal dung, often mixed with straw from stables and known as farmyard manure, is the most common form of organic fertilizer. Manure is a food source for earthworms. It also makes crop residue with a high C:N ratio more palatable to earthworms. Sludge and compost can greatly stimulate earthworm populations by providing a quality feedstock for them. There is good evidence that most inorganic fertilizers favor the buildup of large numbers of earthworms, probably due to the increased amounts of crop residues being returned to the soil (Duiker and Stehouwer, 2007).

2.7.4 The effects of chemicals

The effects of pesticides on earthworms depend on the type of pesticide and its rate of application, earthworm species and age, and environmental conditions. Increasing soil metal concentration reduces earthworm activity, interfering with reproduction, decreasing biomass, and finally causing mortality. Most contact fumigant nematicides/fungicides are broad-spectrum biocides that kill most earthworms, even those living deep in the soil (Edwards and Bohlen, 1996; Duiker and Stehouwer, 2007).

2.8 The role of earthworms in organic matter and nutrient cycles

2.8.1 Fragmentation and incorporation of organic matter

Earthworms have major role in the brake down of organic matter and the release and recycling of the nutrients that it contains. They remove partially decomposed plant litter and crop residues form the soil surface, ingest it, fragment it and transport it to the sub surface layers. Their fecal material is in the form of casts which can vary greatly in size and form, and are deposited on the soil surface, in their burrows or in space below the soil surface. The cast tend to be much more microbially active than the surrounding soil and have plant nutrient in form that can be readily utilized. Through these various interactions, earthworms are often key organisms in the overall breakdown of organic matter and transformation of major and minor mineral nutrients (Edwards and Bohlen, 1996).

Earthworms are probably the most important invertebrates in many soils in initial stage of the recycling of organic matter. The feeding habits of different earthworm species influence their effects on litter fragmentation and incorporate into soil. Many kinds of leaf litter are not acceptable to earthworms when they first fall to the soil surface, and they require a period of weathering before they become palatable to the earthworms. The rate of breakdown depends also upon the type of litter. Earthworms are much more attracted to moist litter material than to dry, and they are much more active in moist soil and litter (Edwards and Bohlen, 1996). Earthworms can consume very large amounts of litter, and amount they ingest seems to depend more on the total amount of suitable organic matter available than on other factors. The tropical forests in Nigeria, the litter fall was three or four times as much as in temperate forest, and suggested that earthworms were the most important animals in fragmenting and incorporating it into soil (Edwards and Bohlen, 1996).

2.8.2 Nutrient cycling

Earthworms can have major influences on nutrient cycling processes in many ecosystems. Lavelle and Martin (1992) showed four scales of earthworm effect on organic matter and nutrient cycle:

1. during transit through the earthworm gut;
2. in freshly deposited earthworm casts;
3. in aging casts; and
4. during the long-term genesis of the whole soil profile.

Their effects at each of these scales are influenced by soil type, climate, vegetation and the availability and quality of organic matter.

Carbon: Although earthworms consume and turn over a large amount of organic matter, their contribution to total heterotrophic soil respiration is small, accounting usually for only 5-6% of total energy flow in terrestrial ecosystems. The small contribution of earthworms to overall CO_2 output from ecosystems is due to their low assimilation efficiencies. Carbon assimilation efficiencies ranging from 2 to 18% have been reported for several species of endogeic earthworm. The types and amount of carbon in earthworm casts differ from those of surrounding soil. The amount of carbon in earthworm cast is greater than in surrounding soil (Edwards and Bohlen, 1996).

Nitrogen: Significant amounts of nitrogen can pass directly through the earthworm biomass in terrestrial ecosystems. Satchell (1963, quoted in Edwards and Bohlen, 1996) estimated that 60-70 kg nitrogen/ha/yr were return to the soil in the dead tissue of *L. terrestris* in woodland in England. Dead earthworms decompose rapidly and the nitrogen in earthworm tissues turns over rapidly and is mineralized readly. Satchell (1967, quoted in Edwards and Bohlen, 1996) reported that nearly 70% of the nitrogen in dead earthworm tissue was mineralized in 10-20 days. Many researchers have reported considerably more nitrogen in cast than in the surrounding soil (Edwards and Bohlen, 1996). It is clear that earthworms can make a substantial contribution to the over all turn over of available forms of mineral nitrogen, especially when the amounts produced in earthworm cast are considered as well as the amounts produced in mucus secretions and form the decaying tissues of dead earthworms (Edwards and Bohlen, 1996).

Phosphorus: Most researchers who have examined the available phosphorus in earthworm casts and the surrounding soil, have reported that casts usually have more available phosphorus than soils without earthworms. Much of increase in the availability of phosphorus in earthworm cast relative to that of surrounding soil is due to enhanced phosphatase activity in the casts (Satchell and Martin, 1984). The inorganic and organic phosphorus was concentrated particularly in the fine-size fractions of the casts. The rates of release of inorganic phosphorus in the casts was about four times faster than that in the surface soil (Sharpley and Syers, 1976).

Other nutrients: The concentrations of exchangeable calcium, magnesium and potassium are usually significantly greater in earthworm casts than in undigested soil. Nye (1955) reported that the cast of the tropical earthworm *Hippopera nigeriae* were much richer in exchangeable calcium and magnesium than the top soil in forests. Nijhawan and Kanwar (1952, quoted in Edwards and Bohlen, 1996) reported that there was more calcium in casts than in soil, and there was more available potassium, manganese, exchangeable calcium, magnesium, and sodium in large earthworm casts than in either soil or in small casts.

2.9 The information of Sakaerat Environmental Research Station

2.9.1 Location

SERS was established by the Thai government on September 19, 1967. It is administered by the Thailand Institute of Scientific and Technological Research as a faculty for ecological and environmental research. It is located at 14° 30'N and 101° 55'E, approximately 300 km from Bangkok and 60 km from Nakhon Ratchasima on highway 304. The area covers Phuluang, Wang Nam Khieo, and Udomsap subdistricts and Pacthongchai District. SERS is situated in mountainous terrain at altitude of 280-762 m above sea level, covering 78 km^2. (TISTR, 2002; Charoenpol, 2003). The Sakaerat Environmental Research Station (SERS) is the UNESCO biosphere reserve. It was supported by the UNESCO/MAB Programme since 1978.

2.9.2 Climate

The average annual temperature is 26°C ranging from 8-37°C and the average annual rainfall is 1,260 ml. The average relative humidity in SERS is 81.9%. The average relative humidity is 86.4% in rainy season, 83.3% in winter and 77.9% in summer. There are three seasons: the rainy season (May to October), winter (November to February) and Summer (March to mid-May). The wettest month is September and the driest months are between January to March (TISTR, 2002; Charoenpol, 2003).

2.9.3 Land use and vegetation

Dry evergreen forest and dry dipterocarp forest covered about 70% of SERS (Table 2.1). The remaining areas are bamboo, forest plantation, and grassland (TISTR, 2002). However, in 2008 grassland areas is decreased by forest plantation.

Table 2.3 Defined land use in Sakaerat Environmental Research Station in the year 2000 (TISTR, 2002).

Land Use Category	Km^2	Rai	Percentage
1. Dry evergreen forest	46.84	29,260	59.97
2. Dry dipterocarp forest	15.51	9,060	18.57
3. Forest plantation	14.46	9,038	18.52
4. Bamboo forest	1.12	697	1.43
5. Grassland	0.93	582	1.19
6. Building and official areas	0.25	157	0.32
Total	78.06	48,800	100.00

1) Dry evergreen forest

The dry evergreen forest occupies mostly in the southwest section around Khao Khiat, Khao Khieo, and Khao Ma Kha extending northeastward along the northern boundary to Khao Hin Kerng. It has a dense canopy of four stories. The upper storey is 21-40 m high and consists of dominant plant species such as *hopea ferrea* Pierre, *Hopea odorata* Roxb., *Shorea sericeiflor* Fisch. & Hutch. And *Irvingia malayana* Oliv. Ex A. Benn. The middle storey is 15-20 m high and consists of important species such as *Hydnocarpus ilicifolius* King., *Memecyulon ovatum* J.E. Smith, and *Walsura trichosatemo* Miq. The lower storey is about 4-14 m high and consists of important species such as *Baccaurea sapida* Muell. Arg., *Apodytes dimidate* E. Mey. Ex Arn., and *Olea salicifolia.* The undergrowth is less than 4 m high and consists of seedling and shrubs. In addition, the bamboo is found in the higher elevation of Khao Khieo and Khao Khiat (TISTR, 2002; Charoenpol, 2003).

2) Dry dipterocarp forest

This forest type appears in the northeast section of the SERS area. Naturally exposed sandstone is predominantly found on the forest floor with lateritic soil as the predominant soil type. Generally, the dry dipterocarp forest has an open stand characteristic and is composed of three stories. The upper storey is 21-35 m high. The dominant species are *Shorea obtuse* Wall., *Shorea siamensis* Miq., *Dipterocarpus intricatus* Dryer, and *Dipterocarpus tuberculatus* Roxb. The middle storey is 11-20 m high and the important species includes *Quercus kerrii* Craib, *Gardenia sootepensis* Hutch., *Gardenia obtusifolia* Roxb., and *Randia tomentosa* Hook.f. The ground cover is usually composed of seedlings and grasses. The dense mass of *Arundinaria pusiilla* Cheval. & A.Camus, and *Imperata cylindrical* Beauv.

are frequently found. Ground fires occur annually during the dry season (TISTR, 2002; Charoenpol, 2003).

2.9.4 Geology and soil

Bedrocks are exposed along streams and at the escarpment SERS on the Southeast; elsewhere there is thick soil and vegetation cover. The whole area is underlain by sandstone of the Phra Wiharn formation of the Korat group. The upper soil texture is characterized as clay loam, sandy loam, and sandy clay loam. Lower soil is clayey. Soil thickness varies from 70 to 100 cm more; however, soil is very thin in dry dipterocarp forest. The soil series of SERS includes Korat (Kt), Lat Ya (Ly), Tha Yang (Ty), Warin (Wn), Kamphaeng Saen (Ks), Sai Ngam (Sg), Muak Lek (Ml), and Khao Yai (TISTR, 2002; Charoenpol, 2003).

2.9.5 Other information related to SERS

Aksornkoae (1971) found that organic matter content in dry evergreen forest was higher than that in dry dipterocarp forest, and the level of nitrogen in dry evergreen forest was higher than that in dry dipterocarp forest because of higher amount of litter and organic matter. Udomchok (1980, quoted in Chroenpol, 2003) reported that soil texture in dry dipterocarp forest had moderately coarse texture, and low fertility, low water holding capacity. The soil was very shallow and its components were similar to those of dry evergreen forest. Usually, there is forest fire every dry season. The water runoff at the surface caused more serious loss of plant nutrient compared with dry evergreen forest, which has more plant cover and more litter. Dry evergreen forest had more potassium, magnesium and ferrous content than dry dipterocarp forest. Phuriyakorn (1982) reported that the organic matter, nitrogen, phosphorus, potassium, and ferrite were higher in dry evergreen forest than in dry dipterocarp forest but in the maize and cassava fields had the highest calcium and magnesium level. Sakurai *et al*. (1988) pointed out that soil in Sakaerat was very shallow and in poor condition. When forest fire occurs in the dry dipterocarp forest, soil erosion would follow, leading to loss of organic matter on the soil surface. Soil properties such as clay content and associated properties (water holding capacity, cation exchange capacity, soil permeability, and soil moisture) become worse easily and shortly, after soil erosion.

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CHAPTER III

THE DIVERSITY AND DISTRIBUTION OF TERRESTRIAL EARTHWORMS IN SAKAERAT ENVIRONMENTAL RESEARCH STATION AND ADJACENT AREAS, NAKHON RATCHASIMA, THAILAND

3.1 Abstract

The distributions of terrestrial earthworms were studied in the Sakaerat Environmental Research Station (SERS) and adjacent areas. The earthworms and soil samples were collected in the same 30x30x30 cm^3 sampling sites from four vegetation types (dry evergreen forest, dry dipterocarp forest, forest plantation, and grassland) four agricultural lands (rice paddy, sugarcane, cassava, and mango) and three types of residential areas (household, SERS building area, and Silvicultural Research Station area). The digging and hand sorting method was used to collect the earthworms, three times during rainy season (June, August, and October) in 2006. Identification of terrestrial earthworms was based on external and internal morphology. Nineteen species of five families were found in studied areas. *Pontoscolex corethrurus,* the only member of the Glossoscolecidae, had the highest population density followed, by 11 species of Megascolecidae, three species of Moniligastridae, three species of Octochaetidae, and finally, *Gordiodrilus elegans*,

the only species of Ocnerodrilidae, was found in only a household area. Most earthworms collected were adults. Highest population densities were found in residential areas followed by agricultural lands and forest types. The earthworm density was highly significant different in October. The highest density was in SERS (611.1 ind/m^2), and the lowest was in DIF (61.1 ind/m^2). The highest species diversity was 11 in SRS but the highest diversity index was 1.71 in rice paddy.

3.2 Introduction

Earthworms have important roles in soil physical, chemical, and biological properties (Edwards, 2004). Earthworms eat soil organic matter and litter, and increase availability of plant nutrients in their casts (Brown *et al*., 2004). The nutrients can increase plant growth and yield of crops as the result (Edwards and Bohlen, 1996). These are good indications that earthworm activities and behavior interact strongly with physical, chemical and biological properties of soil. But there is still inadequate knowledge of the basic biology and ecology of earthworms, especially in Thailand. Therefore, this study will give new information on earthworms in Thailand and will be valuable resources (species richness, population distributions) for future basic and applied earthworm research, and also increase knowledge and understanding about earthworms for people who work in the field of ecology, agriculture and environmental science.

3.3 Materials and methods

3.3.1 Study Site

The Sakaerat Environmental Research Station (SERS) is the UNESCO biosphere reserve. It was established in 1967, primarily as a site for research on dry evergreen and dry dipterocarp tropical forest and was supported by the UNESCO/MAB Programme since 1978. Other vegetation types in SERS are bamboo, forest plantation and grassland. SERS is administered by the Thailand Institute of Scientific and Technological Research aiming to be a natural laboratory for students and providing training and seminars in ecological and environmental research. SERS is located at 14° 30'N and 101° 55'E at an altitude of 280-762 m above sea level, covering 78 km^2 on the edge of Thailand's Khorat Plateau about 300 km north-east of Bangkok. The average annual temperature is 26°C, the average annual rainfall is 1,260 ml and average relative humidity is 81.9%. There are three seasons: the rainy season (May to October), winter (November to February) and Summer (March to mid-May). The wettest month is September and the driest months are from January to March.

Some 5,300 people live around SERS in 1999. They make their living from growing crops and rice but also using the forest for food and wood gathering. That leads to illegal hunting and tree cutting in the area.

The study sites (as shown in Figure 3.1) consisted of four types of forest in SERS, namely dry evergreen forest (DEF), dry dipterocarp forest (DIF= fired, DINF= non fired), forest plantation (PL), a grassland site (G), four types of agricultural land, including mango plantation (M), sugarcane plantation (S), cassava plantation (C), and rice paddy (R) and three types of residential areas, including house area (H), SERS building area (SERS), and Silvicultural Research Station area (SRS).

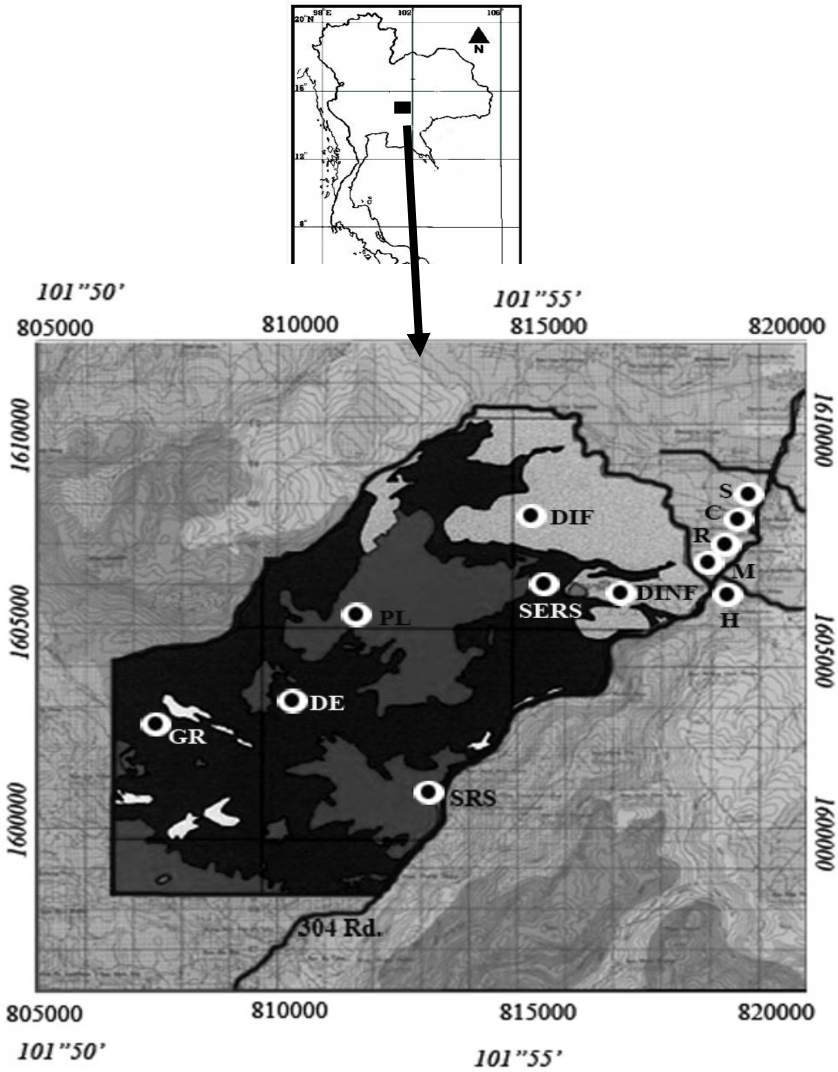

Figure 3.1 SERS location and earthworm collecting sites; DE = dry evergreen forest, DIF = dry dipterocarp forest-fired, DINF = dry dipterocarp forest-non fired, PL = forest plantation, G = grass land, M = mango plantation, S = sugarcane plantation, C = cassava plantation, R = rice paddy, H = household area, SERS = SERS office building area, and SRS = office building area of Sakaerat Silvicultural Research Station.

3.3.2 Earthworms and soil sampling

Earthworm and soil samples were collected from the areas where suitable for earthworm living such as more litter cover, or more earthworm cast presented. The samples were collected from the site in 30x30x30 cm^3 by hand sorting method in June, August and October during rainy season of 2006. There are four replications per site. The external morphology keys of Gates (1972), and Sims and Easton (1972) were used for earthworm identifications.

Soil samples (500 g) were taken to measure pH, moisture, organic matter, N, P, and K. Soil pH were determined in a water suspension at a 2:5 soil:water ratio, on fresh samples. Soil moisture was determined by percent of the weight of fresh soil sample after dried at 105°C for 24 hours (Buurman and Velthorst, 1996). The organic matter was determined following Walkley and Black (1934). Total N was analysed by the micro Kjeldahl method (Buurman and Velthorst, 1996). Available phosphorus was measured colourimetrically, based on the reaction with ammonium molybdate and development of the ‘Molybdenum Blue’ colour (Brey and Kurtz, 1945). Exchangeable K and Ca were determined by atomic absorption spectrophotometry and flame emission (Tran and Simard, 1993). Plant litter were collected in every sites except in the residential areas (H, SERS, and SRS). The plant litter were used to determined OM, OC, and C:N ratio.

3.3.3 Data analysis

Evenness and Shannon-Wiener index (Krebs, 1985) were use to compare the diversity of earthworms among sites. Differences in earthworm numbers and species abundance among land use types were analyzed with ANOVA. The Pearson correlation was employed to find relationship among soil parameters, environmental factors and earthworm density. All data were calculated by using SPSS version 14.0 program for windows.

3.4 Results and discussion

3.4.1 Earthworm diversity

SRS was the most diverse habitat for earthworms, containing 11 species, while the lowest was DIF which had only three species (Table 3.1). The greatest species evenness was 0.80 in DINF. The highest Shannon-Wiener index (H') was 1.71 in rice paddy and the lowest was 0.95 in mango plantation.

The species richness of all area types ranged from 3 to 11 species. They were not different from other tropical rainforests that contained 4 to 14 species. Edwards and Bohlen (1996) stated that earthworm diversity ranged from 1 to 15 species, while most earthworm communities contained around 3-6 species. Generally, more species of earthworm were found in residential and agricultural areas than in the forests. Because the residential and agricultural areas are more subject to species introduction, so they get the exotic species. Nevertheless, Stephenson (1930) stated that the spreading of terrestrial earthworm are more limited depending on their own activities for reaching new regions. Because the cocoons of earthworms are usually deposited under the surface, hence are far less accessible to any means of transport; and they contain few embryos, often only one; so that earthworms spreading through their own exertions can only be very slow. Man has played an important part in the spread of earthworms. Botanical Gardens are obviously likely to be centres of dispersal for such introduced species in new country.

So Sakaerat Silvicultural Research Station areas, where many trees were planted had the highest diversity of earthworms.

Table 3.1 Species diversity and evenness of earthworms in different habitats

	Forest Habitats					Agriculture habitats				Residence habitats		
Index	DE	DIF	DINF	PL	G	R	S	C	M	H	SERS	SRS
Species richness	8	3	6	5	8	9	8	10	6	6	8	11
Eveness	0.64	0.65	0.80	0.59	0.68	0.78	0.77	0.63	0.53	0.67	0.70	0.62
Species Diversity(‘H)	1.33	0.72	1.43	0.96	1.41	1.71	1.60	1.45	0.95	1.20	1.45	1.50

DE = dry evergreen forest, DIF = dry dipterocarp forest-fired, DINF = dry dipterocarp forest-non fired, PL = forest plantation, G = grass land, M = mango plantation, S = sugarcane plantation, C = cassava plantation, R = rice paddy, H = household area, SERS = SERS office building area, and SRS = office building area of Sakaerat Silvicultural Research Station

3.4.2 Earthworm distribution

Nineteen species of five families (Glossoscolecidae, Megascolecidae, Moniligastridae, Octochaetidae, and Ocnerodrilidae) were found in this study (Table 3.2). Interestingly, *Pontoscolex corethrurus*, the only species of Glossoscolecidae, had the highest number of individuals and was distributed all over the areas except in dry dipterocarp forest and sugarcane plantation.

Many earthworm species were present in many places. Three earthworms (*P. corethrurus*, *Drawida beddardi*, and *Dichogaster affinis*) were found in nine habitats. Whereas, five species (*Amynthas alexandri*, *Metaphire peguana*, *Metaphire planata*, *Metaphire posthuma*, and *Dichogaster modiglianii*) were present in seven habitats. In contrast, five earthworms were very site-specific species such as *Polypheretima elongata* in sugarcane plantation, *Dichogaster bolaui* in dry dipterocarp forest (fired), *Gordiodrilus elegans* in household area, *Amynthas* sp.1 in grassland and *Amynthas* sp.2 in dry evergreen forest.

Table 3.2 The average of earthworm distribution and density (ind/m^2) in June, August, and October in 2006.

Earthworm Family/species	Forest Habitats					Agricultural habitats				Residential habitats			Average
	DE	DIF	DINF	PL	G	R	S	C	M	H	SERS	SRS	
Glossoscolecidae													
Pontoscolex corethrurus	55.6	-	-	182.4	100.9	30.6	-	62.0	106.5	70.4	148.2	99.1	71.3
Megascolecidae													
Amynthas alexandri	0.9	-	-	-	3.7	-	2.8	1.9	-	1.9	0.9	2.8	1.2
Amynthas sp. 1	-	-	-	-	0.9	-	-	-	-	-	-	-	0.1
Amynthas sp. 2	0.9	-	-	-	-	-	-	-	-	-	-	-	0.1
Amynthas sp.3	-	27.8	2.8	-	-	3.7	-	1.9	-	-	-	0.9	3.1
Amynthas sp.4	3.7	-	6.5	-	-	-	-	-	-	-	-	-	0.8
Metaphire bahli	-	-	-	-	-	-	12.0	-	23.2	13.9	36.1	33.3	9.9
Metaphire houlleti	3.7	-	-	0.9	-	8.3	13.0	7.4	-	-	-	0.9	2.9
Metaphire peguana	-	6.5	6.5	-	0.9	-	-	0.9	2.8	-	50.0	13.0	6.7
Metaphire planata	-	-	0.9	-	-	37.0	34.3	19.4	11.1	4.6	-	37.0	12.0
Metaphire posthuma	-	-	-	-	4.6	18.5	31.5	0.9	2.8	35.2	-	0.9	7.9
Polypheretima elongata	-	-	-	-	-	-	65.7	-	-	-	-	-	5.5
Moniligastridae													
Drawida beddardi	16.7	-	1.9	2.8	28.7	-	0.9	-	2.8	0.9	17.6	2.8	6.3
Drawida sp.1	-	-	-	-	-	7.4	-	11.1	-	-	-	-	1.5
Drawida sp.2	-	-	-	-	-	4.6	-	-	-	-	22.2	-	2.2
Octochaetidae	-	-	-	-	-	-	-	-	-	-	-	-	-
Dichogaster affinis	1.9	-	16.7	1.9	17.6	0.9	4.6	1.9	-	-	7.4	2.8	4.6
Dichohaster modiglianii	11.1	-	-	7.4	24.1	0.9	-	3.7	-	-	2.8	1.9	4.3
Dichogaster bolaui	-	2.8	-	-	-	-	-	-	-	-	-	-	0.2
Ocnerodrilidae													
Gordiodrilus elegans	-	-	-	-	-	-	-	-	-	132.4	-	-	11.0
Juvenile and unknown	1.9	-	-	0.9	13.0	14.8	8.3	2.8	4.6	10.2	5.6	10.2	6.0

DE = dry evergreen forest, DIF = dry dipterocarp forest-fired, DINF = dry dipterocarp forest-non fired, PL = forest plantation, G = grass land, M = mango plantation, S = sugarcane plantation, C = cassava plantation, R = rice paddy, H = household area, SERS = SERS office building area, and SRS = office building area of Sakaerat Silvicultural Research Station

The Southeast Asian earthworm is dominated by species of Megascolecidae, Moniligastridae, Octochaetidae, and some Ocnerodrilidae (Edwards and Bolhlen, 1996; Fragoso *et al*., 1999). The most diverse and successful group of earthworm species in this region is the pheretimoid-related genera *Pheretima*, *Polypheretima*, *Metaphire*, and *Amynthas*. In both natural and disturbed ecosystems, the exotic *P. corethrurus* or *Polypheretima elongata* are generally dominant (Fragoso *et al*., 1999). On the other hand, Edwards and Bolhlen (1996) postulated that the family Moniligastridae has a very large range, encompassing South-East and eastern Asia. The majority of this area is colonized by only one genus, *Drawida*, which inhabits a larger area than the megascolecid genus, *Pheretima*. Members of the family Glossoscolecidae, *Pontoscolex corethrurus* is now distributed widely in tropical areas throughout the world (Edwards and Bolhlen, 1996). Family Megascolecidae that constitute a *Pheretima* group that includes *Amynthus* spp. apparently original from Eastern and South-East Asia. *Dichogaster* spp. of Octochaetids family, especially *Dichogaster bolaui* probably originally from western Africa, but now are widely distributed throughout tropical and warmer temperate regions. Ocnerodrilus spp. probably originated from central America but now are pantropical. The Moniligastrids *Drawida* spp. probably originated from eastern Asia are now pantropical (Edwards and Bolhlen, 1996). These could be suggests that the result from this study, the exotic species should be consists of the *P. correthurus* of Glossoscolecids, *Dichogaster* spp. of Octochatids, and *Gordiodrilus elegans* of Ocnerodrilids. Whereas, the native species should be the Pheretimoids of Megascolecids and *Drawida* spp. of Moniligastrids.

Exotic earthworm have many special characteristics such as potential for hermaphroditism, adoption of polypliod inheritance, tolerance of environmental variability, habitat specificity, opportunism in choice of food, ability to withstand chemical stress, association with cultivated soil and ecological plasticity (Lee, 1987). Fragoso *et al*. (1992) stated that peregrine species with pantropical distributions were dominant in disturbed environments because they had greater tolerances than native species such as *P. corethrurus* and *D. affinis*. However, the native Moniligastrids; *Drawida* spp. had well distributions. While *Amynthus* sp.3 and *M. peguana* of Megascolecids both presented in dry dipterocarp forest with unsuitable condition (see Table 3.4) for earthworms. Suggest that these species could adapt to the sites which less contain amount of both moisture and organic matter.

3.4.3 Earthworm density

A total of 2,044 earthworms were collected in this studied. Of these, 1,966 individuals were identified to species and 78 were unidentified. All earthworm specimens were divided into 3 age groups, 1,382 adults (67.61%), 393 juveniles (19.23%) and 269 sub-adults (13.16%). The highest earthworm density was *P. corethrurus* (average 71.3 ind/m^2; see Table 3.2) followed by *Metaphire planata* (average 12.0 ind/m^2), and *Metaphire bahli* (average 9.9 ind/m^2). The lowest density earthworms were *Amynthas* sp.1 and *Amynthas* sp.2 (average 0.1 ind/m^2).

The numbers of earthworm were highest in October (201.6 ind/m^2) followed by August (142.1 ind/m^2) and June (93.3 ind/m^2) respectively (Table 3.3). Edwards and Bohlen (1996) stated that when the rain began, the population consisted of juvenile individuals. The mature earthworms were found one month later and predominated to the end of wet season.

Table 3.3 The earthworm density in sakaerat environmental research station and adjacent Areas, 2006.

Area Types	June		August		October		average
	Ind/m^2	S.E	Ind/m^2	S.E	Ind/m^2	S.E	
DE	47.2	32.8	163.9	36.7	77.78c	32.7	96.3
DIF	16.7	16.7	33.3	19.8	61.11c	21.5	37.0
DINF	8.3	8.3	0.0	0.0	97.22c	41.4	35.2
PL	111.1	29.8	194.4	79.2	283.33bc	139.4	196.3
G	94.4	29.6	258.3	24.2	230.56bc	11.5	194.4
R	111.1	44.7	130.6	27.4	138.89bc	26.6	126.9
S	250.0	124.9	169.4	78.5	100.00c	45.8	173.2
C	130.6	65.2	105.6	44.1	105.56c	18.4	113.9
M	175.0	98.6	113.9	65.6	172.22bc	95.2	153.7
H	94.4	40.2	133.3	63.5	183.33bc	54.9	137.0
SERS	8.3	8.3	252.8	183.4	611.11a	120.4	290.7
SRS	72.2	54.5	150.0	50.2	358.33b	112.9	193.5
Average	93.3	17.6	142.1	21.1	201.6	28.8	145.7

DE = dry evergreen forest, DIF = dry dipterocarp forest-fired, DINF = dry dipterocarp forest-non fired, PL = forest plantation, G = grass land, M = mango plantation, S = sugarcane plantation, C = cassava plantation, R = rice paddy, H = household area, SERS = SERS office building area, and SRS = office building area of Sakaerat Silvicultural Research Station.

Generally, earthworm densities were highest in residential areas followed by agricultural lands and forests. The highest density was in SERS (611.1 ind/m^2), and the lowest was in DIF (61.1 ind/m^2). The earthworm density was significantly different in October.

As the results, it is difficult to assess precisely which habitats can support large earthworm populations. Earthworm populations can range from less than one earthworm to more than 2000 ind/m^2 (Edwards and Bohlen, 1996). Fragoso *et al.* (1999) concluded that earthworms communities in several agroecosystem, two more important determinants of the communities were time of disturbance (which measures time elapsed since first perturbation), and the kind of agricultural practices (amount and intensity of soil destructive, agricultural practice e.g. use of tillage, pesticides, fertilizers). The number of earthworms in regularly cultivated arable soils are usually variable, and are intermediate between the more sterile habitats and those pastures and natural grasslands which can support large numbers of earthworms (Edwards and Bohlen, 1996). For instance, in Cuba the earthworm density was 413 ind/m^2 in forests and 338 ind/m^2 in pastures (Edwards and Bohlen, 1996). However, this study showed that earthworm densities were lower in natural forests than those in mild and heavy disturbed in residential and agricultural areas. As well as in Mexico, the earthworms from natural ecosystems showed lower abundances than those from disturbed sites (Fragoso *et al*., 1999). In Brazil, earthworm in pasture (602 ind/m^2) was greater than in forests (202 ind/m^2) (Fragoso *et al*., 1999). In India, number of earthworms was higher in tree plantation followed by crop and forest respectively (Fragoso *et al*., 1999). In Thailand, Kosavititkul (2005) reported that the highest abundance of earthworm was 93.2 ind/m^2 in moist evergreen forest and the lowest was 11.1 ind/m^2 in grassland. The high density in residential areas than other areas in this study may caused by mildly disturbance and species introduction by human activities.

3.4.4 Environmental factors

The climate factors such as rainfall, relative humidity, and ambient temperature were obtained from only four metrological stations in SERS. The results indicated that the average amount of rainfall was not significantly different. The maximum amount of rainfall was 148.93 mm (Table 3.4). The mean relative humidity was highly significant different among forest types, the highest was 89.00%. The average ambient temperature was not significant different. The mean of maximum temperature was 27.80°C.

The soil factors consisted of soil moisture, soil pH, nitrogen, phosphorus, potassium, calcium, organic matter, and C:N ratio. All of these factors were highly significant different among the vegetation types and land used. The greatest soil moisture was in grass land (23.81%) followed by rice paddy. While the driest was in dry dipterocarp forest. The soil pH was ranging from 4.93-7.21. The acidic soil (rang 4.93-5.89) were found in forests. However, in agricultural land the pH was lightly acidic ranging from 5.75-6.30. Whereas the neutral soil (pH 6.63-7.21) were found in residential areas.

The soil temperature was significantly different among land used types. The soil temperature was higher in agricultural areas, followed by residential areas and forest areas respectively. The highest soil temperature was in sugarcane plantation areas (28.63°C). In contrast the lowest soil temperature was in dry evergreen forest (23.96°C).

The nitrogen content was highest in dry evergreen forest (2.25 g/kg) and the lowest was in mango plantation (0.75 g/kg). The phosphorus content seemed to be similarly in all sites. The highest was in SERS area sites. But it was very low in the grassland. The potassium content was high in SERS and SRS. The calcium content was higher in residential areas especially in SERS (2.88 g/kg). The greatest organic matter was in forest types, especially in dry evergreen forest (3.72 g/kg). While it was quite lower in agricultural areas. As well as the C:N ratio those higher in residential areas followed by forest and agricultural areas. However, the highest was 12.79 in mango plantation.

The plant litter were collected form every sites excepted residential areas. The results indicated that organic matter was highly significant different between land use types. The highest organic matter was 71.64% in mango plantations while the lowest was in sugarcane plantation (40.76%). C:N ratio was highest in mango plantation (62.5) and lowest in forest plantation areas (19.5). Stephenson (1930) stated that climate was important to some earthworm but not to all genera. In this study, environmental factors cannot explain the earthworm density in our sites. The differences depend on earthworm species in each habitat, especially an exotic one. The density of *P. corethrurus*, which is well adapted to human disturbed areas, was 24% in rice paddy and up to 92% in forest plantation (Table 3.4). This species alone contributed to the high earthworm density in residential, agricultural, grassland and forest plantation areas. However interestingly data could be discussion in the relationships between environmental factors and the earthworm distributions and density those presented in Table 3.1 and 3.3. The highest density was SERS followed by PL, G and SRS those composed of high suitable values of environmental factors for earthworms. For instances, SERS had high values of soil pH, phosphorus, potassium, calcium and C:N ratio. As the same causes, PL had high values of nitrogen and potassium, G, had high soil moisture and potassium values, and SRS had high values of pH, phosphorus, calcium, and C:N ratio. In contrast, dry dipterocarp forest that limited of suitable factor for earthworms, which had the lowest of soil moisture and height soil temperature. Thus earthworm density was very low. However, two species of Pheretimiods, which presented high density, were *Amynthus* sp.3 and *M. peguana* those could tolerant in this habitat. The data of environmental factors among forest types are shown in Table 3.4.

Table 3.4 The environmental factors among vegetation types at SERS and adjacent areas

	Vegetation types											
Factors	DEF	DIF	DINF	PL	G	R	S	C	M	H	SERS	SRS
Climate factors												
Rainfall(mm)	123.51	107.37	113.97	148.93	148.93	107.37	107.37	107.37	107.37	107.37	113.97	148.93
RH(%)	85.52	89.00	86.59	83.44	83.44	89.00	89.00	89.00	89.00	89.00	86.59	83.44
Atemp(°C)	26.93	27.03	27.80	26.70	26.70	27.03	27.03	27.03	27.03	27.03	27.80	26.70
Soil factors												
Miosture	19.02abc	10.57ef	8.87f	17.58bcd	23.81a	21.12ab	16.21bcd	13.13def	14.85cde	19.26abc	16.74bcd	18.25bc
pH	5.48d	5.89cd	5.54d	4.93e	5.59d	6.30bc	5.92cd	5.75cd	6.06cd	7.20a	7.21a	6.63b
Temp(°C)	23.96d	27.83a	26.04b	24.50d	24.58d	27.92a	28.63a	27.75a	25.75bc	26.08b	24.83cd	26.17b
N(g/kg)	2.25a	1.41cd	1.68bcd	2.06ab	1.81bc	1.53cd	1.38cd	1.53cd	0.75e	1.45cd	1.71bcd	1.31d
P(g/kg)	0.017c	0.011c	0.014c	0.012c	0.006c	0.052c	0.122bc	0.036c	0.330a	0.242ab	0.346a	0.296a
K(g/kg)	0.41abc	0.31bc	0.36abc	0.43 abc	0.42 abc	0.24cd	0.40 abc	0.13d	0.35 abc	0.39 abc	0.52a	0.48ab
Ca(g/kg)	1.03d	0.67d	0.73d	0.61d	0.64d	1.34cd	0.89d	0.84d	1.07d	1.94bc	2.88a	2.32ab
OM(%)	3.72a	1.72cde	2.30bcd	2.4bc1	2.29bcd	1.02ef	0.74f	0.74f	1.55def	1.39ef	2.76b	2.21bcd
C/N	9.36	7.31	7.71	6.76	7.27	4.25	3.29	2.91	12.79	5.83	9.79	9.40
Litter factors												
OM(%)	65.50ab	63.07abc	59.10abc	57.61 bc	68.12ab	43.99d	40.76d	50.91cd	71.64a	na	na	na
C/N	20.37c	20.03c	26.64c	19.57c	23.10c	45.21	23.69c	25.81c	62.50a	na	na	na

Mean in the columns followed by different letter are significantly different at P = 0.05

3.4.5 The relationship of earthworms and environmental factors

The earthworm densities were positively significant correlated ($p < 0.05$) with rainfall, soil moisture, nitrogen, calcium, and organic matter (Table 3.5). However, they were negatively correlated with temperature, both ambient and soil temperature.

Soil moisture content was a major factor affecting earthworm activities (Minnich, 1977). Water constitutes 75-90% of the earthworm body earthwormd, so the prevention of water loss was critical for earthworm survival (Edward and Bolhen, 1996). The largest number of earthworms were found in soils with moisture contents between 12 and 30% (Minnich, 1977). Therefore, dry dipterocarp forest had the lowest number of earthworm.

Earthworms can increase available nitrogen, especially casts, mucus secretions and decaying tissues (Edward and Bolhen, 1996). Many species of earthworm possess calciferous glands that are involved in the production of calcium carbonate spherules, which may have an important influence on calcium availability in some soils (Piearce, 1972).

The availability of organic matter is one of the most important factors influencing earthworm abundance (Edward and Bolhen, 1996). Earthworms feed on dead and decaying plant, the primary source of food for them. The presence of large earthworm population in the soil indicated high organic matter content (Minnich, 1977). Hendrix *et al*. (1992) reported a strong positive correlation between earthworm population density and soil organic matter content across 10 sites. Because of their limited capacity for moving about, earthworms are obligate to live very close to their sources of food (Lee, 1985).

Table 3.5 The Correlations among Earthworm Density and Environmental Factors

	Earthworm density	Rain fall	Rh	Ambient temperature	Soil moisture	soil pH	Soil temp	N	P	K	Ca	Soil OM
Rain fall	.205*											
Rh	.137	.351*										
Ambient temperature	-.105	-.698**	-.539**									
Soil moisture	.237**	.169*	-.153	.077								
Soil pH	.137	-.142	.083	.194*	.05							
Soil temp	-.073	-.202*	.303**	.057	-.196	.194*						
N	.231**	.295**	-.075	-.150	.156	-.176*	-.230**					
P	.099	-.006	.086	-.007	.063	.392**	-.077	-.009				
K	.114	-.06 3	-.278**	.173*	.025	.247**	.184*	.188*	.252**			
Ca	.327**	.142	.105	-.029	.208*	.449**	-.140	.239**	.609**	.217**		
Soil OM	.172*	.226**	-.197*	.052	.166*	-0.111	-.490*	.659**	.242**	.324**	.385**	
Soil C/N	.048	-.021	-.169*	.116	.068	.011	-.389**	-.135	.298**	.259**	.229**	..571**
Om (litter)	-.158	-	-		-	-	-	-	-	-	-	-
C/N (litter)	.013	-	-	-	-	-	-	-	-	-	-	-

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

3.5 Conclusion

A total 2,044 individuals of 19 earthworm species were found in this study. They belonged to the following five families: Glossoscolecidae, Megascolecidae, Moniligastridae, Octochaetidae, and Ocnerodrilidae. These 19 species were *P. corethrurus*, *A. alexandri*, *Amynthas* sp.1, *Amynthas* sp.2, *Amynthas* sp.3, *Amynthas* sp.4, *M. bahli*, *M. houlleti*, *M. peguana*, *M. planata*, *M. posthuma*, *P. elongata*, *D. beddardi*, *Drawida* sp.1, *Drawida* sp.2, *Di. affinis*, *Di. modiglianii*, *Di. bolaui*, *and Gordiodrilus elegans*. The most abundant was *P. corethrurus*, which presented in every forest type except dipterocarp forest. The rarest were *Amynthas* sp.1 and *Amynthas* sp.2, those found only in grassland and dry evergreen forest respectively. The adult stage was the most abundant, followed by juvenile and sub-adult. The highest species diversity and species richness of earthworms were found in rice paddy and around the Silvicultural Research Station offices respectively. The evenness of earthworm was highest in unburned dipterocarp forest. The exotic *P. corethrurus* was found in every habitat except in dry dipterocarp forest and sugarcane plantation. *Polypheretima elongata* was found only in sugarcane plantation while *Gordiodrilus elegans* was found only in household area. Population densities were highest in October followed by August and June. The earthworm density was highest in residential areas followed by agricultural lands and forests. The earthworm density was significantly different among sites in October. The highest density was in SERS (611.1 ind/m^2) and the lowest was in DIF (61.1 ind/m^2). Environmental factors, such as soil moisture, rainfall, total nitrogen, and organic matter, were very important for earthworm management.

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CAPTER IV

THE COMPARISON OF EARTHWORM DIVERSITY AND THEIR DYNAMICS BETWEEN DRY EVERGREEN AND DRY DIPTEROCARP FOREST AT SAKAERAT ENVIRONMENTAL RESEARCH STATION, NAKHON RATCHASIMA, THAILAND

4.1 Abstract

The diversity and dynamic of terrestrial earthworms in dry evergreen and dry dipterocarp forests were compared in Sakaerat Environmental Research Station (SERS). Four replications of earthworm and soil samples were collected in the 30x30x30 cm^3 sampling sites, once a month in 2006. Identification of terrestrial earthworms was based on external and internal morphology. Thirteen earthworm species in four families were found in this area, nine species of Megascolecidae, two species of Octochaetidea, one species of Glossoscolecidae, and one Moniligastrid species. The earthworm diversity were not different, nine species in dry evergreen forest and eight species in dry dipterocarp forest. However, earthworm density was significantly higher in dry evergreen forest (46.53 ind/m^2) than dry dipterocarp forest (13.43 ind/m^2). The highest density was found in August (163.9 ind/m^2) in dry evergreen forest, while the highest density (66.7 ind/m^2) of dry dipterocarp forest was

found in October. Earthworm number was low in dry season and not present in February and December. Earthworm density was positively correlated with rainfall, relative humidity, soil moisture, nitrogen content and calcium content, but negatively correlated with soil temperature.

4.2 Introduction

Earthworms are composed of the highest biomass among tropical soil fauna (Fragoso and Lavelle, 1992), and they have the important roles in soil physical, chemical, and biological properties (Edwards, 2004; Lee, 1985). Earthworms eat litter and leave more available plant nutrients in their casts on the soil surface (Brown *et al.*, 2004), those can increase plant growth and yield of crops as a result (Edwards and Bohlen, 1996). The different tropical forest types could alter the quantities and qualities of litter input to the soils. Differences in litter quality and chemistry may trigger changes in the abundance and community structure of earthworms (Grainger, 1988). These are good empirical evidences that earthworm activities and behavior interact strongly with physical, chemical and biological properties of soil. The Sakaerat Environmental Research Station (SERS) is the UNESCO biosphere reserve which was established in 1967. The SERS has two major natural vegetation types. They are dry evergreen and dry dipterocarp forest, and other vegetation types in SERS are bamboo, forest plantation and grassland. The natural vegetation at SERS supports a high faunal diversity. Some 430 vertebrate species are known to be present at SERS (TISTR, 2008); however, there is still inadequate knowledge of the basic biology and ecology of earthworm, especially the relationship between earthworm communities with the environment of two major forest types in SERS. Therefore, the present study will give new information of earthworm in SERS and will be a valuable resource of species richness, population dynamics of earthworm in Thailand which can be applied research on earthworms in the future.

4.3 Materials and methods

4.3.1 Study site

The Sakaerat Environmental Research Station (SERS) is the UNESCO biosphere reserve. It was established in 1967, primarily as a site for research on dry evergreen and dry dipterocarp tropical forest and was supported by the UNESCO/MAB Programme since 1978. Other vegetation types in SERS are bamboo, forest plantation and grassland. SERS is administered by the Thailand Institute of Scientific and Technological Research aiming to be a natural laboratory for students and providing training and seminars in ecological and environmental research. It is located at 14° 30'N and 101° 55'E at an altitude of 280-762 m above sea level, covering 78 km^2 on the edge of Thailand's Khorat Plateau about 300 km north-east of Bangkok. The average annual temperature is 26°C, the average annual rainfall is 1,260 mm and average relative humidity is 81.9%. There are three seasons: rainy season (May to October), winter (November to February) and summer (March to mid- May). The wettest month is September and the driest months are from January to March (TISTR, 2008). The study sites consists of four replications per each forest type. The sampling sites are shown in Figure 4.1.

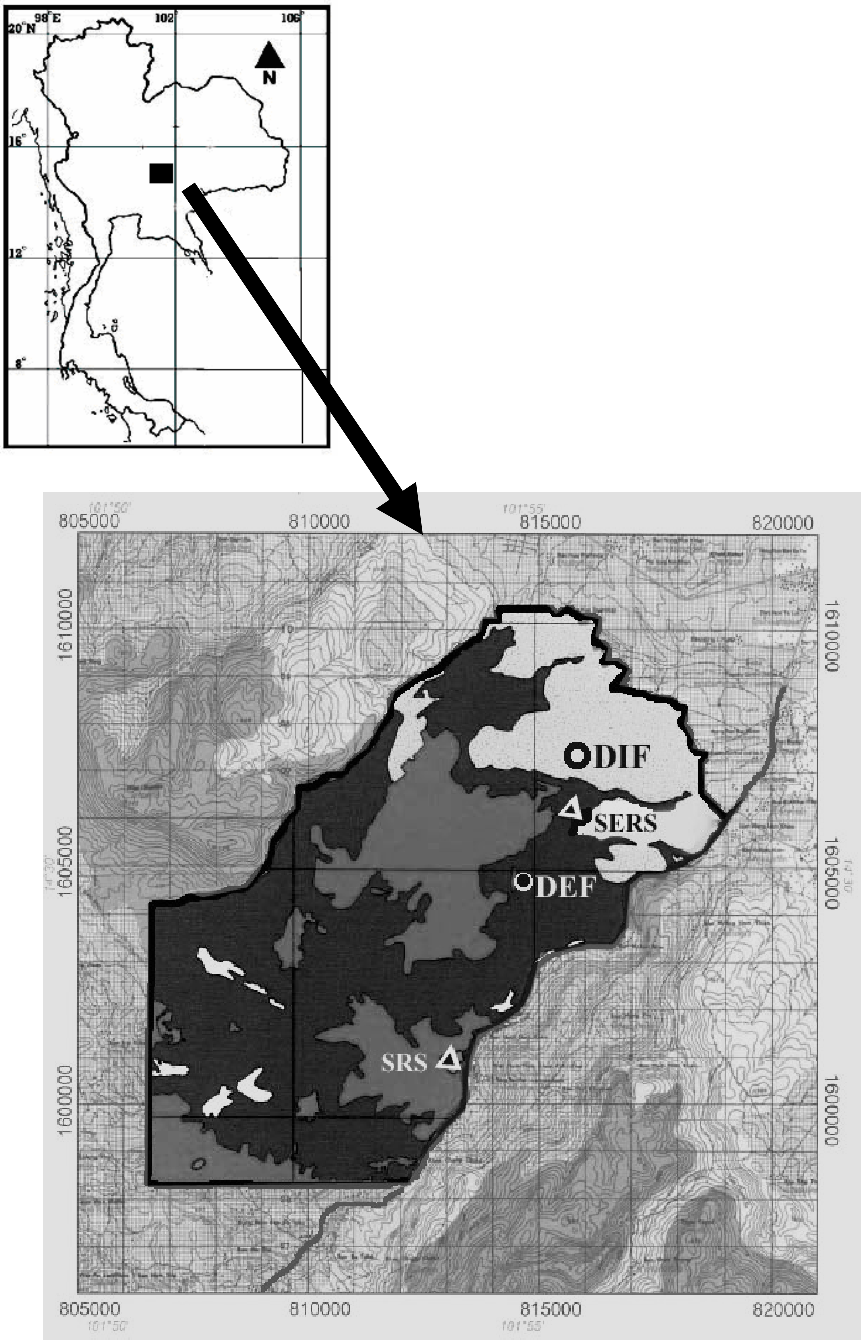

Figure 4.1 Map showing the location of earthworm collecting sites: DEF = dry evergreen forest, DIF = dry dipterocarp forest-fired, SERS = SERS office building area, and SRS = office building area of Sakaerat Silvicultural Research Station

4.3.2 Earthworm, soil, and plant litter sampling

Earthworm and soil samples were collected in 30x30x30 cm^3 by hand sorting method once a month (January-December, 2006). The external and internal morphology keys of Gates (1972), and Sims and Easton (1972) were used for earthworm identifications. Soil sample (500 g) was taken to measure pH, moisture, N, P, K, Ca, and organic matter. Soil pH were determined in a water suspension at a 2:5 soil : water ratio, on fresh samples. Soil moisture was determined by percent of the weight of fresh soil sample after dried at 105°C for 24 hours. Total nitrogen was analyzed by the micro Kjeldahl method (Buurman *et al.*, 1996). Available phosphorus was measured colourimetrically, based on the reaction with ammonium molybdate and development of the 'Molybdenum Blue' colour (Bray and Kurtz, 1945). Exchangeable K was extracted by the Mehlich-3 procedure and determined by atomic absorption spectrophotometry and flame emission (Tran and Simard, 1993). The organic matter was determined following Walkley and Black (1934). The dry-ashing method involves the removal of organic matter by combustion of the sample at medium temperature (375 to 600°C) in muffle furnace. Plant litter samples were collected from every sites to determined organic matter and C:N ratio.

4.3.3 Data analysis

Differences in earthworm density and environmental factors between forest types were analyzed with compared means-independent-sample t-test. The Pearson's correlation was employed to find the relationship correlation among environmental factors with earthworm populations. All analyses were calculated by using SPSS program version 14.0 for windows.

4.4 Results and discussion

4.4.1 Earthworms density and dynamic

Thirteen earthworm species belonging to four families were collected in SERS over the study period (Table 4.1). Nine earthworm species in four families were found in dry evergreen forest, while eight species in three families were found in dry dipterocarp forest. This is higher than seven species in four genus reported by Kosavititkul and Wannitikul (2006). Three same species which have been found in previous study are *Amynthas alexandri*, *Metaphire peguana*, and *Dichosgaster affinis*.

Table 4.1 The density (mean±SE) of earthworm species in dry evergreen forest and dry dipterocarp forest at SERS in 2006.

Families/Species	Dry evergreen forest	Dry dipterocarp forest
Glossoscolecidae		
1. *Pontoscolex corethrurus*	26.2±7.9	-
Megascolecidae		
2. Amynthas alexandri	1.2±0.8	-
3. A. defecta	0.5±0.5	-
4. A. sieboldi-group	-	0.7±0.7
5. Amynthas sp.2	0.2±0.2	-
6. Amynthas sp.3	-	1.9±0.9
7. Amynthas sp.4	0.9±0.7	1.6±.1.6
8. M. houlleti	0.9±0.6	-
9. M. peguana	-	4.9±1.9
10. M. planata	-	0.2±0.2
Moniligastridae		
11. Drawida bedarddii	8.3±3.8	1.5±0.8
Octochaetidae		
12. Dichogaster affinis	0.5±0.3	0.7±0.4
13. Di. modiglianii	5.1±2.5	0.7±0.5
Unknown	2.8±1.5	1.6±7.9
Total	46.5±9.9	13.4±7.9

The most abundance and the highest density was *Pontoscolex corethrurus* (26.1 ind/m^2), the only one species of family Glossoscolecidae, presented only in dry evergreen forest. Generally, this species can be found in several areas, they are common in year-round where moisture and other requirements are met. In this study, the less moisture probably causes them to withdrawn form dry dipterocarp forest. Edwards and Bohlen (1996) stated that this species was a cosmopolitan species with pantropic distribution, and Gates (1972) said that it was the most widely distributed earthworm. Dechainea *et al*. (2005) and Zou *et al*. (2006) reported that this species was the dominated in tropical wet forest.

Four species (*Amynthas* sp.4, D. *beddardi*, *Di. affinis*, and *Di. modiglianii*) were found in both forests. *A. alexandri*, *A. defecta*, *Amynthas* sp.2, and *M. houlleti* were found only in dry evergreen forest. Whereas *Amynthas* sp.3, *A. sieboldi*-group, *M. peguana*, and *M. planata* were found only in dry dipterocarp forest. *Amynthas* and *Metaphire* genera (known as Pheretima group) are indigenous to Southeast Asia, while *Di. Modiglianii* was distributed in Malay Peninsula, where as *Di. Affinis* was also reported in Thailand, Malay Peninsula and Pacific Ocean Island (Julka, 1988).

The average annual earthworms density 3.5 times higher in dry evergreen forest (46.5 ind/m^2) than in dry dipterocarp forest (13.4 ind/m^2) (Table 4.1). The highest earthworm density was in August (163.9 ind/m^2) and in October (66.7 ind/m^2) in dry evergreen and dry dipterocarp forest respectively (Table 4.2).

Earthworm density in dry evergreen forest is higher than tropical forest in Sarawak (Collins, 1980; Anderson *et al*., 1983) but lower than in Malaysia (Leaky and Proctor, 1987). Whole earthworm density in dry dipterocarpforest is lower than the same forest in Nigeria (Cook *et al*., 1980). However, earthworm density in SERS was less then tropical evergreen forests in the South of Thailand (Watanabe *et al*., 1966).

Earthworm populations fluctuated over year. Generally, they were highest in wet season and lowest in summer. Earthworm population in dry evergreen forest started to increase in June, reached peak in August and declined in October (Table 4.2 and Figure 4.2). Whereas, earthworm in dry dipterocarp forest had high population only in September and October. Surprisingly, high earthworm population was found in April near wildlife water reservoirs in dry dipterocarp forest.

Table 4.2 The monthly density of earthworm (mean± SE) in dry evergreen forest and dry dipterocarp forest at SERS in 2006.

	Earthworm density (ind/m^2)	
Month	Dry evergreen forest	Dry dipterocarp forest
January	8.3 ± 8.3	-
February	-	-
March	8.3 ± 8.3	-
April	5.6 ± 5.6	25.0 ± 11.5
May	8.3 ± 8.3	-
June	47.2 ± 32.8	8.3 ± 8.3
July	94.4 ± 34.4	-
August	163.9 ± 36.7	2.8 ± 2.8
September	130.6 ± 39.4	50.0 ± 10.6
October	77.8 ± 32.7	66.7 ± 18.7
November	13.9 ± 7.0	8.3 ± 8.3
December	-	-

- = data not found

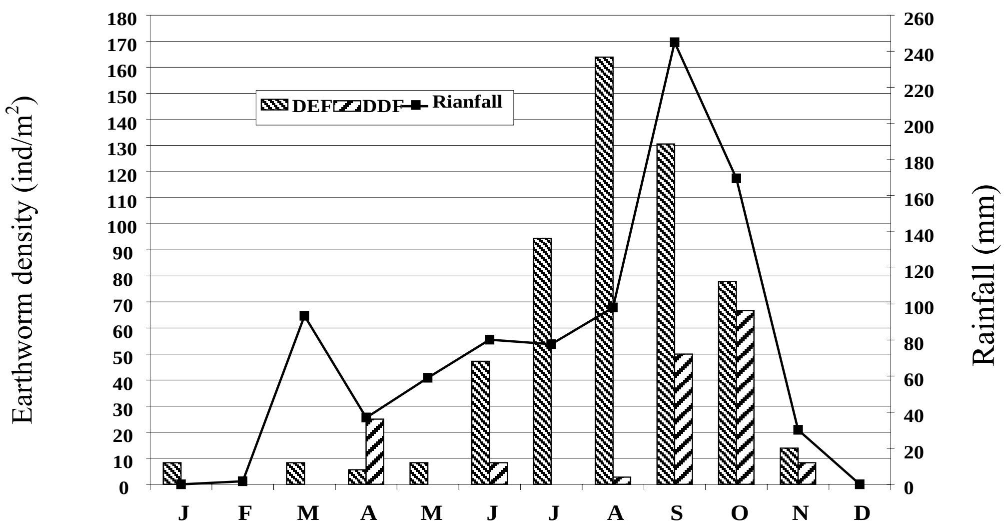

Figure 4.2 Earthworms density and environmental factors in SERS 2006: DEF = earthworm density in dry evergreen forest, DDF = earthworm density in dry diptercarp forest, Rianfall = annual rain fall (mm).

Notably, earthworm population depended on monthly rainfall, especially in dry dipterocarp forest (Figure 4.2)

The seasonal effect on earthworm populations have been reported by many authors (Ghafoor *et al.*, 2008; Edwards and Bohlen, 1996; Lee, 1985; Gates, 1972). Generally, earthworms in tropical climate were active and present in the rainy season, 4-6 months between May and October (Bhadauria *et al.*, 2000; Gates, 1961; Kaushal and Bisht, 1994; and Bith *et al.*, 2003). By the end of rainy season, earthworms disappeared generally from the upper layers of the soil (Gates, 1972). All species of worms seemed to be quiescent in summer and winter.(Edwards and Bohlen, 1966).

The numbers of adult earthworms were more than those of juvenile and sub-adult every month (Figure 4.3). However, allage classes were dramatically increased during wet season from June to October.

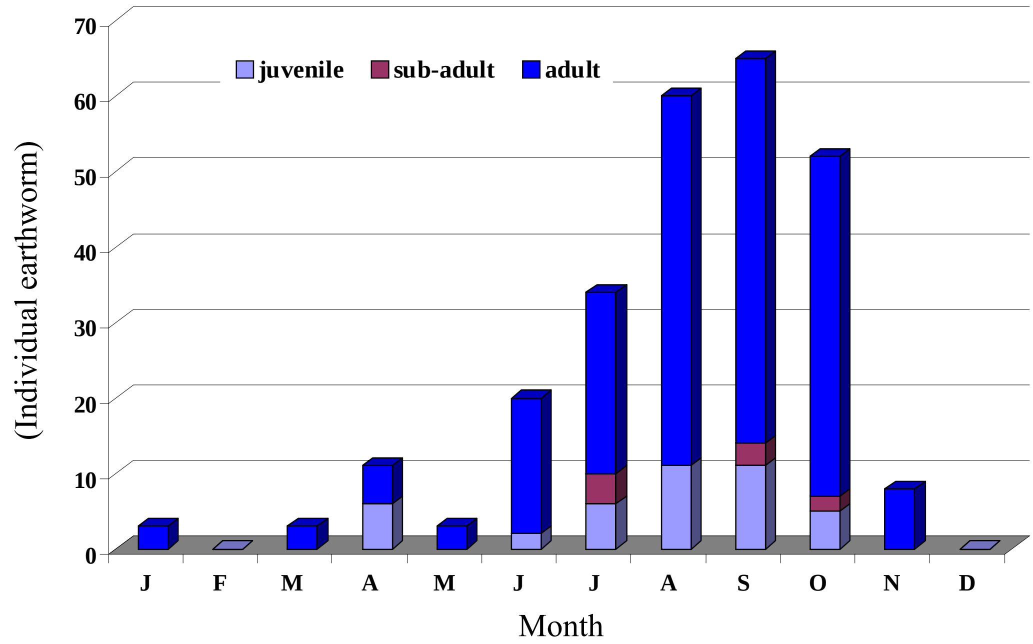

Figure 4.3 Number of earthworm in different age classes in SERS 2006

4.4.2 Environmental factors between two forest types

The climate data were obtained from the metrological station in SERS which was nearest to the sampling site. The factors those highly significant different between two forest types were soil moisture, soil temperature, and nitrogen content. Additionally, relative humidity, potassium and organic matter content were significantly different. Most higher in dry evergreen forest, except the relative humidity which higher in dry dioterocarp forest (Table 4.3).

These results quite similar to the previous study by Charoenpole (2003) who found that soil moisture, soil organic matter, nitrogen, potassium, and calcium content were lower in dry dipterocerp forest than in dry evergreen forest. Because dry dipterocarp forest has low ability of retaining moisture, less crown cover of tree, more water runoff at the soil surface, and has less litter resulting in less breaking down into organic matter and soil nutrients. Nevertheless, Udomchok (1980, quoted in Chroenpol, 2003) reported that soil properties in dry dipterocarp forest were very shallow and forest fire usually occured in every dry season. Moreover, the surface runoff caused more serious loss of plant nutrient compared with dry evergreen forest, which had more plant cover and more litter. Puriyakorn (1982) also showed that the soils of all land use type in the Sakaerat forest normally showed an acid reaction (pH ranges 4.8-5.7).

Table 4.3 The mean (±SE) comparison of earthworm density and factors between dry evergreen forest and dry dipterocarp forest in SERS

Factors	Dry evergreen	Dry dipterocarp	t-test t	t-test P-value
Earthworm density (ind/m^2)	46.5 ± 9.9	13.4 ± 3.7	3.135	.003**
Environmental factors				
Rainfall (mm)	79.4 ± 10.9	69.2 ± 11.0	.657	.513
Relative humidity (%)	84.8 ± 0.7	87.3 ± 0.6	-2.569	.012*
Temperature (°C)	26.9 ± 0.3	26.7 ± 0.03	0.46	.647
Soil factors				
Moisture (%)	14.5 ± 1.0	10.1 ± 0.8	3.592	.001**
Temperature (°C)	24.1 ± 0.2	27.2 ± 0.3	-8.818	.000**
pH	5.4 ± 0.9	5.7 ± 0.6	-1.888	.062
N (g/kg)	0.2 ± 0 .01	0.2 ± 0.01	5.32	.000**
P (g/kg)	7.9 ± 0.1	7.8 ± 0.1	0.198	.843
K (g/kg)	326.1 ± 14.1	272.5 ± 15.4	2.574	.012*
Ca (g/kg)	614.3 ± 74.3	446.2 ± 42.6	1.963	.053
OM (%)	1.8 ± 0.3	1.0 ± 0.2	2.558	.012*

*,**, significant at P < 0.05 and P< 0.01, respectively.

4.4.3 Relationship of earthworm and environmental factors

Earthworm density in each forest was positively significant correlated with amount of rainfall, relative humidity, and soil moisture, but negatively significant correlated with soil temperature when pool data (Table 4.4). Pool data also showed significant correlation with soil nitrogen and calcium. Edwards and Bohlen (1996) stated that soil moisture can influence the numbers and biomass of earthworms at any given location. Bith *et al.* (2003) found that earthworm density and biomass were significant correlated with soil moisture, C, temperature and pH. Earthworms can make more substantial contributions to the overall recovery of available forms of mineral nitrogen. (Edwards and Bohlen, 1996; Lee, 1985). Lavelle *et al.* (1992) found that the casts of *P. corethrurus* had more than five times the amount of available nitrogen as the surrounding soil. About calcium content, many species of earthworms possess calciferous glands that are involved in the production of calcium carbonate spherules, which may have an important influence on calcium availability in some soils (Piearce, 1972).

Table 4.4 The correlations between earthworm density and environmental factors in dry evergreen forest and dry dipterocarp forest.

Factors	Pearson correlation coefficient		
	Dry evergreen	Dry dipterocarp	Pool data
Rainfall	.482**	.692**	.486**
Relative humidity	.329*	.531**	.249*
Ambien temperature	.140	-.005	.110
Soil moisture	.471**	.374**	.486**
Soil temperature	-.006	-.110	.231*
Soil pH	-.046	.030	.086
N	.009	.009	.259*
P	.051	-.161	-.004
K	.079	.042	.135
Ca	.310*	.129	.317**
OM	.160	.010	.196

* significant at $P < 0.05$; ** = significant at $P < 0.01$,

4.5 Conclusions

Only 259 earthworms of 13 species were found in this study. Nine and eight species were presented in dry evergreen and dry dipterocarp forest respectively. *P. corethrurus* was the dominant earthworm species. More earthworm densities were presented in dry evergreen forest than dry diptercarp forest. High density were presented in rainy season, amounting to the maximum from June to September and then declining from October to November in winter season, and disappeared in summer. Earthworms density were positively significant correlated with rainfall, relative humidity, soil moisture, nitrogen content, and soil calcium whereas negatively significant correlated with soil temperature.

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CHAPTER V

CONCLUSION AND RECOMMENDATION

Earthworm and soil samples were collected from specific earthworm-rich areas indicated by the high amount of litter covers and earthworm casts. These sample data are area-specific, therefore, they are not generalizable to earthworm population and soil type of the whole area.

5.1 Conclusion

Two types of earthworm diversity survey were conducted in SERS. The first study focused on earthworm distribution in many land use types according with level of human disturbance in rainy season, the most populated time of the year. The second study focused deeper into the dynamic of earthworm population in two major SERS, dry evergreen and dry dipterocarp forest throughout the year. From both studies, 21 earthworm species were found. They are list as follows; fourteen species of Megascolecidae (*Amynthas alexandri*, *A. defecta*, *A. sieboldi*-group, *Amynthas* sp. 1, *Amynthas* sp.2, *Amynthas* sp.3, *Amynthas* sp.4, *Metaphire bahli*, *M. houlleti*, *M. peguana*, *M. planata*, *M. posthuma*, and *Polypheretima elongata)*, three species of Moniligastridae (*Drawida beddardi*, *Drawida* sp.1, and *Drawida* sp.2) three species of Octochaetidae (*Dichogaster affinis*, *Di. bolaui*, and *Di. modiglianii*), one species of Glossoscolecidae (*Pontoscolex corethrurus*) and one species of Ocnerodrilidae (*Gordiodrilus elegans*).

For the first study, the earthworms and soil samples were collected in the same 30x30x30 cm^3 sampling sites from four vegetation types (dry evergreen forest, dry dipterocarp forest, forest plantation, and grassland) four agricultural lands (rice paddy, sugarcane plantation, cassava plantation, and mango plantation) and three types of residential areas (household areas, SERS building area, and Silvicultural Research Station area). The digging and hand sorting method was used to collect the earthworms, three times during rainy season (June, August, and October) in 2006. Identification of terrestrial earthworm was based on external and internal morphology. Nineteen species of five families were found in studied areas. *Pontoscolex corethrurus,* the only member of the Glossoscolecidae, had the highest population density followed, by 11 species of Megascolecidae, three species of Moniligastridae, three species of Octochaetidae, and finally, *Gordiodrilus elegans*, the only species of Ocnerodrilidae, was found in only a household area. Most earthworms collected were adults. Highest population densities were found in residential areas followed by agricultural lands and forest types. The earthworm density was highly significant different in October. The highest density was in SERS (611.1 ind/m^2), and the lowest was in DIF (61.1 ind/m^2). The highest species diversity was 11 in SRS but the highest diversity index was 1.71 in rice paddy.

For the second study, four replications of earthworm and soil samples were collected in the same 30x30x30 cm^3 sampling sites from dry evergreen and dry dipterocarp forest, once a month in 2006. Identification of terrestrial earthworms was based on external and internal morphology. Thirteen earthworm species in four families were found in this area, nine species of Megascolecidae, two species of Octochaetidea, one species of Glossoscolecidae, and one Moniligastrid species. The earthworm diversity were not different, nine species in dry evergreen forest and eight species in dry dipterocarp forest. However, earthworm density was significantly higher in dry evergreen forest (46.5 ind/m^2) than dry dipterocarp forest (13.4 ind/m^2). The highest density was found in August (163.9 ind/m^2) in dry evergreen forest, while the highest density (66.7 ind/m^2) of dry dipterocarp forest was found in October. Earthworm number was low in dry season and not present in February and December. Earthworm density was positively correlated with rainfall, relative humidity, soil moisture, nitrogen content and calcium content, but negatively correlated with soil temperature.

5.2 Recommendation

There are a few recommendation for future research and applications of earthworm.

1. Researcher should use molecular technique to identify earthworm along with morphological methods, especially for very small or incomplete earthworm samples.
2. High concentration of alcohol should be added into samples for better and longer preservation of earthworm.
3. Residential earthworms such as *M. posthuma*, *M. peguana*, *M. bahli*, *M. planata* may be used for vermicompost while *M. posthuma*, *M. bahli*, *M. planata*, and *M. houlleti*, found in agricultural areas, may be beneficial for soil quality improvement.

APPENDICES

APPENDIX A

EARTHWORM DESCRIPTION

In this study, earthworm samples identification were performed using the external and internal morphology keys of Gates (1972) and Sims and Easton (1972). However, since the samples in some areas were spares, errors in identification may be occurred. It is, therefore, highly recommended that in order to employ the results of this study effectively, users should study more about other morphology keys.

Twenty one earthworm species in five families were collected in Sakaerat Environmental Research Station and adjacent areas. *Pontoscolex corethrurus* is the only one of **Glossoscolecidae**. **Megascolecidae** thirteen species are in; *Amynthas alexandri*, *A. defecta*, *A. sieboldi*-group, *Amynthas* sp.1, *Amynthas* sp.2, *Amynthas* sp.3, *Amynthas* sp.4, *Metaphire bahli*, *M. houlleti*, *M. peguana*, *M. planata*, *M. posthuma*, and *Polypheretima elongata.* Three species of **Moniligastridae** are *Drawida beddardi*, *Drawida* sp.1, and *Drawida* sp.2. Three species of **Octochaetidae** are *Dichogaster affinis*, *Di. modiglianii*, and *Di. bolaui*. One species of **Ocnerodrilidae** is *Gordiodrilus elegans.* The earthworm characteristics were described as follows.

A.1 Family GLOSSOSCOLECIDAE

1930. Glossoscolecidae, Stephenson, **The Oligochaeta.** p. 884.

1972. Glossoscolecidae, Gates, **Trans. Amer. Phil. Soc.** 62: p. 52.

Setae sigmoid, mostly single-pointed, rarely double-pronged, usually ornamented, with few exceptions 8 per segment. Dorsal pores absent, spermathecal pores rarely present. Clitellum usually beginning behind xiv. Male pores in the clitellar region, usually in the anterior portion of the region; or in front of the clitellum, rarely behind it. Usually one gizzard, rarely several, in front of the testis segments; often one rudimentary gizzard at the hinder end of the oesophagus, gehind the ovarian segment. Meganephridial; rarely two pairs of nephridia per segment. Ectal end of as vas deferens usually simple, often, however, with muscular apparatus (bursa propulsoria or copulatory pouch), rarely with prostatic glands. Penial setae absent; copulatory setae often present.

Genus *Pontoscolex* (Schmarda, 1861)

1900. *Pontoscolex*, Michaelsen, **Das Tierreich.** 10: p. 424.

1930. *Pontoscolex*, Stephenson, **The Oligochaeta.** (Oxford), p. 895.

1972. *Pontoscolex*, Gates, **Trans. Amer. Phil. Soc.** 62: p. 53.

Digestive system, with paired, solid, 'panicled tubular' calciferous glands in vii-ix, each gland with a more or less rudimentary distal appendage and a duct from ventral or median and passing to gut dorsalaterally just in front of a septal insertion, with a well–developed intestinal typhlosole but with out caeca and supra-intestinal glands. Vascular system, with complete dorsal (single), ventral, and subneural trunks, The letter adherent to the parietes and the dorsal trunk markedly moniliform in several preintestinal segments, a supra-esophageal trunk in vi-xiv, paired extra-esophageal trunks (median to the hearts) united on gut at midventral with connectives to supra-esophageal and subneural, hearts of vi-ix lateral, of x, xi. Nephridia, macroic, vesiculate, in intestinal segments holoic, the transversely placed bladders elongately ocarina-shaped and opening to the exterior through short, thick walled and rather conical ducts from the ventral side, anteriorly bladders elongately sausage-shaped and opening to the exterior through terminal ducts. Nephropores, obvious. Pigment, none. Septa, all present at least from v/vi.

1) ***Pontoscolex corethrurus*** (Muller, 1856)

1856. *Lumbricus corethrurus*, Muller, **Abhandl. Naturgesch, Ges. Halle.** 4: p. 26. (Type locality, Itajahy, Brazil).

1916. *Pontoscolex corethrurus*, Stephenson, **Rec. Indian Mus.** 12: p. 349.

1972. *Pontoscolex corethrurus*, Gates, **Trans. Amer. Phil. Soc.** 62: p. 54.

Diagnosis: Sexthecal, pores minute and superficial, at *C* and at or close to vi/vii-viii/ix. Clitellum, saddle-shaped, intersegmental furrows slightly indicated at maximal tumescence in xiv/xv-xxi/xxii. Female pore, on left side in front of xiv/xv. Male pores, lateral to *B* at or near xx/xxi. Setae very closely paired, quincunx arrangement. Calciferous glands 3 pairs in vii-ix. Intestinal caecum, none. Peristomium, flaccid, Color, none.

Description

External characters: Total length 3.4-9.0 mm, width 2.1-4.0 mm, segmental number, 147-280. Prostomium lacking. Sexthecal, pores minute and superficial, at *C* and at or close to vi/vii-viii/ix. Clitellum, saddle-shaped, Dorsal pore absent. Female pore, on left side, a minute transverse slit in or close to *AB* and slightly in front of xiv/xv. Male pores, lateral to *B* (at or near xx/xxi), intersegmental furrows slightly indicated at maximal tumescence. Setae usually present from i-ii in which they are very closely paired, *AB* and *CD* gradually wider from iii, one rank after another becoming more and more irregular until the 'quincunx' arrangement is attained ectally by transverse rows of fine teeth, one or both setae of ventral couples in some of xiv-xxii genital and ornamented ectally with longitudinal rows of gouges Peristomium, flaccid, Live specimens unpigmented, head portion pink to yellowish or light purple, clitellum light pink, body yellowish to light pink.

Internal characters: Septa, v/vi membranous, vi/vii-xiii/xiv thickly muscular and displaced posteriorly, ix/x apparently inserted on parietes over site of intersegmantal furrow x/xi, septum x/xi and next few close together. Intestinal origin xiv or xv. Typhlosole beginning in region of xxi, lamelliform, height greater than width of gut lumen. Seminal vesicles, one pair in xiii, lateromesially flattened. Spermathecae, 3 pairs in vii-ix, each small transparence long, ducts slender, non diverticulum and small ampullar.

Habitats: This species were collected in every sites except in dry dipterocarp forest and sugarcane plantation

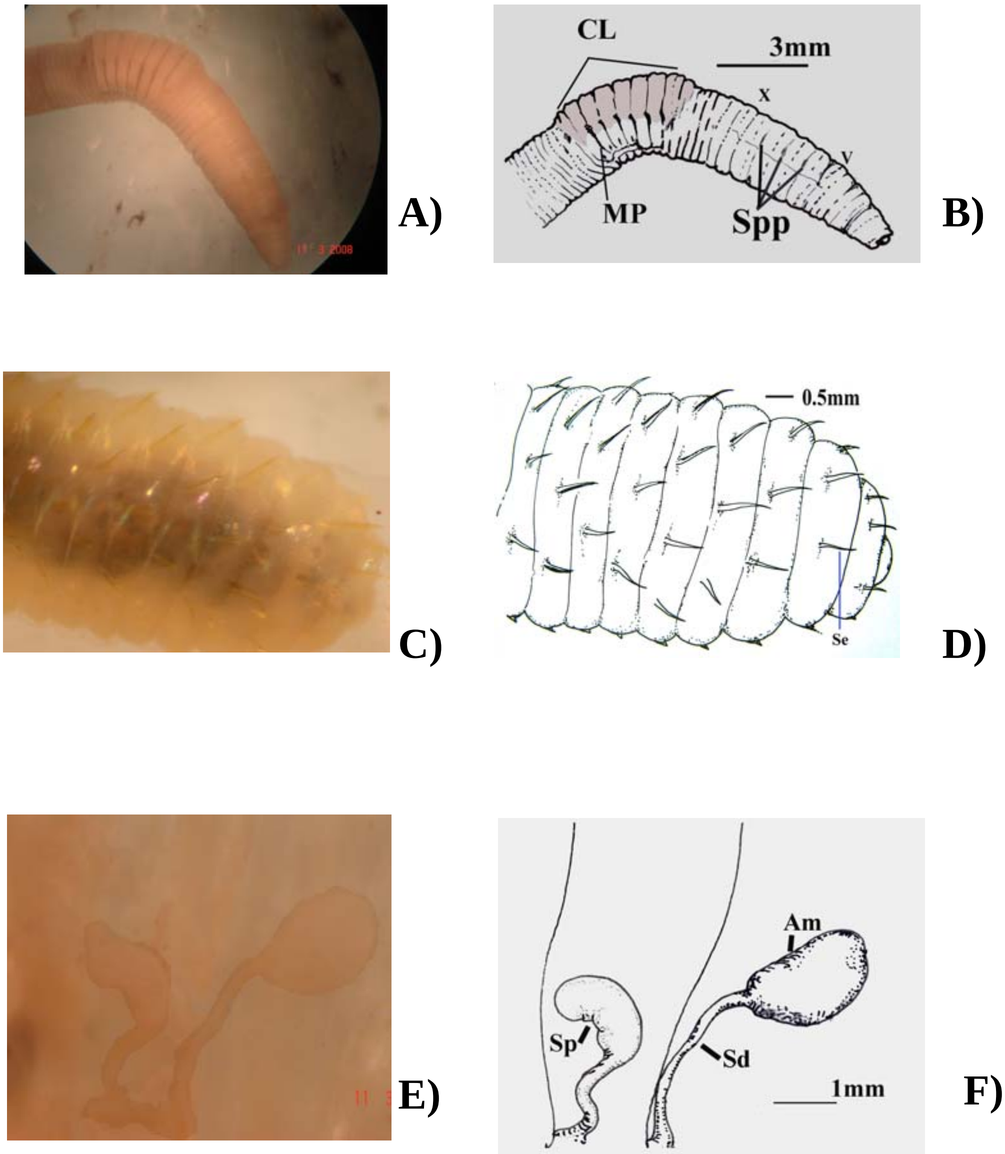


Figure A.1 Photographs and line drawings of *Pontoscolex corethrurus*: A, B, lateral view of clitellum (Cl), male pore (Mp), spermathecal pores (Spp); C, D, ‘quincunx’ arrangement of setae (Se); E, F, (two of three right spermatheca), ampulla (Am), spermathecal duct (Sd), spermatheca (Sp).

A.2 Family MEGASCOLECIDAE

1891. Megascolecidae, Rosa, **Ann. Naturhist. Hofmus.** Wien. 8: p. 379.

1930. Megascolecidae, Stephenson, **The Oligochaeta.** p. 818.

1959. Megascolecidae, Gates, **Bull. Mus. Comp. Zool.** Harvard collage. 112: p. 255.

1972. Megascolecidae, Gates, **Trans. Amer. Phil. Soc.** 62(7): p. 130.

Digestive system, with intestinal origin behind ovarian segment. Vascular system, with a supraesophageal trunk or trunks, extra-esophageals median to the hearts, hearts that are in part latero-esophageal and with the terminal pair behind the last testis segment. Setae sigmoid, simply pointed, either lumbricine or perichaetine in arrangement. Clitellum beginning with or in front of segment xv. One pair of male pores, usually on either xvii or xviii, seldom on xix. Female pores paired, or a single median pore, with few exceptions on xiv. An oesophageal gizzard usually present. Two pairs of testes in segments x and xi, or one pair only, in x or xi. One or two pairs of prostates; prostates rarely absent. One pair of ovaries in xiii.

Megascolecidae is a large family of earthworms which has native representatives in Australia, New Zealand, Southeast and East Asia, and North America**.** Similar genera include *Amynthas*, *Archipheretima*, *Duplodicodrilus*, *Metaphire*, *Metapheretima*, *Pithemera*, and *Polypheretima*. In combination, these ‘pheretimoid’ genera have about 1,000 species making them an important ecological and taxonomic group of Oriental species. Sims and Easton (1972) divided the genus *Pheretima* into eight genera: *Archipheretima*, *Pithemera*, *Ephemitra*, *Metapheretima*, *Planapheretima*, *Amynthas*, *Metaphire*, and *Pheretima.*

Genus *Amynthas* (Kinberg, 1867)

1895. *Perichaeta*, Beddard, **A monograph of the order Oligochaeta.** p. 388.

1972. *Amynthas*, Sims and Easton, **Biol. J. Linn. Soc.** 4: p. 211.

2003. *Amynthas*, Blakemore, **Org. Divers. Evol.** 3(3): p. 3.

Megascolecidae with cylindrical bodies of varying length. Setae numerous, regularly arranged around each segment. Clitellum annular, xiv-xvi, rarely begining on xiii. Male pores paired, discharging directly onto the surface of xviii. Female pore single, rarely paired, xiv. Spermathecal pores small or large, usually paired but occasionally numerous or single between iv/v and viii/ix. Gizzard between septa vii/viii and ix/x. Oesophageal pouch absent. Intestinal caeca present originating in xxvii. Testes holandric or metandric. Prostatic glands racemose. Copulatory pouches absent. Ovaries paired in xiii. Spermathecae usually paired, rarely multiple or single. Meronephridial, nephridial layer rarely present on spermathecal ducts.

2) *Amynthas alexandri* (Beddard, 1901)

1901. *Amynthas alexandri*, Beddard, **Proc. Zool. Soc. London.** 1900: p. 988.

(Type locality, supposedly Calcutta. Type, in the British Mus.)

1972. *Pheretima alexandri*, Gates, **Trans. Amer. Phil. Soc.** 62(7): p. 155.

Amynthas alexandri, Sims and Easton, **Biol. J. Linn. Soc.** 4: p. 234.

Diagnosis: Spermathecal pores 4 pairs in v/vi-viii/ix, ventro-lateral. Clitellum annular in xiv-xvi. Female pore mid-ventral in xiv. Male pores paired in xviii. Genital marking absent. Holandric. Seminal vesicles paired large, in xi and xii. Prostate glands, large in xvi-xxii.

Description

External characters: Total length 113-165 mm by 4.8-5 mm, segments 78-126. Octothecal, pores minute, superficial, more than 1/3 C apart, at v/vi-viii/ix. Male pores, in xviii, minute, superficial, each in rather circular area between arms of a U-shaped ridge that is open mesially. Female pore, median. (Genital marking, none) Clitellum, setae non, xiv-xvi, occasionally reaching into xvii. Setae, enlarged in ii-ix, 47-60/x, 62-70/xx, between male pore, 18. First dorsal pore, at xii/xiii. Prostomium, rudimentary (in two small parts distinguished from adjacent marginal lobes of peristomium only by presence of pigment). Color, in dorsum, pinkish to deeper red, yellowish to dark brown, slate, sometimes lacking in very narrow stripes at segmental equators.

Internal characters: Septa, viii/ix-ix/x aborted, vi/vii-vii/viii (and sometimes v/vi) much thickened, x/xi-xi/xii. Spermathecae, rather small, duct markedly narrowed in the parietes, diverticulum from median face of duct at parietes, longer than main axis, with slender stalk and a variously looped wider portion entally. Hearts, in viii unaborted dorsal portions to gizzard, in ix. Holandric. Testis sacs, paired and vertical or unpaired and horseshoe-shaped, hearts of x-xi and vesicles of xi included. Seminal vesicles, large, in xi-xii. Intestinal origin, in xv (sometimes in xvi). Typhlosole, lamelliform, ending in region of x circumstance. Caeca, simple, in xxvii-xx. Prostates, large, in xvi-xxii, duct muscular and variously looped or coiled.

Habitats: This earthworm species was found in several habitats higher in grassland, sugarcane plantation and Sakaerat Silvicultural Research Station.

Dynamic: This earthworm was common from August to October.

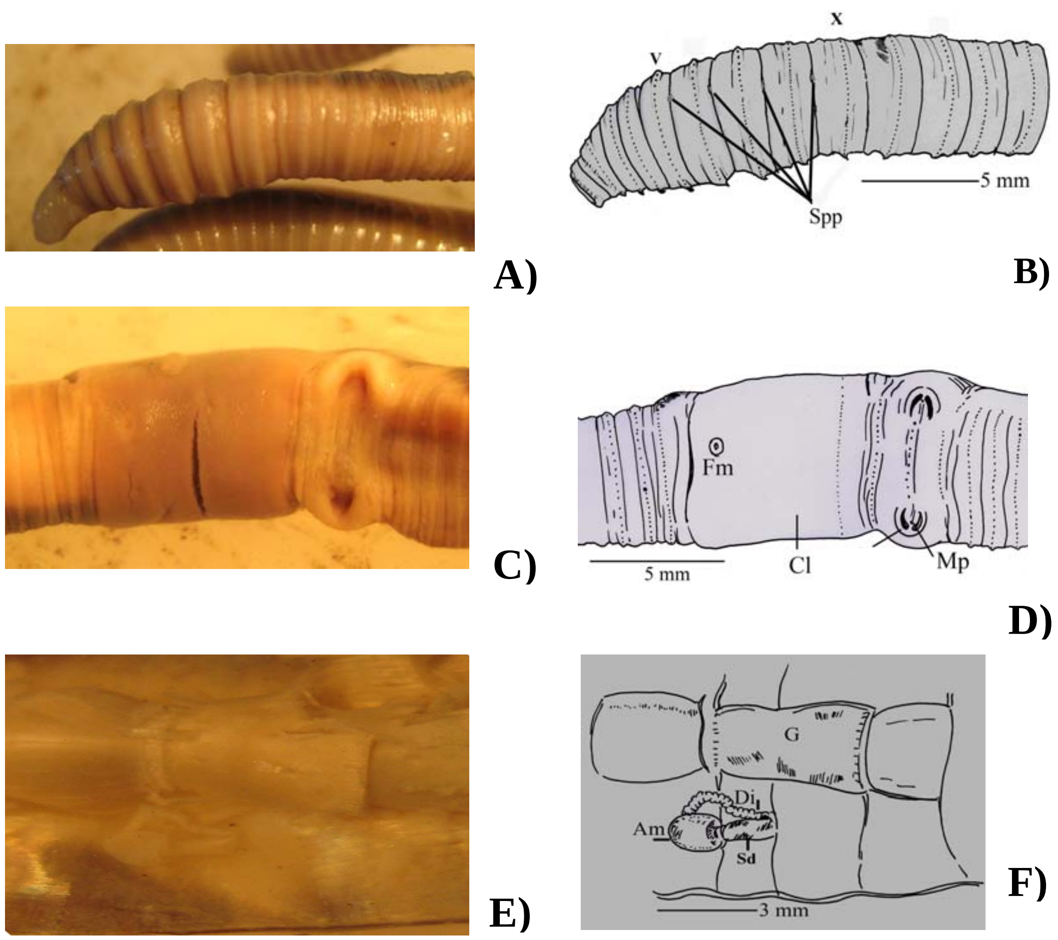


Figure A.2 Photographs and line drawings of *Amynthas alexandri*: A, B, lateral view of spermathecal pores (Spp); C, D, female pore (Fm), male pore (Mp), clitellum (Cl); E, F, (one of four left spermatheca), ampulla (Am), spermathecal duct (Sd), diverticulum (Di).

3) *Amynthas* sp.1

Diagnosis: Spermathecal pores 4 pairs in v/vi/vii/viii/ix, ventral *A/B* a part. Clitellum in xiv-xvi, smooth annular. Female pore mid-ventral in xiv. Male pores paired in xviii. Genital marking large, 2 pairs in xviii/xix, xix/xx. Holandric. Seminal vesicles paired big wide dorsal lobe in xi-xii. Prostate single cordate mass in xviii.

Description

External characters: Body cylindrical throughout. Total length 170-256 mm by 8-10 mm, at segment x, 7.5-9.5 mm at clitellum, segment number 112-154. Prostomium prolobic, with tongue open. Setae perichaetine regularly distributed around segmental equetors, 14-24 at viii, 8-14 between spermathecal pores. Spermathecal pores 4 pairs, small on little nubs in v/vi-viii/ix. First dorsal pore xi/xii. Clitellum xiv-xvi, annular, smooth, setae invisible externally. Female pore single at mid-ventral in xiv. Male pore widely spaced, superficial on elliltical hard porophores surrounded by low ring collar. Huge genital marking in xviii/xix, xix/xx. Lateral, more than 1/4 circumference apart. Setae between male pores present.

Internal characters: Septa viii/ix/x, absent, v/vi/vii/viii, x/xi/xii thick other thin. Big collar glands in ix on oesophagus. Hearts in segments x-xiii. Holandric, testis sacs low, joined ventrally. Seminal vesicle xi, xii, xii huge size. Spermatheca on septa vi-ix, ental, sperm in planar chamber loops. Intestinal originating in xv. Dorsal lobes present prostate, single cordate mass, duct muscular, mostly straight sessile. Genital marking glands discs in xix-xx. Intestinal caecum simple smooth originating in xxvii extending anteriorly to xx.

Habitats and dynamic: One specimen was collected in grassland in August.

Remark: This earthworm species was keyed to *Amynthas diffringer*-group

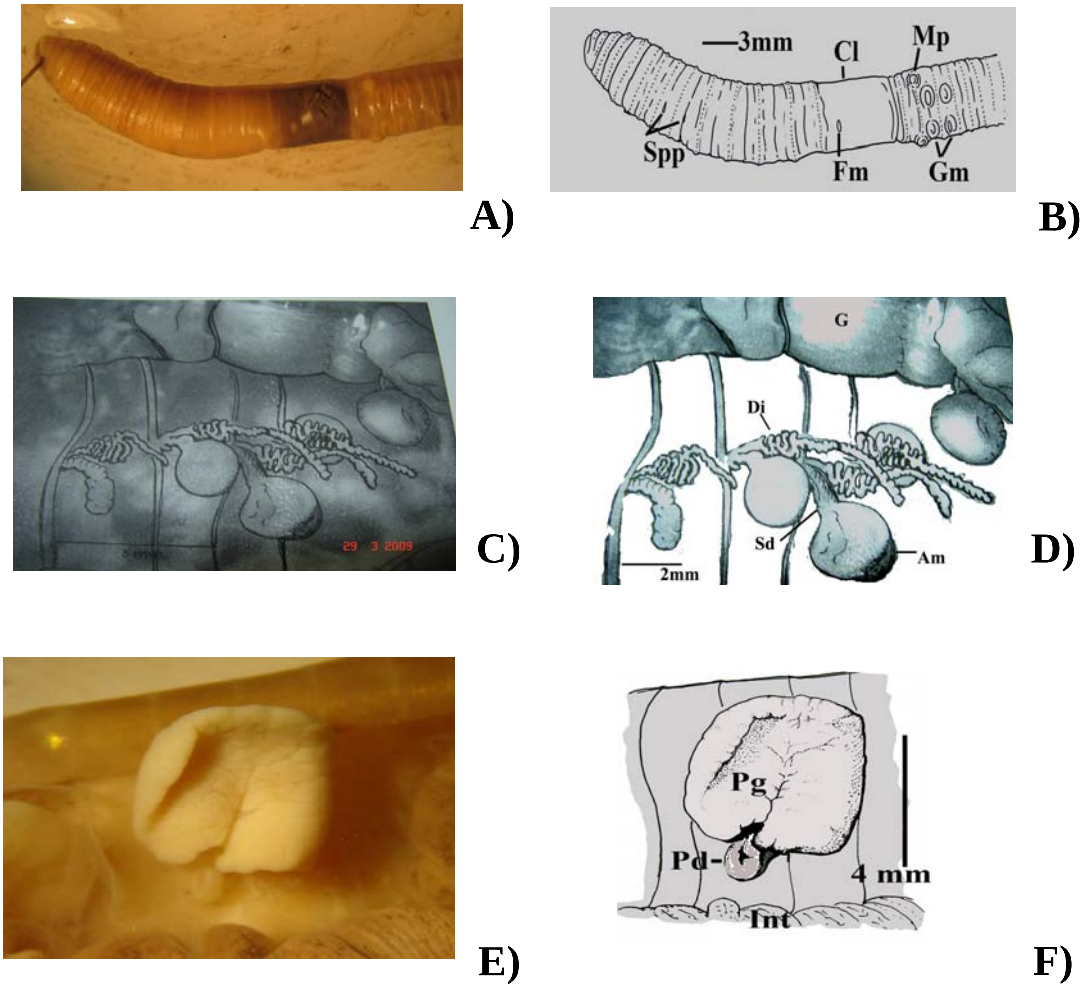


Figure A.3 Photographs and line drawings of *Amynthas* sp.1: A, B, ventral view of anterior portion, spermathecal pores (Spp), female pore (Fm), male pore (Mp), clitellum (Cl), genital marking (Gm); C, D, left spermatheca, ampulla (Am), spermathecal duct: (Sd), diverticulum (Di); E, F, right prostate, prostate gland (Pg), prostate duct (Pd), intestinal (Int).

4) *Amynthas defecta*

1972. *Pheretima defecta*, Gates, **Trans. Amer. Phil. Soc.** 62(7): p. 189.

Diagnosis: Large body, cylindrical throughout. Prostomium lacking, with tongue open. Spermathecal pores lateral in v/vi/vii/viii. First dorsal pore xii/xiii. Clitellum annular smooth in xiv-xvi; setae invisible externally. Female pore mid-ventral in xiv. male pore on body surface of segment xviii, rather than deep in pocket within the body, associated with cluster of small genital markings on segment xviii. Color bluish to dark.

Description

External characters: Total length 120-170 mm by 5-8 mm. Segments, 114-138. Setae regularly distributed around segmental equators, enlarged at ventrum, 116-120 in viii. Setae between spermathecal pores 18-22. First dosal pore in xii/xiii. Clitellum xiv-xvi, annular, smooth, setae non. Spermathecal pores 3 pairs on v/vi/vii/viii. Lateral, more than 1/3 *C* apart. Female pore single, mid-ventral in xiv. Male pore small associated large bump at xviii.

Internal characters: Septa v/vi/vii slightly thick, viii/ix-xi/xii aborted. Gizzards viii-ix. Intestinal origin in xv. Spermathecae, 3 pairs, vi-viii, ampulla pear shaped. Duct shorter than ampulla, diverticulum 2-3 folds, stalk tubular. Intestinal caecum manicated, originating in xxvii-xxii. Typhlosole, present. Last hearts xiv. Holandric. Testis sacs, paired, ventrally connected in x, xi. Seminal vesicles large in xi-xii. Prostate glands large, duct with long muscular tubular open directly to male pore externally in xviii.

Habitats and dynamic: Two specimens were collected in dry evergreen forest in January.

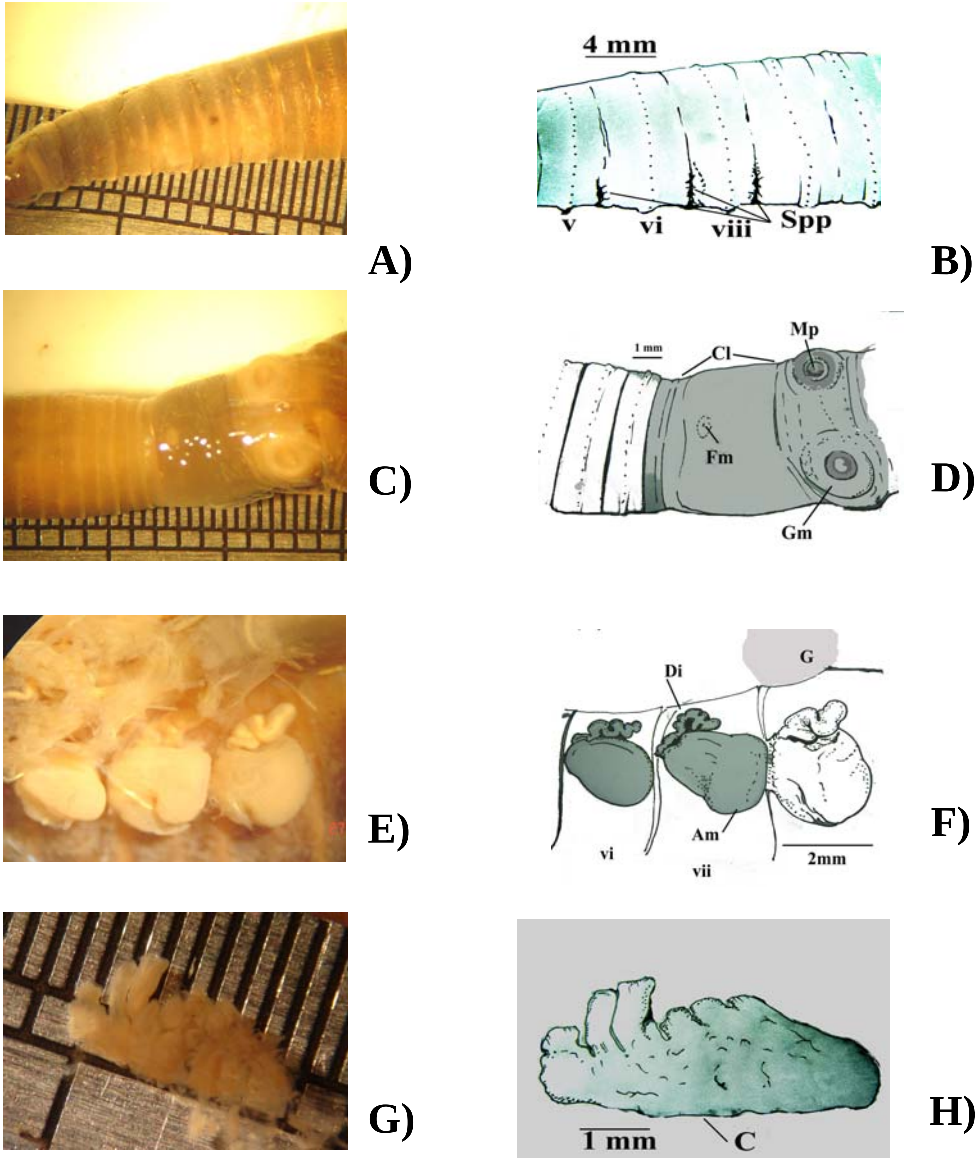


Figure A.4 Photographs and line drawings of *Amynthas defecta*: A, B, lateral view of anterior portion, spermathecal pores (Spp); C, D, clitellum region,female pore (Fm), male pore (Mp), clitellum (Cl), genital marking (Gm); E, F, left spermatheca, ampulla (Am), diverticulum (Di); G, H, left manicate caecum (C).

5) *Amynthas sieboldi* - group

1972. *Amynthas sieboldi*, Sims and Easton, **Biol. J. Linn. Soc.** 4: p. 213.

2003. *Amynthas gracilis*, Blakemore, **Org. Divers. Evol.** 3(3): p. 34.

Diagnosis: Earthworm with medium size, cylindrical throughout. Prostomium epilobic, with tongue open. Spermathecal pores lateral in vi/vii/viii/ix. First dorsal pore xii/xiii. Clitellum annular xiv-xvi; setae invisible externally. Female pore mid-ventral in xiv. Male pores lacking in side large bump in xviii.

Discription

External characters: Total length 95-112 mm by 3-4.2 mm, 4.2 mm at viii, 3.5 at clitellum, 4 mm at xxx. Segments 83-94. Setae regularly distributed around segmental equators, 58 at viii, 42 at xx, 44 at xxx. Between spermathecal pores 10. First dorsal pore in xii/xiii. Clitellum xiv-xvi, annular, smooth, setae none. Spermathecal pores 3 pairs on vi/vii/viii/ix. Lateral, more than 1/3 *C* apart. Female pore single, mid-ventral in xiv. Male pores lacking associated large bump genital markings. Color, brown to dark-brown.

Internal characters: Septa vi/vii/viii thickly muscular, viii/ix/x aborted, x/xi-xiv thinly muscular. Gizzards viii-x. Intestinal origin in xvi. Spermathecae, 3 pairs vii-ix, ampulla warty spherical, duct short, diverticulum ovate, stalk muscular. Intestinal caecum simple, originating in xxvii extending enteriorly to xxii. Last oesophageal hearts in xiv. Testis, Holandric. Testis sacs, paired, ventrally connected in x, xi. Seminal vesicles large in xi-xii with dorsal lobe. Prostate glands large in xviii, ducts thick, muscular.

Habitat and dynamics: Three specimens were collected in dry dipterocarp forest in September.

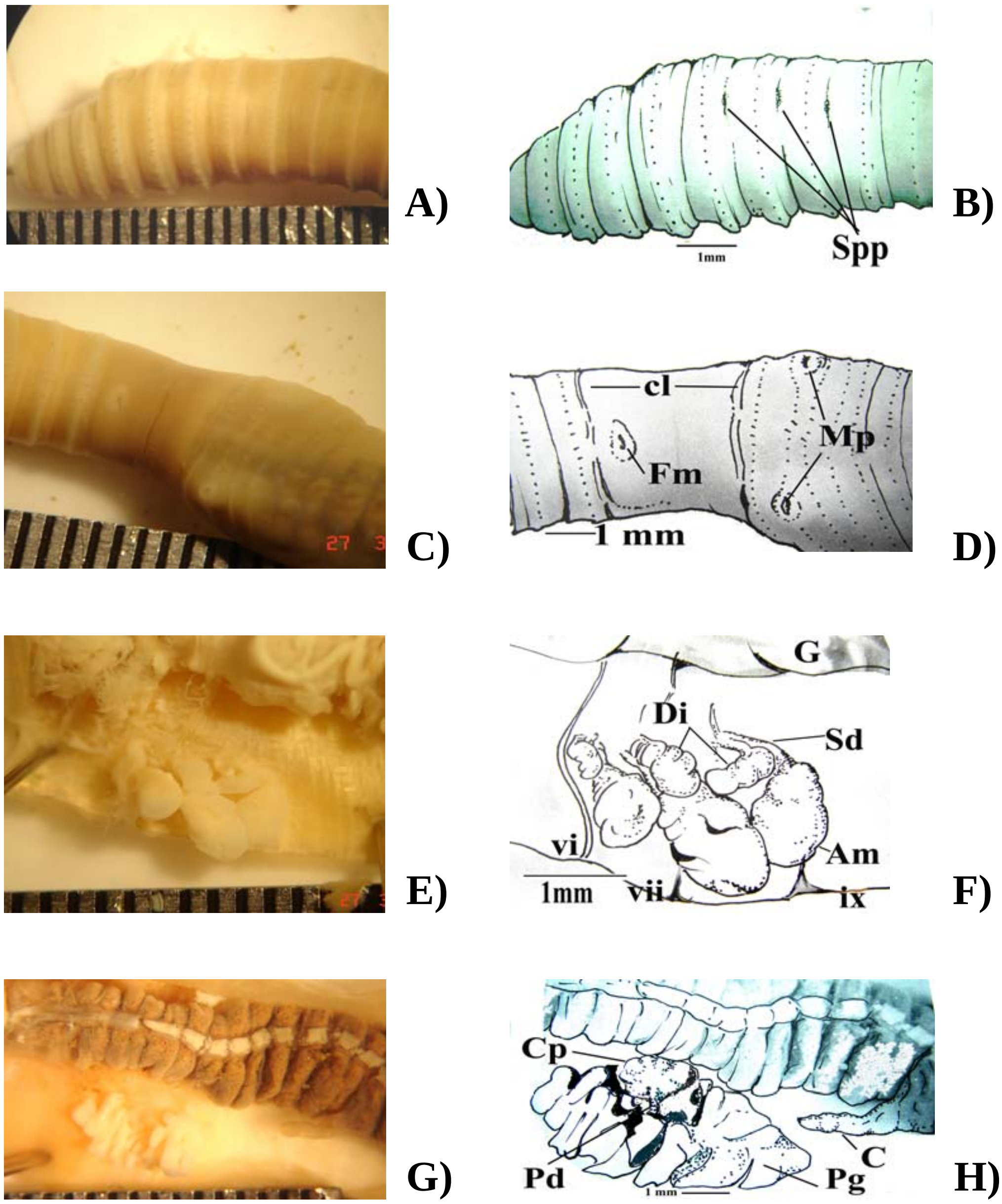


Figure A.5 Photographs and line drawings of *Amynthas sieboldi* -group: A, B, lateral view of anterior portion, spermathecal pores (Spp); C, D, Clitellum region, female pore (Fm), male pore (Mp), clitellum (Cl); E, F, left spermatheca, ampulla (Am), diverticulum (Di), spermathecal duct (Sd); G, H, left prostate, prostate gland (Pg), prostate duct (Pd), copulatory pouch (Cp), left caecum (C).

6) *Amynthas* sp.2

Diagnosis: Spermathecal pores vi/vii/viii. Hearts 10-13. Genital gland, non. Prostates ducts muscular, Prostate gland 3-4 main block lobes. Male pores are large disc (superficial). There must be two genital papillae (penial setae) along the circumference of large disc.

Description

External characters: Total length 70-120 mm by 3.5-6 mm segment number 64-78. Prostomium lacking. Setae regularly distributed around segmental 47-58. First dorsal pore in xii/xiii. Clitellum xiv-xvi, annular, smooth, setae none. Spermathecal pores 2 pairs on vi/vii/viii. Lateral, more than 1/3 *C* apart. Female pore single, mid-ventral in xiv. Male pores are large disc (superficial). There must be two genital papillae (penial setae) along the circumference of large disc.

Internal characters: Septa vi/vii/viii muscular, viii/ix/x absent, x/xii-xiii/xiv thinly; gizzard oval ball in viii. Pairs spermathecae in vii-viii. Intestinal origin xv; typhlosole unrecognised. Holandric, testes sac in x and xi. Seminal vesicle, large in xi, xii, which small inform dorsal lobe. Intestinal caeca simple, originating in xxvii extending anteriorly to xxv. Oesophageal hearts in x-xiii , of x occasionally lacking, xxi-xiii paired. Prostates U shaped large. Also, in the exit of prostatic duct there is racemose with 3-4 main block lobes.

Remark: No photograph of this species is displayed because only one specimen was collected in dry evergreen forest in August, and it was already decomposed. This earthworm was keyed to *Amynthas tokioensis*-group.

7) *Amynthas* sp.3

Diagnosis: Large pigment earthworm with cluster genital marking. Spermathecal pores, small in vi/vii/viii/ix. Spermathecae large, fold diverticulums mostly (5 of 6) wholly or partly stuck to ampulla duct. Testes sacs, annular, all-inclusive dorsal blood vessel, hearts, and seminal vesicles. Intestinal caecum, simple in xv/xvi.

Description

External characters: Total length 70-285 mm by 3-12 mm. segmental number 124-138. Prostomium prolobic. Setae regularly distributed around segmental equators, 64-74 in viii, between spermathecal pores 18-24. First dorsal pore in xii/xiii. Clitellum xiv-xvi, annular, smooth, setae non. Spermathecal pores 3 pairs on vi/vii/viii/ix. Lateral, more than 1/3 *C* apart. Female pore single, mid-ventral in xiv. Male pore, superficial with associated cluster genital markings. Genital marking paired in xvii-xix. Color, brown to dark-brown.

Internal characters: Septa vi/vii/viii muscular, viii/ix/x absent, x/xii-xiii/xiv thinly muscular; gizzard viii-x. Pairs spermathecae in vi-viii, ampulla pear shaped, ducts shorter than ampulla, diverticulum small ovate, stalk slender. Intestinal origin xv; typhlosole lacking. Intestinal caeca simple, originating in xxvii, extending anteriorly to xxiv. Oesophageal hearts three pairs in xi-xiii. Holandric, testes sac in x and xi. Seminal vesicle acinous, large in xi, xii, which small inform dorsal lobe. Prostates small in xviii, three main lobes, ducts muscular.

Habitat and dynamic: This species were collected in dry dipterocarp forest and rice paddy. They presented during June and October, higher in October.

Remark: This earthworm species was keyed to *Amynthas seiboldi*-group

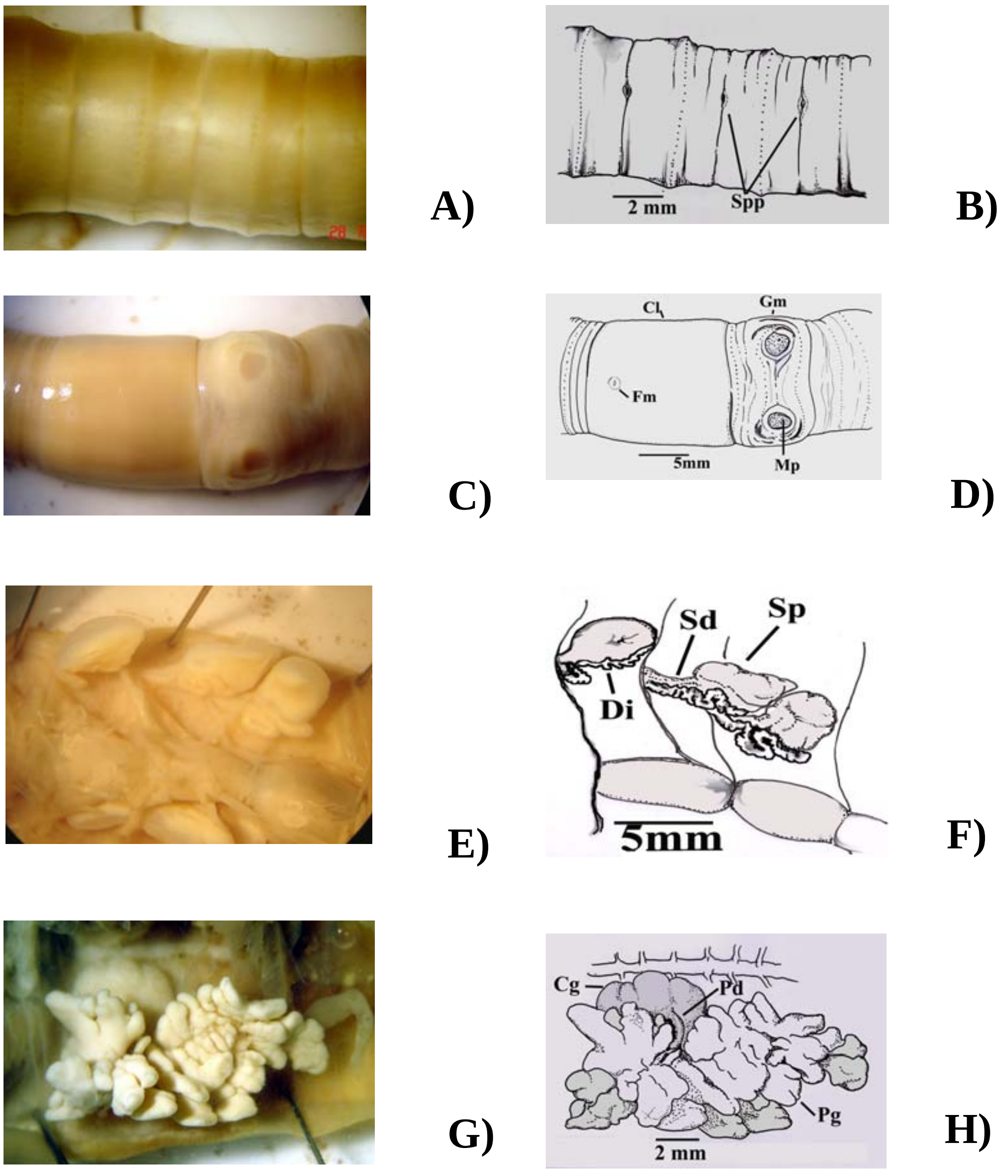


Figure A.6 Photographs and line drawings of *Amynthas* sp.3: A, B, lateral view of anterior portion, spermathecal pores (Spp); C, D, clitellum region, female pore (Fm), male pore (Mp), clitellum (Cl), genital markings (Gm); E, F, right spermatheca (Sp), ampulla (Am), diverticulum (Di), spermathecal duct (Sd); G, H, left prostate, prostate gland (Pg), prostate duct (Pd), copulatory gland (Cg).

8) *Amynthas* sp.4

Diagnosis: Large worm, dark pigment. Spermathecal pores minute in furrows in vi/vii/viii/ix. Spermathecae large, fold diverticulums mostly (5 of 6) wholly or partly stuck to ampulla duct. Testes sacs, annular, all-inclusive dorsal blood vessel, hearts, and seminal vesicles. Intestinal caecum, simple in xxv/xvi.

Description

External characters: Total length 162-270 mm by 3.5-6 mm. segment number 164-178. Setae regularly distributed around segmental equators, 68-72 in viii, between spermathecal pores 38-42. First dorsal pore in xii/xiii. Clitellum xiv-xvi, annular, smooth, setae non. Spermathecal pores 3 pairs on vi/vii/viii/ix. Lateral, more than 1/3 *C* apart. Female pore single, mid-ventral in xiv. Male pore lacking associated genital markings. Genital marking paired, large bumps, widely horseshoes'-like in xviii. Color, brown to dark-brown.

Internal characters: Septa v/vi-vii/viii thick, viii/ix/x absent, x/xi/xii muscular, but thin, other membranous. Intestinal originating in ½ xv, intestinal caecum simple large slender. Last hearts in xiii. Big gland collar in ix, paired in v. Holandric, annular all-encoupassing testes sacs through dorsal blood vessel, hearts, and seminal vesicles. Seminal vesicles large, wide dorsal lobes. Prostates large in xvi-xx, multilobed but not deeply so. Duct slender, muscular, one or two bends. No gland at male field. Spermathecae large in vii/viii/ix. Diverticulum glued to duct, ampullar over whole length, and iridescent area on every spermatheca. GM gland above spermathecal duct level in v-vii on right side, vi, viii on left side.

Habitat and dynamic: This species were collected in both dry evergreen forest and dry dipterocarp forest in October.

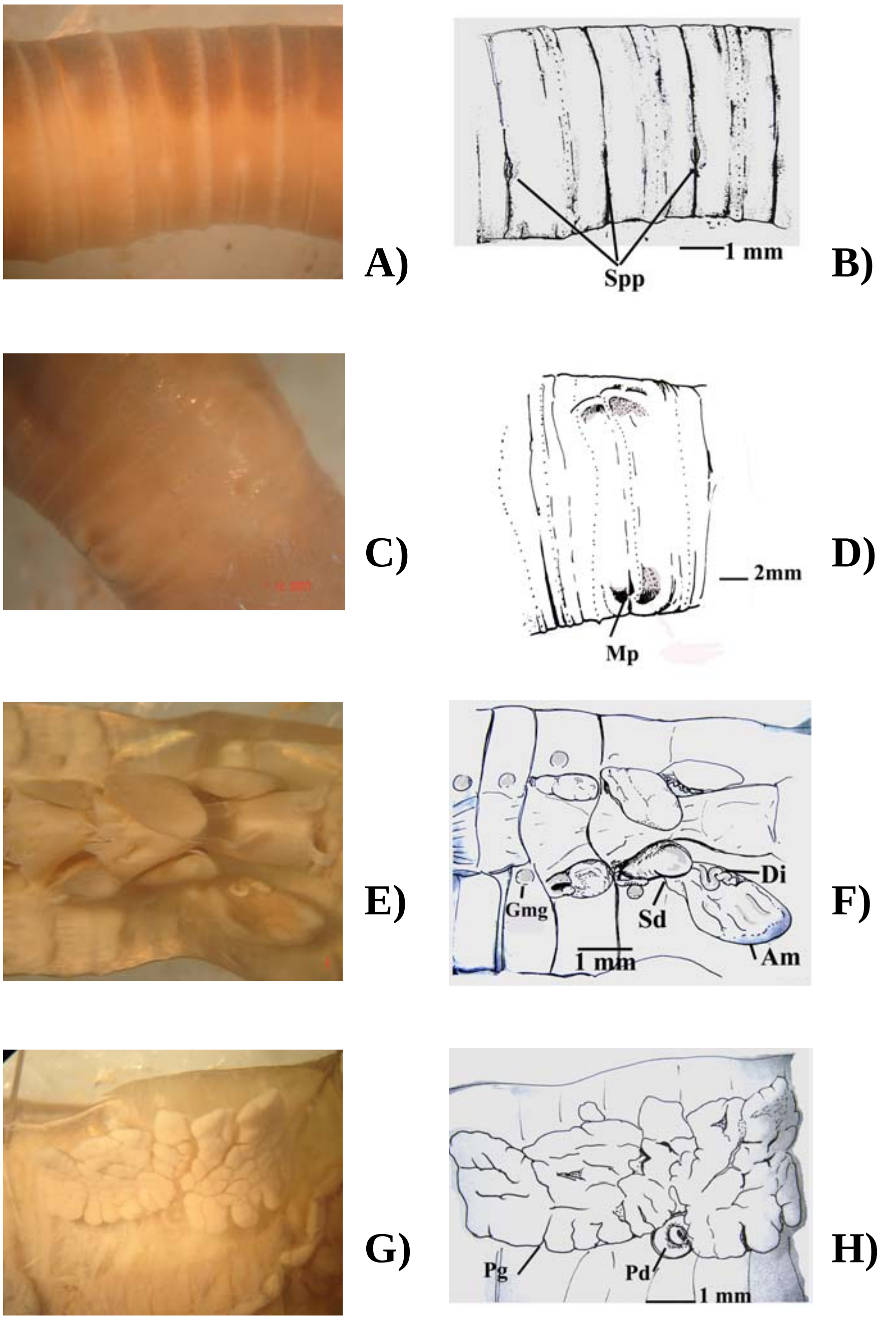


Figure A.7 Photographs and line drawings of *Amynthas* sp.4: A, B, lateral view of anterior portion, spermathecal pores (Spp); C, D, male pores region, male pore (Mp); E, F, spermatheca (Sp), ampulla (Am), diverticulum (Di), spermathecal duct (Sd), genital marking gland (Gmg); G, H, prostate, prostate gland (Pg), prostate duct (Pd).

Genus *Metaphire*

1895. *Perichaeta*, Beddard, **A monograph of the order Oligochaeta.** p. 388.

1900. *Pheretima*, Michaelsen, **Das Tierreich.** 10: p. 234.

1972. *Metaphire*, Sims and Easton, **Biol. J. Linn. Soc.** 4: p. 215.

2004. *Metaphire*, Tsai, Tsai, and Shen, **J. Nat. Hist.** 38: p. 877.

Megascolecidae with cylindrical bodies. Setae numerous, regularly arranged around each segment. Clitellum annular, xiv-xvi. Male pores paired within copulatory pouches on xviii, rarely xix or xx. Female pores single, rarely paired. Spermathecal pores usually large transverse slits, seldom small, paired, occasionally single or multiple, between iv/v and ix/x. Gizzards between septa vii/viii and ix/x. Oesophageal pouches absent. Intestinal caeca present, Originating in or near xxvii. Testes holandric, rarely proandric or metandric. Prostatic glands racemose. Copulatory pouches present, often with stalked glands, secretory diverticula absent. Ovaies paired xiii. Spermathecae paired, rarely single or numerouse. Meronephridial, nephridia absent from the spermathecal ducts.

9) *Metapire bahli* (Sims and Easton, 1972)

1939. *Pheretima peguana*, Kirtisinghe, **Spolia Zeylanica.** 21: p. 89.

(Histology of gut of specimens from Colombo, Ceylon).

1972. *Pheretima bahli* , Gates, **Trans. Amer. Phil. Soc.** 62(7): p. 209.

Metaphire bahli, Sims and Easton, **Biol. J. Linn. Soc.** 4: p. 241.

Diagnosis: Megascolecidae with cylindrical bodies of varying length, size 63-112 by 3.7-5 mm Segments, 83-116. Prostomium, prolobous. Setae numerous, regularly arranged around each segment, 36-62. First dorsal pore, at xii/xiii. Color, only in dorsum, yellowish. Spermathecal pores, fairly widely separated but less than 1/3 *C* apart at vi/vii-viii/xix. Clitellum annular smooth, xiv-xvi. Female pore, median. Male pore paired on each genital markings with small conical bump on inner ridge, invaginate in xviii. Genital markings, large.

Description

External characters: Total length 63-112 mm by 3.7-5 mm with 83-116 segments. Prostomium prolobous. Setae 30 in iii, 49 in viii, 63 in xii, between spermathecal pores 18-30 in v-vii. First dorsal pore in xii/xiii. Clitellum xiv-xvi, annular, smooth, setae non. Spermathecal pores 3 pairs on vi/vii-ix. Lateral, less than 1/3 *C* apart. Female pore single, midventral in xiv. Male pores, each at tip of a small, conical, penial body protuberant messily from lateral wall of deep parietal invagination the lumen of which is about twice as wide as the external aperture. Genital markings, invaginate, each on posterior or anterior face of aperture, two pairs, at xvii/xviii and xviii/xix.

Internal characters: Septa, v/vi/vii/viii muscular, viii/ix-x/xi aborted, xi/xii-xii/xiii thick. Spermathecae, small, seminal chamber shortly ovoidal to ellipsoidal. Seminal vesicles, large, especially those of xi that may reach forward to vii/viii. Holandric.testis sac small, ventral both in 11. Intestinal origin, in xv. Caeca, simple, in xxvii-xxii. Typhlosole, present. Prostates, in xvii-xxi, ducts 3-4 mm long, each in a U-shaped loop with the ectal limb thicker. GM glands, sausage-shaped or ellipsoidal.

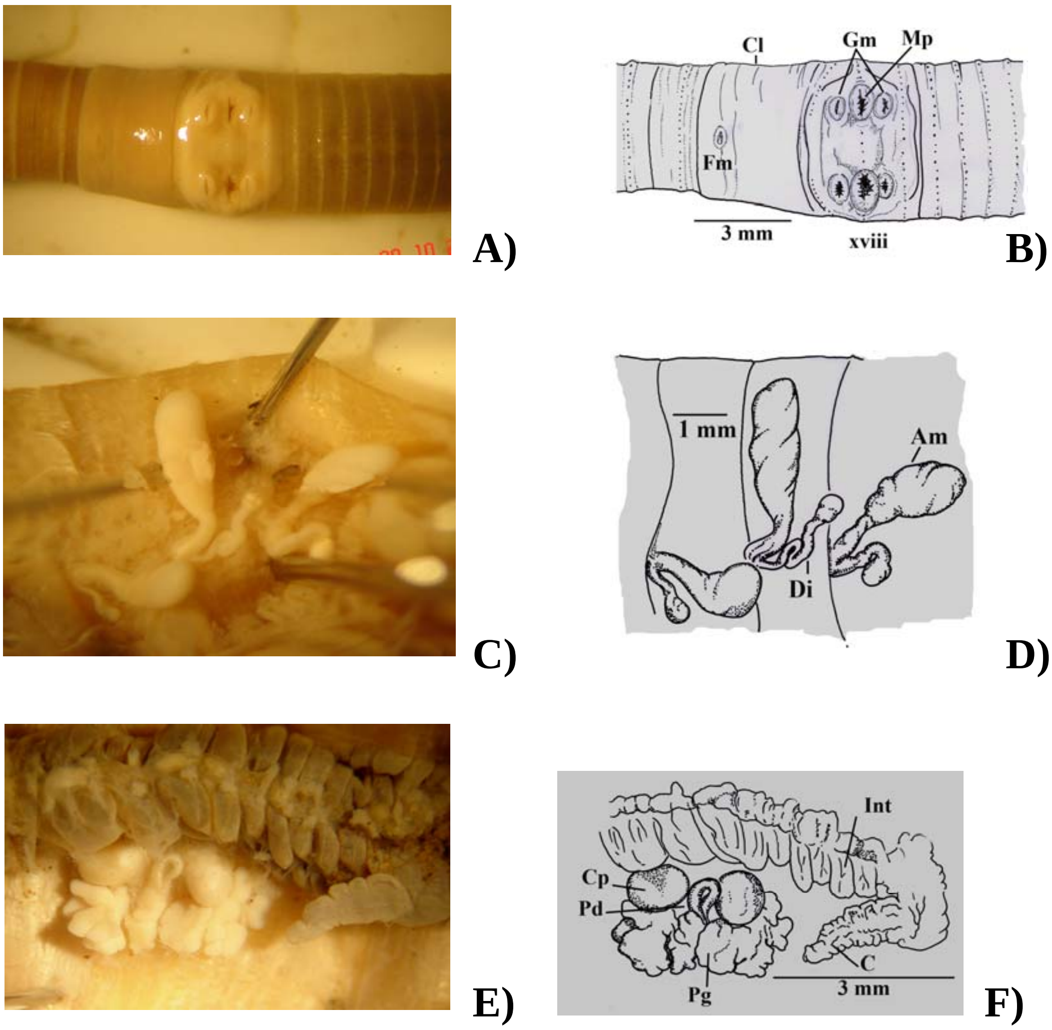


Figure A.8 Photographs and line drawings of *Metapire bahli*: A, B, ventral view of clitellum region, female pore (Fm), male pore (Mp), clitellum (Cl), genital markings (Gm); C, D, right spermatheca (Sp), ampulla (Am), diverticulum (Di); E, F, left prostate region, prostate gland (Pg), prostate duct (Pd), copulatory pouch (Cp), caecum (C), intestine (Int).

10) *Metaphire houlleti* (Perrier, 1872)

1972. *Metaphire houlleti*, Sims and Easton, **Biol. J. Linn. Soc.** 4: p. 217.

Diagnosis: Dark purple-brown dorsal earthworms. Sexthecal, primary pores minute and within parietal invaginations opening through transverse slits somewhat less than ½ C apart at 6/7-8/9. Male pores, in xviii, minute, each on a penial body within a copulatory chamber opening to exterior through an equatorial aperture. Female pore, median. Clitellum, xiv-xvi.

Description

External characters: Total length 53-135 mm by 3-4 mm, 132 segments. Prostomium zygololobic. Setae 64-68 in viii, between spermathecal pores 14-20. First dorsal pore in xii/xiii. Clitellum xiv-xvi, annular, smooth, setae non. Spermathecal pores 3 pairs on vi/vii-ix, thick lips. Lateral, more than 1/3 *C* apart. Female pore single, midventral in xiv. Male pore paired in xviii, ventro-lateral, Setae between male pores present (14-16). No genital marking.

Internal characters: Septa, viii/ix-ix/x aborted, v/vi-vii/viii thickened. Hearts, of viii with aborted dorsal portions to gizzard, of ix lateral but usually aborted on one side, in x. Spermathecae, duct ectal to diverticular junction with narrow lumen that opens into a parietal invagination without externally recognizable demarcation from the duct itself, diverticulum with short, slender stalk and wider, elongate, seminal chamber that is variously looped. Holandric. Testis sacs ventral united. Semial vesicles very small with dorsal lobe. Intestinal origin, in xv. Typhlosole, present. GM glands, long stalked, usually coelomic but sometimes buried in parietes. Prostates large duct, big loop, muscular, to dorsal end an oval. Intestinal caecum simple, slender in xxvii-xxiii.

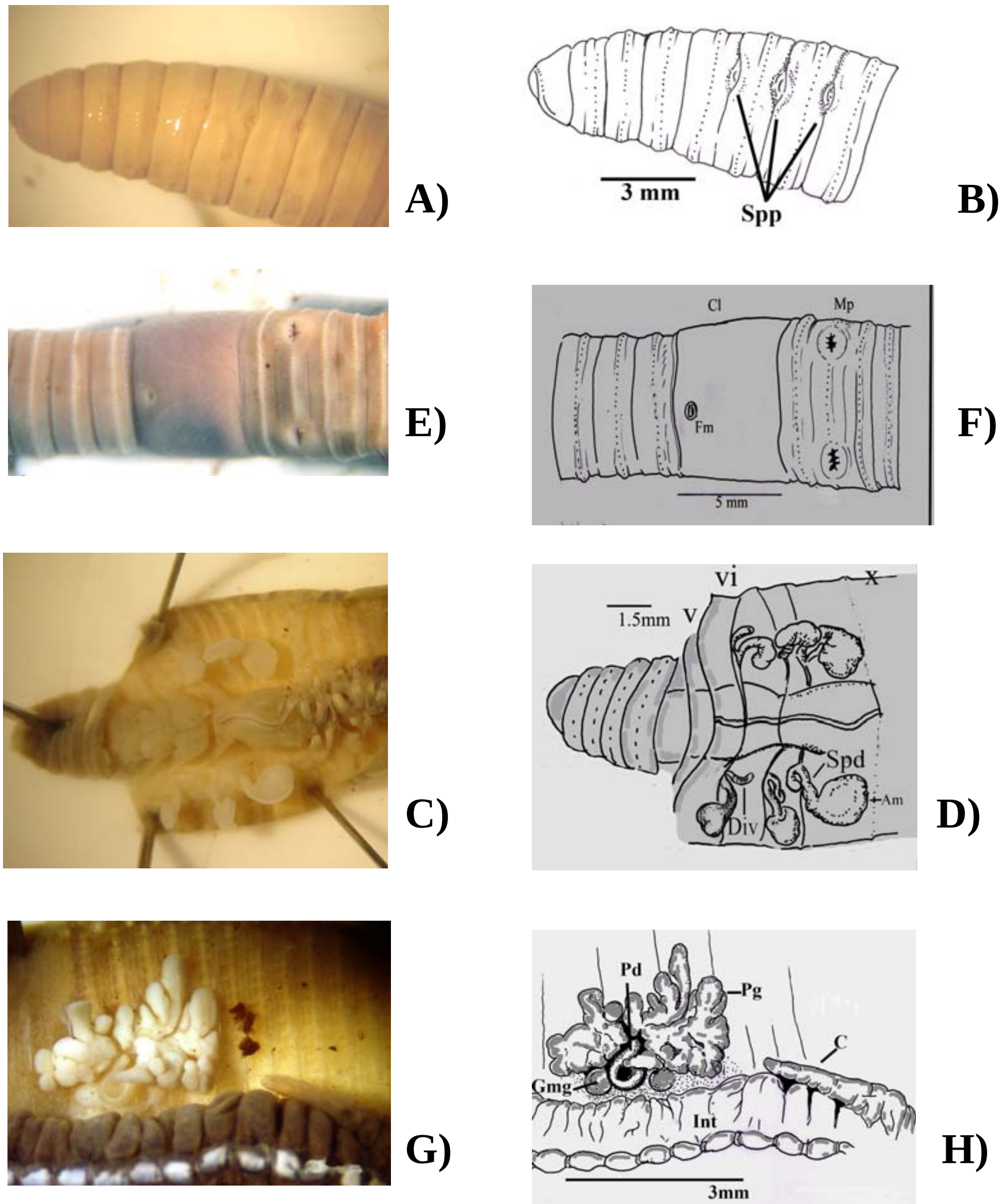


Figure A.9 Photographs and line drawings of *Metaphire houlleti*: A, B, lateral view of spermathecal pores (Spp); C, D, clitellum region, female pore (Fm), male pore (Mp), clitellum (Cl); E, F, spermathecae, ampulla (Am), spermathecal duct (Sd), diverticulum (Div); G, H, right prostate region, prostate gland (Pg), prostate duct (Pd) caecum (C), genital marking gland (Gmg), intestine (Int).

11) *Metaphire peguana* (Rosa, 1890)

1890. *Perichaeta peguana*, Rosa, **Ann. Mus. Civ. Sto. Nat. Genova.** 30: p. 113. (Type locality, Rangoon. Type, in the Genoa Mus.).

1972. *Pheretima peguana,* Gates, **Trans. Amer. Phil. Soc.** 62(7): p. 207.

Metaphire peguana, Sims and Easton, **Biol. J. Linn. Soc.** 4: p. 239.

2003. *Metaphire peguana*, Blakemore, **Organ. Diver. Evol.** 3(3): p. 24.

Diagnosis: Megascolecidae with cylindrical bodies of varying length. Prostomium, epilobous, tongue open. Setae numerous, regularly arranged around each segment, a, b follicles of postclitellar segments enlarged and more protuberant into coelomic cavities. First dorsal pore, at xii/xiii. Color, only in dorsum, reddish. Segments, 77-128. Size, 95-156 by 5-7 mm. Spermathecal pores small, sexthecal, pores minute superficial, ca. 2/7 *C* apart, at vi/vii-viii/xix. Clitellum annular smooth, xiv-xvi. Female pore, median. Male pore paired on each genital marking hollow inside in xviii minute. Genital markings, transversly elliptical, with firm glistening surface and obvious central aperture, two pairs, across (intersegment) xvii/xviii, xviii/xix.

Desription

External characters: Total length 95-156 mm by 5-7 mm, 77-128 segmental number. Setae 40-60 in v, between spermathecal pores 8-15. First dorsal pore in xii/xiii. Clitellum xiv-xvi, annular, smooth, setae non. Spermathecal pores 3 pairs on vi/vii-ix. Lateral, more than 1/3 *C* apart. Female pore single, midventral in xiv. Male pore paired in xviii, ventro-lateral, minute, superficial. Setae between male pores 8-12. Genital marking paired in xvii, xix. Color, brown to dark brown, yellowish on ventrum.

Internal characters: Septa, viii/ix-x/xi aborted, v/vi/vii/viii, xi/xii-xii/xiii muscular. Pigment, reddish, in circular muscle layer. Spermathecae, small to medium-sized, duct shorter than ampulla, with thick wall and narrow lumen, much narrowed in the parietes, diverticulum from anterior face of duct at parietes, longer than main axis, with slender stalk, longer and thicker mid-portion irregularly looped, terminal seminal chamber spheroidal to ovoidal, on vii-ix. Intestinal origin, in xv. Caeca, simple, in xxvii-xxii. Typhlosole, rather small, to rudimentary, ending in region of 59-86th segments. Hearts, in xi-viii an aborted dorsal portions to gizzard, in ix (usually on one side only). Holandric. Testis sacs, paired and ventral. Semial vesicles, large of xi reaching forward alongside gizzard, of xii smaller, each with a large primary ampulla, distinctly demarcated though not protuberant from the main mass. Prostates deeply divided, multi-lobes fan shape, in xvi-xxi, ducts 3-5 mm. long. Gentital marking glands muscular domes glandular interiors, with thick muscular wall and small lumen, slightly protuberant into coelom.

Habitats: This earthworm species was collected in several areas, higher in SERS and SRS, some in dry dipterocarp forest but not in dry evergreen forest.

Dynamic: This species occurred in early of rainy season in April, June, August, September, higher in October.

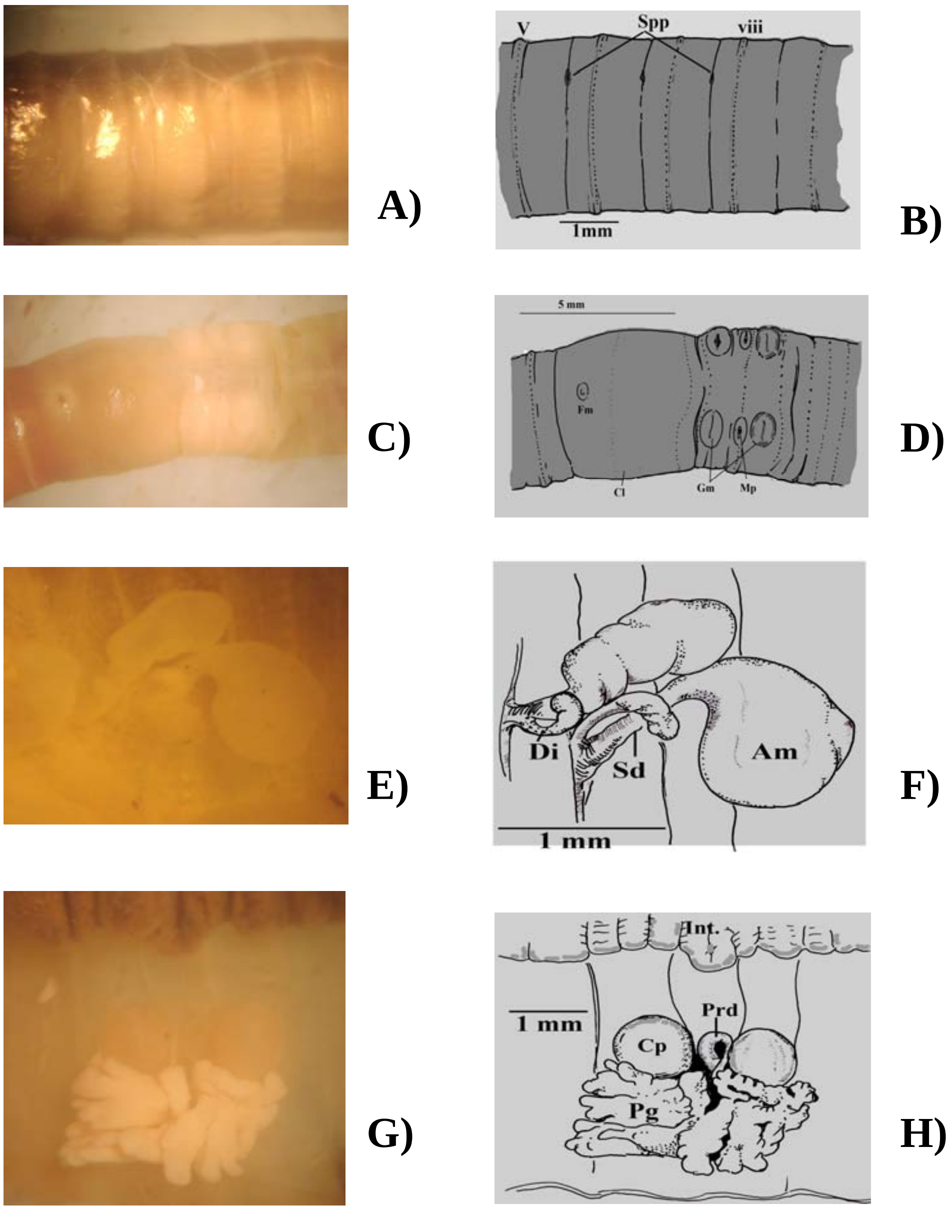


Figure A.10 Photographs and line drawings of *Metaphire peguana*: A, B, lateral view of spermathecal pores (Spp); C, D, clitellum region, female pore (Fm), male pore (Mp), clitellum (Cl), genital markings (Gm); E, F, (two of three) right spermatheca, ampulla (Am), spermathecal duct (Sd), diverticulum (Di); G, H, left prostate gland (Pg), prostate duct (Prd), copulatory pouch (Cp), intestine (Int).

12) ***Metaphire planata***

1926. *Pheretima planata*, Gates, **J. Buma. Res. Soc.** 15: p. 212.

1929. *Pheretima planata*, Stephenson, **ibid.** 31: p. 238.

1930. *Pheretima planata*, Gates, **ibid.** 32: p. 320.

1931. *Pheretima planata*, Gates, **ibid.** 33: p. 405.

1932. *Pheretima planata*, Gates, **ibid.** 34: p. 411.

1933. *Pheretima planata*, Gates, **ibid.** 35: p. 541.

1936. *Pheretima planata*, Gates, **ibid.** 38: p. 446.

1972. *Pheretima planata*, Gates, **Trans. Amer. Phil. Soc.** 62(7): p. 211.

Metaphire planata, Sims and Easton, **Biol. J. Linn. Soc.** 4: p. 217.

Diagnosis: Earthworm with head dark burgundy, then brown dorsal fluted about 12 long grooves. Spermathecal, pores, fairly widely separated at lateral side with 1 or 2 small bump genital markings nearby. Dorsal pores at least in head zone. Clitellum annular. Male pores in xviii. Genital markings, very small.

Description

External characters: Total length 70-145 mm by 3.5 mm segment 74-146. Prostomium lacking (or rudimentary?). Setae 64-68 in viii, 68-72 in xx, between spermathecal pores 14-20. First dorsal pore at head zone, occasionally at x/xi. Spermathecal pores 2 pairs on vi/vii/viii, lateral, more than 1/3 *C* apart. Clitellum, at xiv-xviii, almost annular smooth. setae non. Female pore single, midventral in xiv. Male pores partly everted to form flower-like shape internally coelomic faintly muscular copulatory pouch with large glandular mass anterior and posterior, these masses connect to about 6 round genital markings inside the copulatory pouch. Genital marking very small at xviii.

Internal characters: Quadrithecal, pores minute, superficial, each in a very small circular area slight epidermal modification close to vi/vii-vii/viii, in vii-viii. Septa, v/vi/vii-vii/viii muscular, viii/ix-ix/x aborted, x/xi-xii/xiii slightly muscular. Spermathecae, large enough to reach dorsal parietes, duct elongate, slender, lumen abruptly narrowed in region of diverticular junction, diverticulum longer than main axis, and an elongately ellipsoidal, terminal seminal chamber. Gizzard in viii. Hearts, in viii unaborted dorsal portions to gizzard, in ix lateral but usually lacking on one side, of x (latero?)-esophageal, of xi-xiii latero-esophageal. Intestinal origin, in xv. Intestinal caeca, simple, in xxvii-xx. Typhlosole, small, Holandric. Testis sacs, small ventrally paired, of x ventral, of xi including seminal vesicle. Seminal vesicles, large in xi, xii, each with a digitiform primary ampulla. GM glands, composite, stalked, coelomic. Prostates large, 2 main lobes duct short, muscular.

Habitats: This species presented in agricultural and residential areas, higher in rice paddy as well as Sakaerat Silvicultural Research Station followed by sugarcane plantation, cassava plantation and mango plantation areas. In contrast, they were seldom in forests areas.

Dynamic: This species was occurred at beginning of the rainy season in June, increasing to the highest in October.

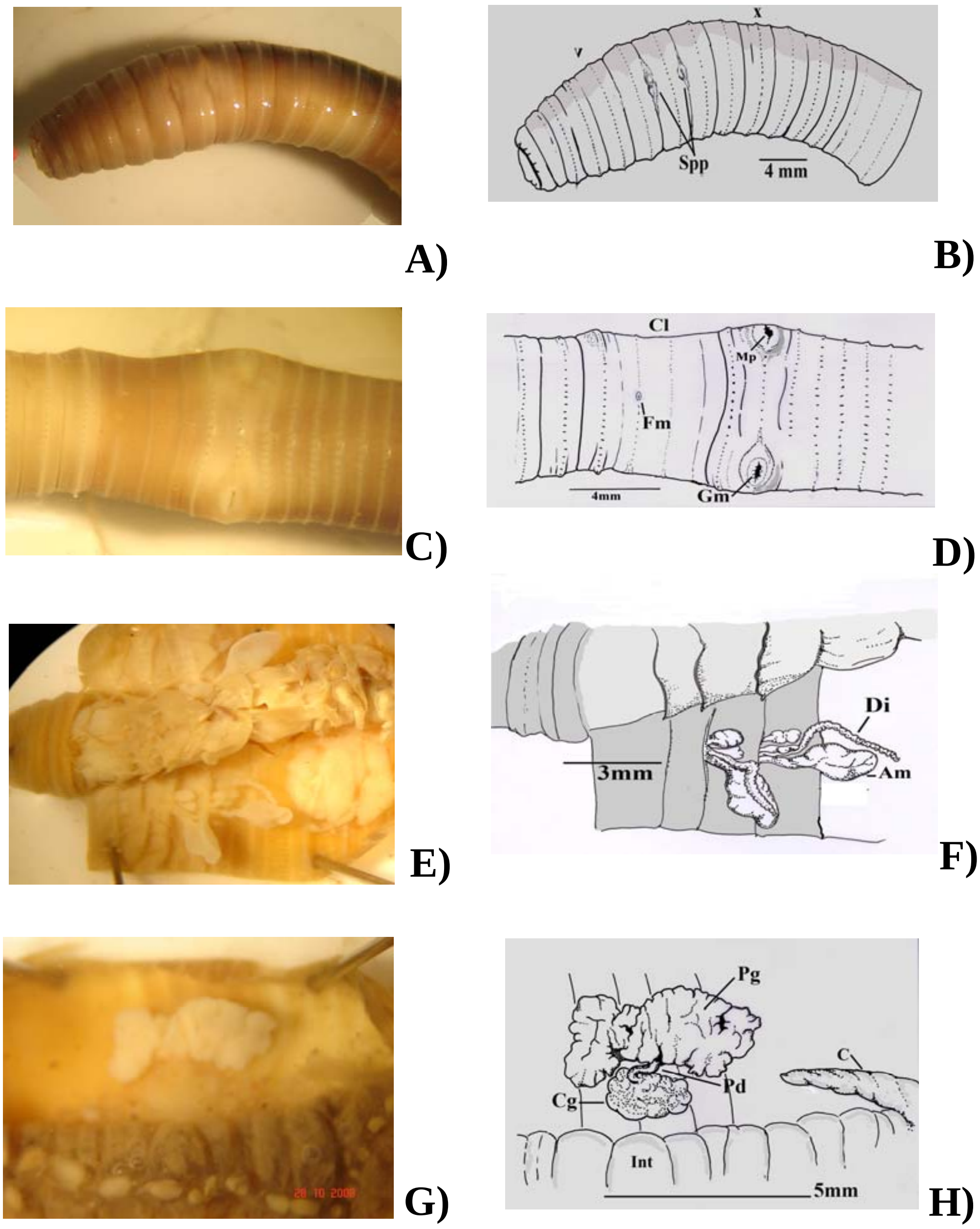


Figure A.11 Photographs and line drawings of *Metaphire planata*: A, B, lateral view of spermathecal pores (Spp); C, D, clitellum region, female pore (Fm), male pore (Mp), clitellum (Cl), genital markings (Gm); E, F, left spermatheca, ampulla (Am), diverticulum (Di); G, H, right prostate, prostate gland (Pg), prostate duct (Pd), copulatory gland (Cg), intestine (Int).

13) *Metaphire posthuma*

1898. *Perichaeta posthuma*, Vaillant, **Ann. Sci. Nat. Ser.** 5, 10: p. 228. (Types in the Paris Mus.)

1912. *Pheretima posthuma*, Stephenson, **Rec. Indian Mus.** 7: p. 278.

1930. *Pheretima posthuma*, Gates, **Res. Indian Mus.** 32: p. 321.

1939. *Pheretima posthuma*, Gates, **Jour. Thailand Res. Soc. Nat. Hist. Suppl.** 12: P. 104.

1970. *Pheretima posthuma*, Soota and Julka, **Proc. Zool. Soc.** Calcutta 23: p. 204.

1972. *Pheretima posthuma*, Gates, **Trans. Amer. Phil. Soc.** 62(7): p. 212.

Metaphire posthuma, Sims and Easton, **Biol. J. Linn. Soc.** 4: p. 217.

Diagnosis: Octhecal, pores minute, superficial, $^1/_3$ C or more apart, in small translucent areas just in front of v/vi-viii/ix. Male pores, in xviii, minute, each in a mall disc on median wall near roof of a slight, eversible invagination with longitudinally crescentic aperture. Female pore, median in xiv. Genital marking, paired, small, circular or nearly so, quatorial, slightly median to male pore levels, present only on xvii and xix (intrasegment). Clitellum, reaching to or nearly to xiii/xiv and xvi/xvii. Setae, small, closely spaced. First dorsal pore, at 12/13. Prostomuim, small, epilobous, tongue short and usually open. Color, light to dark gray.

Description

External characters: Color, brown to dark brown, yellowish on ventrum. Total length 73-115 mm by 3-8.5 mm, segments 86-140. Prostomium small epilobous tongue open. Setae 84-96/vii, 54-68/xx, 64-72/xxx. First dorsal pore in xii/xiii. Clitellum xiv-xvi, annular, smooth, setae present. Spermathecal pores 4 pairs on v/vi-ix. Lateral, more than 1/3 *C* a part. Female pore single, midventral in xiv. Male pore paired in xviii, ventro-lateral, minute, superficial, porophore small 3 pairs on xviii. Setae between male pores 14-18. Genital marking paired intrasegment on xvii, xix.

Internal characters: Septa, v/vi-vii/viii thickly muscular, viii/ix muscular and complete, ix/x aborted. Pigment, brown to dark brown, in circular muscle layer. Spermathecae, rather small, duct shorter than ampula, diverticulum with short stalk from median face of duct near ampulla and longer ellipsoidal seminal chamber. Hearts, of vii and ix lateral (one in ix usually in part or wholly aborted or vestigial), in x-xi lacking, in xii-xiii latero-esophageal. Paired loops with non muscular walls between supra- and extra-esophageal trunks in x-xi. Intestinal origin, in xv. Typhlosole, simply lamelliform. Holandric. Testis sacs, paired, of x ventral, vertically U-shaped in xi. Seminal vesicles, of xi rather small and included in testis sac, of xii larger. Prostates, in xvii-xix, ducts 3-4 mm long, each in a U-shaped loop. GM glands, sessile on parietes. Caeca, simple, in xxvii-xxiv.

Habitats: This species was presented in several areas except in forest. The highest specimens were collected in household areas, followed by rice paddy and sugarcane plantation. Whereas, a few specimens were found in grassland.

Dynamic: The density of this species was occurred in June and highest in August but lowest in October.

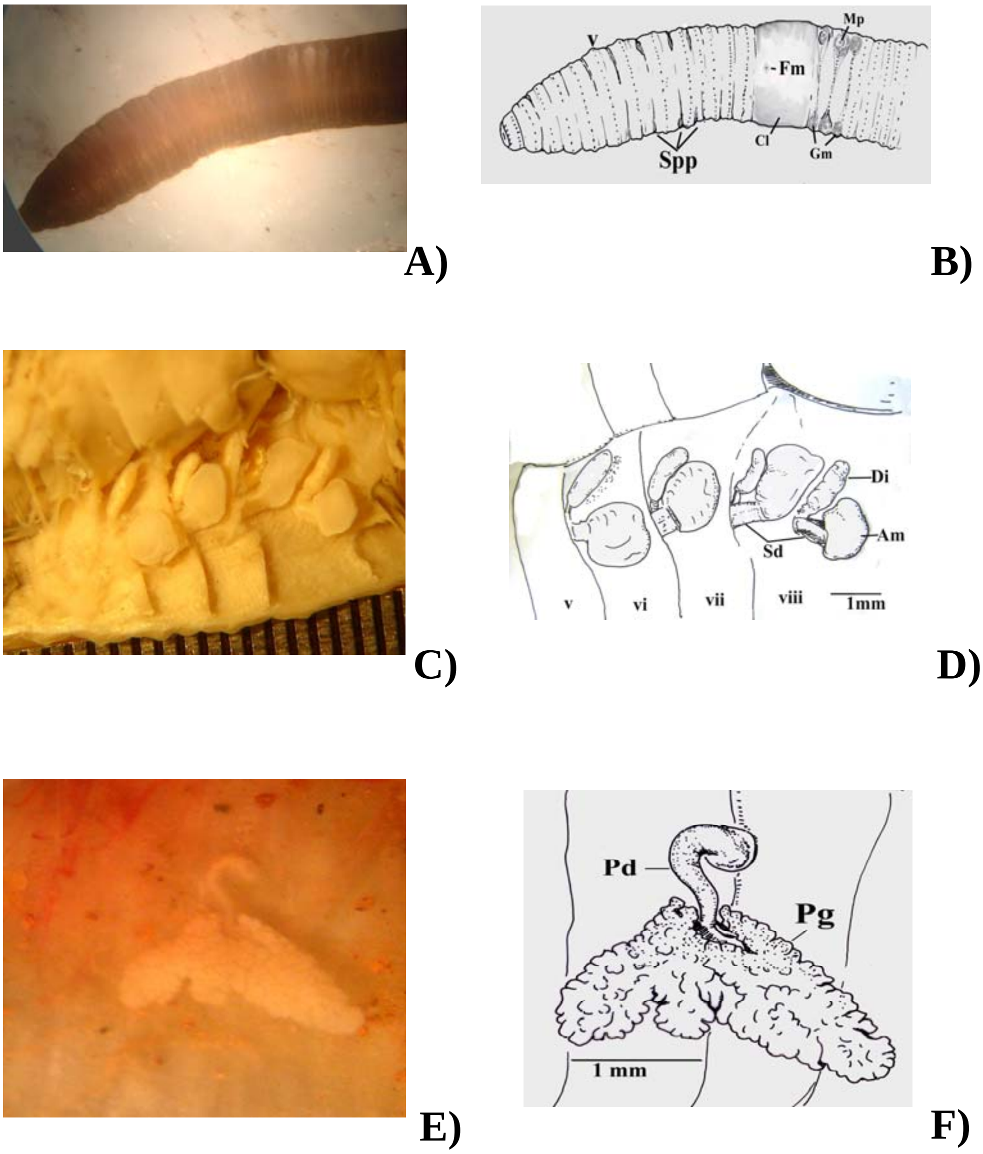


Figure A.12 Photographs and line drawings of *Metaphire posthuma*: A, B, lateral view of anterior region, spermathecal pores (Spp), female pore (Fm), male pore (Mp), clitellum (Cl), genital markings(Gm); C, D, right spermatheca, ampulla (Am), diverticulum (Di), spermathecal ducts (Sd); E, F, left prostate, prostate duct (Pd), prostate gland (Pg).

Genus *Polypheretima*

1900. *Pheretima*, Michelsen, **Tierrich.** 10: pp. 1-575.

1900. *Amynthas*, Beddard, **Proc. zool. Soc. London.** 1900: pp. 609-652.

1972. *Metapheretima (Polypheretima)*, Sims & Easton, **Biol. J. Linn. Soc.** 4: pp. 205, 233.

Megascolecidae with an oesophageal gizzard in viii, intestinal caeca and gizzards absent. Body cylindrical, setae never excessively crowded ventrally, creeping sole absent. Male pores on circular porophores which may be within copulatory pouches. Crescentic genital markings absent. Spermathecal pores small, spermathecal diverticula simple and usually ectal in origin. Clitellum annular, restricted to three segments (xiv-xvi). First dorsal pore between 5/6 and 12/13. Setae perichaetine, never excessively crowded ventrally, dorsal and ventral gaps small (aa= \-2ab, zz= \-2yz). Lateral hearts in x-xii and sometimes xiii. Oesophagus with a well-developed gizzard in viii but lacking calciferous glands and dorsal pouches. Intestine begins in xv or xvi, simple, lacking caeca, gizzards and glandular walls. Usually holandric, occasionally metandric, ? never proandric - testes may be restricted to x in sibogae which is known only from the damaged holotype. The testes of each segment are enclosed in single or paired stout sacs which usually occupy most of the coelom and often enclose the anterior seminal vesicles and the lateral hearts of x and xi. One pair of seminal vesicles in the segment directly posterior to each pair of testes. Prostates racemose. Paired combined male and prostatic pores on the ventral surface of xviii in the setal ring. Male pores situated on circular porophores, often within copulatory pouches. The porophores bearing the male pores are short and stout (cf. penial bodies in Metapheretima) while the openings to the copulatory pouches, when present, are often crescentic. Ovaries free in xiii. Oviducts lead to single or closely paired, midventral, equatorial pore(s) on xiv. Spermathecae each differentiated into duct and ampulla, diverticula simple and ectal in origin, usually as long or longer than main duct and ampulla. Spermathecae arranged in pairs or paired batteries of up to 28 Spermathecae, in one to five adjacent segments between v and ix. Spermathecal pores small, usually intersegmental, rarely segmental. Genital markings always of the discrete type, diffuse genital markings and annular ridges absent. When present on xviii the genital markings are identical to those of adjacent segments; they are never crescentic and closely associated with the male pores. The arrangement of genital markings is variable. The glandular tissue associated with the genital markings may be restricted to the body wall or invade the coelom in the form of stalked glands. The area around the male pores may be infrequently elevated above the body surface.

14) *Polypheretima elongata* (Perrier, 1872)

1872. *Perichaeta elongata*, Perrier, **Nouv. Archs Mus. Hist. nat. Paris.** 5: p. 124.

1972. *Metaphire elongata*, Sims and Easton, **Biol. J. Linn. Soc.** 4: p. 205.

1979. *Polypheretima elongata*, Easton, **Bull. Brit. Mus. Nat. Hist. (Zool.)** 35: p. 53

2005. *Polypheretima elongata*, James, Shih and Chang. **J. Nat. Hist.** 39(14): p. 1026.

Diagnosis: Earthworm with large and long body, cylindrical unpigmented. Male pores on quat penes within shallow copulatory pouches at ventral body side. Female pores single. Spermathecal pores small, numerous arranged in paired ventrolateral batteries, of up to 28 pores, intersegmental in v/vi and or vi/vii, occasionally absent. Holandric, postclitellar genital markings one pair per segment, simple presetal near to the line of the male pores.

Description

External characters: Length 70-320 mm, by 1.5-10 mm, 100-230 segments. No spermathecal pore. Clitellum annular smooth in xiv-xvi. First dorsal pore xii/xiii. Setae 20-120 on vii, 34-88 on xx occasionally setae *a* and *b* enlarged, setal ring regular with ventral gaps (aa=1.5ab=1.5yz=1.5zz). Genital markings simple, large, paired presital on xix and successive segments in with or slightly median to the male pores, occasionally on xix-xxiii.

Internal characters: Septa, v/vi/vii muscular, vii/viii-x/xi absent, xi/xii and other membranous. Spermatheca non. Hearts in ix-xviii. Gizzard in viii. Holandric, testes sacs large, paired, extending to the dorsal line in x and xi, semial vesicles in xi and xii, the anterior pair enclosed in the testest sacs. Pseudoseminal vesicles in xiii and xiv. Prostates large pairs cover xvi-xxii, Muscular long stalk duct, 4-7 mm long in xviii.

Habitats: This species was very site specific, presented only in sugarcane plantation.

Dynamic: This species was common in June and August.

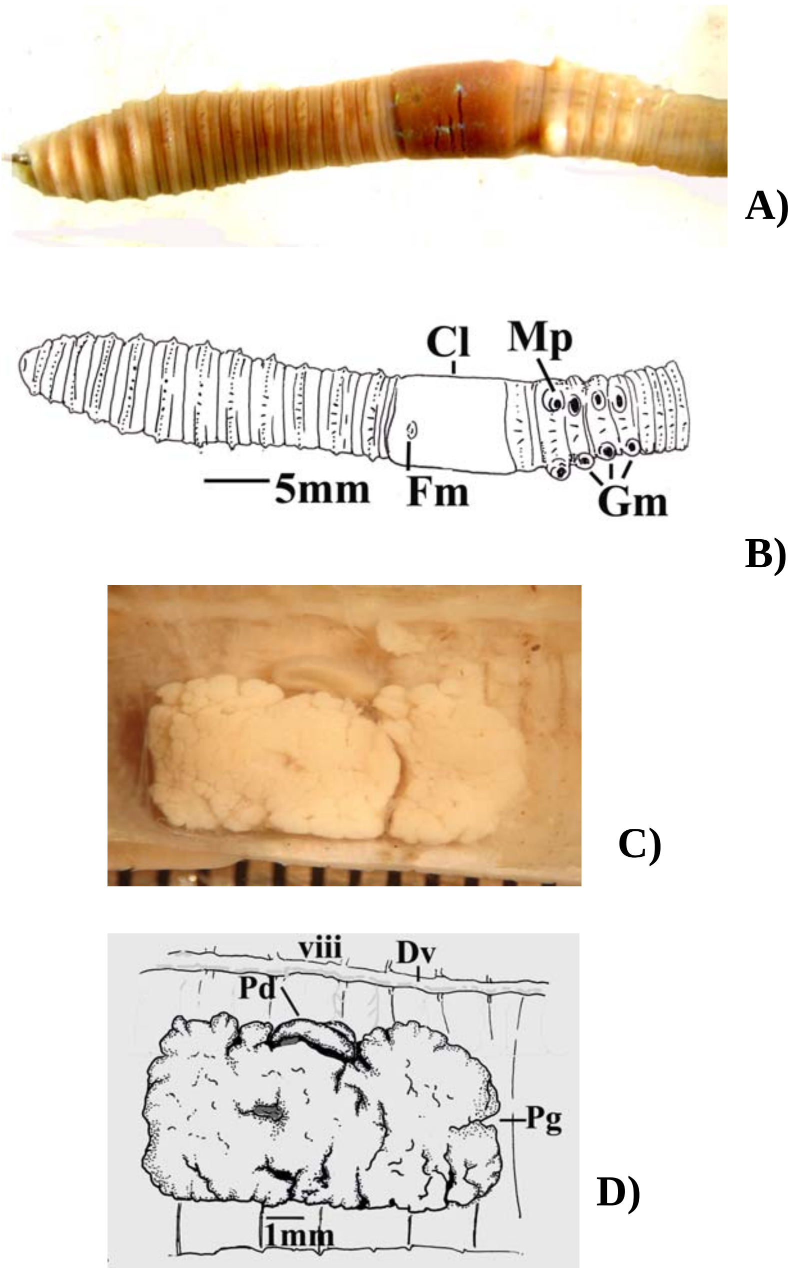


Figure A.13 Photographs and line drawings of *Polypheretima elongata*: A, B, ventral view of anterior portion, female pore (Fm), male pore (Mp), clitellum (Cl), genital markings (Gm); C, D, left prostate, prostate gland (Pg), prostate duct (Pd), dorsal blood vessel (Dv).

A.3 Family MONILIGASTRIDAE

1900. *Moniligastridae*, Michaelsen, **Das Tierreich.** 10: p. 109.

1939. *Moniligastridae*, Gates, **J. Thailand Res. Soc. Nat. Hist. Suppl.** 12(1): p. 72.

1962. *Moniligastridae*, Gates, **Bull. Mus. Comp. Zool. Harvard College.** 127: p. 299.

1972. *Moniligastridae*, Gates, **Trans. Am. Phil. Soc.** 62(7): p. 238.

Digestive system, with gizzards behind ovarian segment, an intestinal origin behind xvii, with paired enterosegmental organs on the intestine dorsally, but without typhosoles, calaiferous and supra-intestinal glands. Vascular system, withdorsal, ventral and subeural trunks, the latter adherent to the parietes, paired extra-esophageal trunks lateral to the hearts and with connectives to the dorsal trunk as well as to the subneural (asymmetrically), but without a supra-esophageal, hearts lateral, last two (uniting mesially to open into the dorsal trunk through a short vertical vessel) two segments in front of ovarian metamere. Excretory system, of holoic and vesiculate nephridia, lacking in ii, (the bladder caecal and from tubule just prior to entry into parietes). Prostomium, prolobous but separated from I, protuberant from roof of buccal cavity behind level of ½. Setae, sigmoid and single pointed, (penial and copulatory setae lacking), four pairs per segment. Dorsal pores, none.

Clitellum, unilayered, annular, intersegmental furrows not obliterated, setae retained, including male and female pore segments. Male pores, behind spermathecal pores and in front of female pores, the latter near *B*. Testes and male funnels, intraseptal, in paired dorsal protuberances of the septum. Seminal vesicles, none.

Sperm ducts, each opens to exterior through a prostate and at or close to the intersegmental furrow next behind that of the septum bearing the male funnels.

Ovaries, vertically elongated and bandlike, both in a chamber closed off mesially from small peri-esophageal and neural spaces. Ova, large, yolky. Ovisacs, dorsal, elongate and backwardly directed, simple pockets of the posterior septum of the ovarian metamere. Spermatecae, attached to posterior face of a septum with ampullae dorsal to the gut.

Genus *Drawida* (Michaelsen, 1900)

1900. *Drawida*, Michaelsen, **Das Tierreich.** 10: p. 114.

1933. *Drawida*, Gates, **Rec. Indian Mus.** 35: p. 419.

1972. *Drawida*, Gates, **Trans. Am. Phil. Soc.** 62(7): p. 244.

Diagnosis: Gizzards, in region of xii-xxvii. Last connectives between extra-esophageal and dorsal trunks on posterior face of ix/x, another pair associated with xiii/ix. Hearts, in each of viii-ix, after joining connectives from extra-exophageal trunks unite mesially above gut and then communicate with dorsal trunk through a short vertical vessel in median plane. Septa, v/vi-ix/x strengthened (usually thickly muscular), parietal insertion of ix/x dislocated posteriorly, x/xi-xi/xii approximated. Nephropores, present from iii. Male porse, at or near x/xi. Female porse, at or just behind xi/xii. Spermathecal pores, at vii/viii. Clitellum, including x-xiii at least. Testes, in ix/x. Prostates, in x. Ovaries, in xi.

15) *Drawida beddardi* (Rosa, 1890)

1972. *Drawida beddardi*, Gates, **Trans. Am. Phil. Soc.** 62(7): p. 246.

2004. *Drawida barwelli,* James, **Micronesica.** 37(1): 11.

Diagnosis: Clitellum, annular, red, ix-xiii. Spermathecal pores 1 pairs in vii/viii. Female porse, at or just behind xi/xii. Male pore, transverse slits at 10/11 in median portion of *BC*. Gizzards, 4, in xii-xv. Testes, in ix/x. Prostates, in x. Ovaries, in xi.

Description

External Characters: Total length 24-126 mm, width 2-4 mm, segment number 130-170. Prostomium prolobus. Clitellum, annular, red, ix-xiii. Spermathecal porse, vii/viii, rather large, at or just median to *CD*. Genital markings, lacking but one or both margings of male apertures may be whitened and with thickened epidermis. Female pores, at or just behind xi/xii. Male pore, transverse slits at x/xi in median portion of *BC*, primary pores minute and on ventral ends of short, tubular penes pendent from roofs of eversible, spheroidal, muscular chambers protuberant more or less conspicuously into coelom.

Internal characters: Gizzards, 4 in xii-xv. Connectives from extra-esophageals, usually on anterior face of viii/ix. Sperm duct, rather short and each assign into a prostate slightly below ental end and directly. Prostates, in x, not unusually long, capsule digitiform, erect or bent, glandular investment restricted to ental end or continued to or nearly to penial chamber. Spermathecae, adiverticulate, duct 6-7 mm. long an ectal portion, thickened. Ovarian chamber, closed off from parietes. Testes, in ix/x. Ovaries, in xi.

Habitats: This species was collected in several areas, higher in grassland, SERS and dry evergreen forest respectively.

Dynamic: This species was common from June to October.

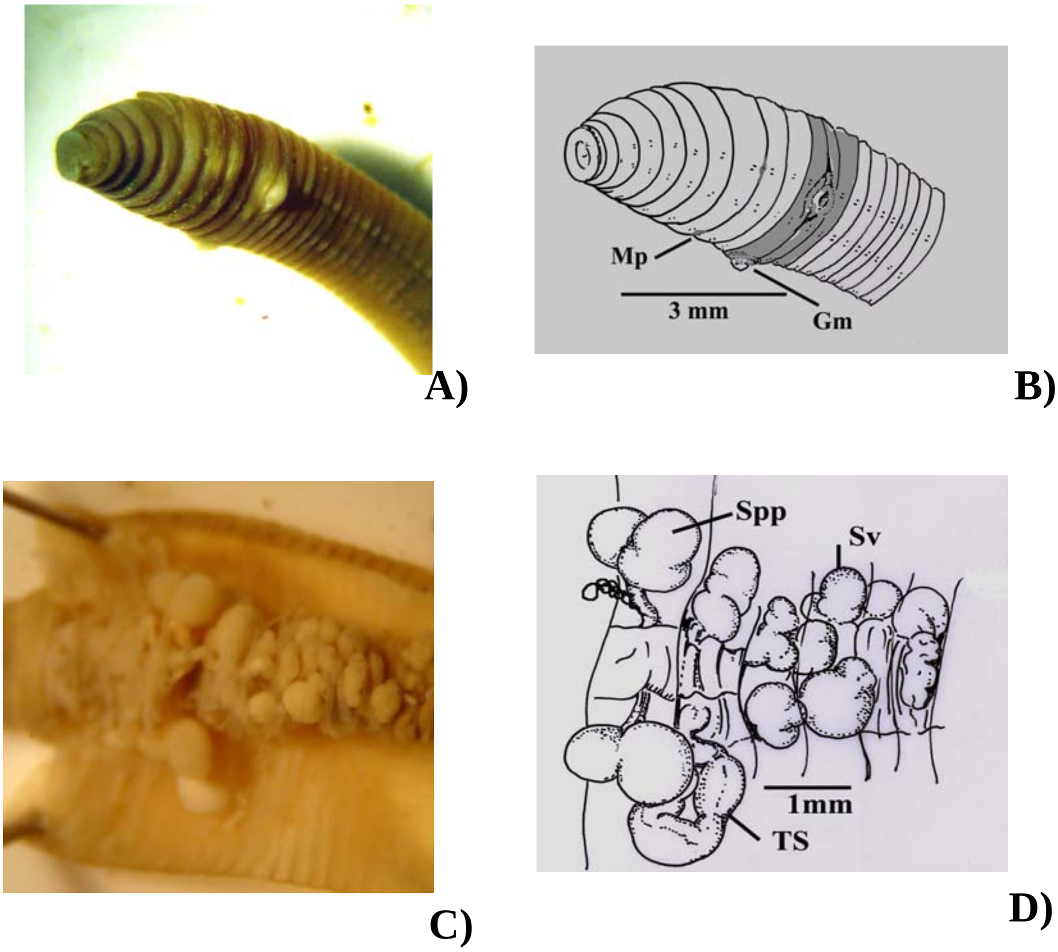


Figure A.14 Photographs and line drawings of *Drawida deddardi*: A, B, anterior at Lateral view of genital region, male pore (Mp), genital marking (Gm); C, D, spermathecae (Sp), seminal vesicle (Sv), and testes (Ts).

16) *Drawida* sp.1

Diagnosis: No clitellum, no genital markings, Male pores on protuberant porophores mainly in x/xi or xi. Spermathecal pores ellipsoid high on vii/viii *CD* level., Ovisac large in xi-xii only, from huge sac in xi/xii via tube through to xiii, then expends. Prostates glandular, C-shaped, large vas deference to tip. Muscular copulatory pouch. Spermathecae in viii, long coil muscular duct to three-lobed, diverticulum small digit ate in vii. Gizzards in xiii, xiv only. Testes ix/x, vas deference very large directly into prostates.

Description

External characters: Color brown on head portion and blue on tail portion, Total length 60-75 mm by 1-3 mm. Non open dorsal pore.

Internal characters: Spermathecae in viii or vii/viii, long coiled tubule to blunt digit ate atrium in vii with apparent convolved internal structure, no glands. Testes sacs in ix/x straight vas deference to curved prostate on muscular copulatory pouch.

Habitats: This species was collected in agricultural land, rice paddy and cassava plantation.

Dynamic: This species was common from June to October.

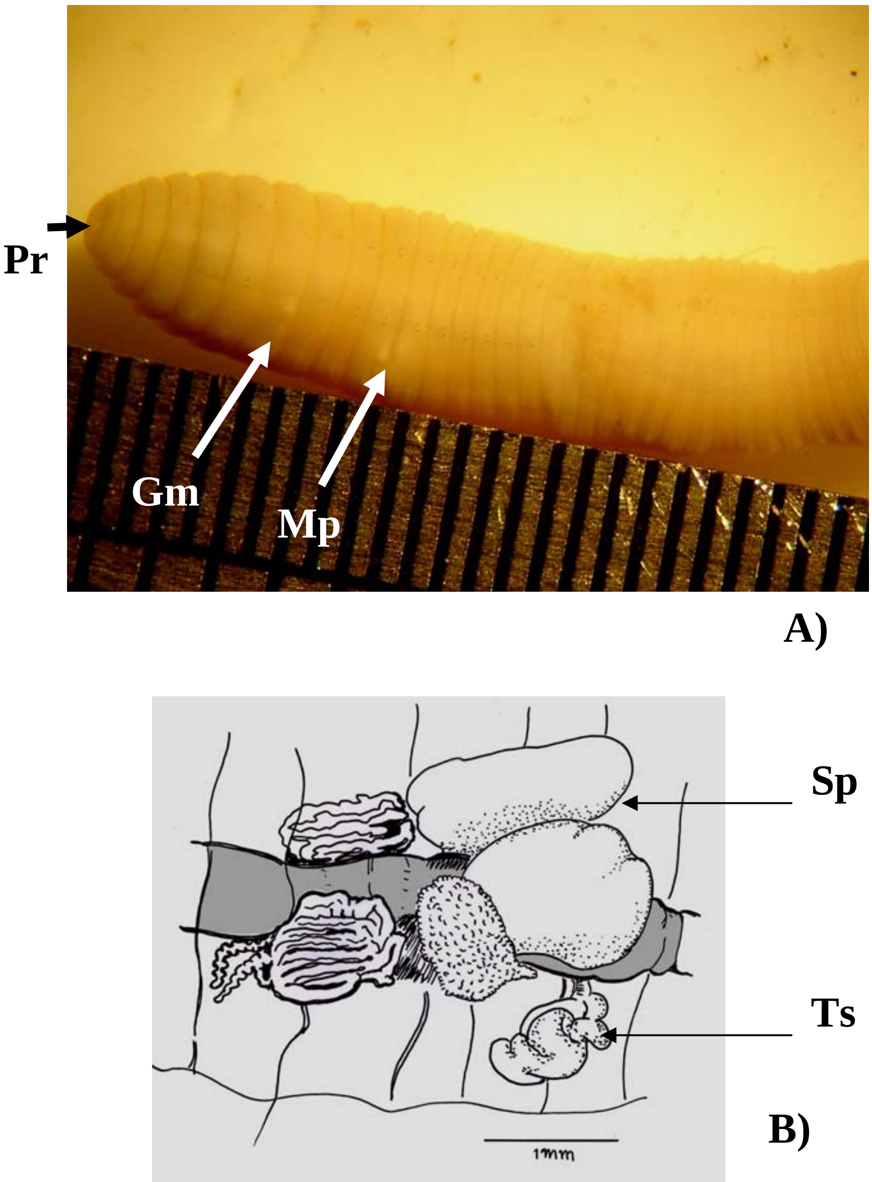
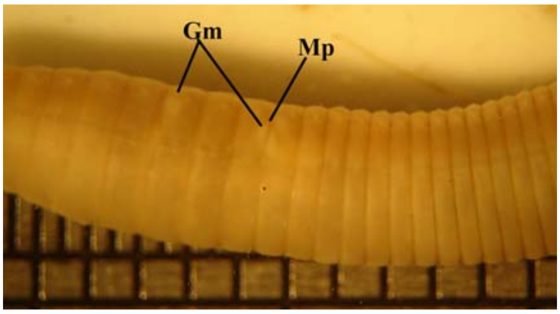


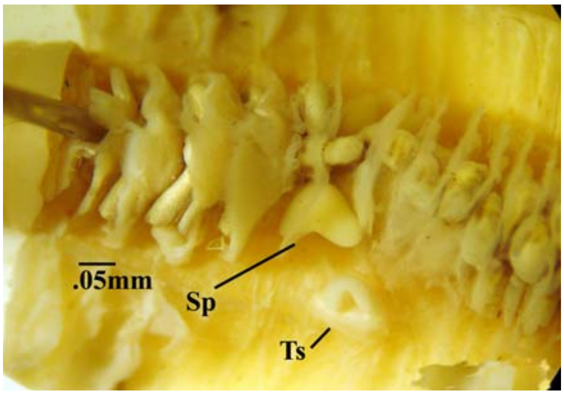
Figure A.15 Photographs and line drawings of *Drawida* sp.1: A, anterior view, prostomium (Pr), genital marking (Gm), male pore (Mp); B, internal characters, spermatheca (Sp), and testes (Ts).

17) *Drawida* sp.2

Diagnosis: Total length 60-85 mm. Clitellum in x-xiv, Spermathecal pores vii/viii, Male pore below *C* in x/xi, non open dorsal pores in v/vi-viii/ix. Last heart in ix. Gizzard in xiii-xiv only. Spermathecae in viii or vii/viii, long coiled tube to blunt digit ate atrium in vii, with apparent convoluted interval structure, no glands. Testes sacs in ix/x, straight vas deference to curved prostate and muscular copulatory busa, long penis aimed forwards. Genital marking at viii near *B*, x paired *BC*, xi paired near *B*.



A)



B)

Figure A.16 Photographs and line drawings of *Drawida* sp.2: A, anterior view, genital marking (Gm), Male pore (Mp); B, internal characters, spermatheca (Sp), and testes (Ts).

A.4 Family OCTOCHAETIDAE

1921. *Octochaetenae*, Michaelsen, **Mitt. Naturhist. Mus. Hamburg.** 38: p. 36.

1959. *Octochaetedae*, Gates, **Bull. Mus. Comp. zoology, Harvard Collage.** 121: p. 254.

Setae lumbricine. Dorsal pores present. Clitellum includes segments 14-18. Prostates tubular discharging on segments xvii and xix or xvii only. Male pores on segment xviii. Penial setae present. Two well developed oesophageal gizzards anterior to septum viii/xix. Paired calciferous glands in segments xv, xvi and xvii, intestinal caeca and gizzards absent. Excretory system meronephric.

Genus *Dichogaster* (Beddard, 1888**)**

1972. *Dichogaster*, Gates, **Trans. Am. phil. Soc.** 62: p. 227.

1988. *Dichogaster*, Julka, **Fauna of India.** p. 98.

Lumbricine. Male pores paired, in seminal grooves, on xvii or xvii/xviii; prostatic pores 2 pairs, at the ends of seminal grooves, on xvii and xix, or one pair on xvii. Oesophagus with 2 gizzards anterior to septum viii/ix and pair of discrete extramural calciferous glands, each gland trilobed, a vertically renifrom lobe in sach of segments xv-xvii with a common duct opening into the gut in xvi; supra-intestinal glands absent; typhlosole lamellifrom, simple. micromeronephridia astomats; paired enteronephric tufts in ii-iv; several, exonephric on the body wall in v and posteriad segments. Paired, stomata, exonephric megameronepharidis in each of few posterior most segments.

18) *Dichogaster affinis*

1923. *Dichogaster affinis*, Stephenson, **Fauna Br. India**, **Oligochaeta.** p. 471.

1931. *Dichogaster sinuosus*, Stephenson, **Proc. zool Soc. Lond.** 1931: p. 74.

1972. *Dichogster affinis*, Gates, **Trans. am. phil Soc.** 62: p. 278.

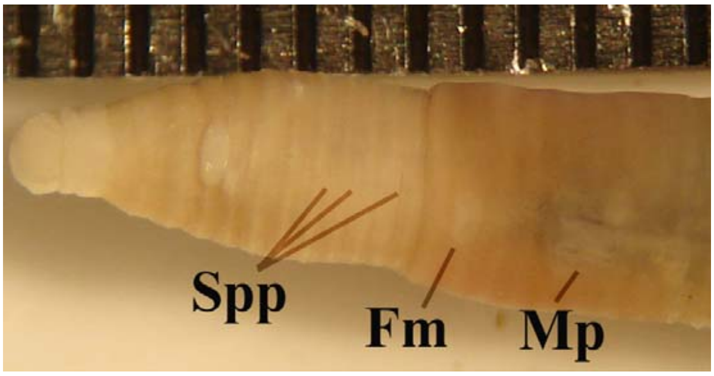
1988. *Dichogaster affinis*, Julka, **The fauna of india.** p. 100.

2004. *Dichogaster affinis*, James, **Micronesica.** 37(1): p. 10.

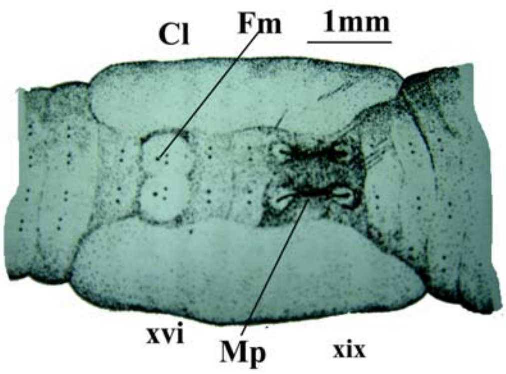
Description

External characters: Length 27-60 mm, diameter 1-2.5 mm, 115-136 segments. prostomium epilobous, tongue closed. First dorsal pore v/vi. Clitellum saddle shape in xiii, xiv-xxi, xxii. 8 setae per segment closely paired. Male pores minute, in seminal grooves on the setal arc of xviii, at a; prostatic pores minute, at the ends of seminal grooves on xvii and xix, at a; seminal grooves almost straight or slinghtly concave between the setal arcs of xvii and xix. Female pores paired, presetal, at or just lateral to a. Spermathecal pores minute, at or close to a. Genital markings often persent, unpairedand median on viii/ix/x, sometimes on vii/viii, x/xi/xii.

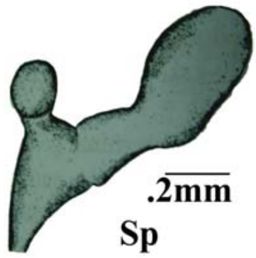
Internal characters: Septa iv/v, vii/viii-xii/xiii slightly muscular, v/vi/vii absent. Gizzard between septa iv/v and vii/viii; typhlosole xxi to xviii-xxvi. Last pair of hearts in xii. Testes and male funnels in unpaired sacs, in x and xi, formed by the peripheral apposition of septa ix/x/xi/xii; seminal vesicles vestingeal, in xi and xii. Prostates 2 pairs, in xvii and xix. penial setae slightly sinuous ectally, ornamented with scale-like markings or teeth in the sinuousities. Each spermatheca with a shortly stalked ental diverticulum. Genital marking glands circular to slightly dome-shaped, concealed beneath the longitudinal muscle layer.



A)



B)



C)

Figure A.17 Photograph and line drawings of *Dichogaster affinis*: A, anterior view, clitellum (Cl), spermathecal pores (Spp), female pore (Fm), male pores (Mp); B, ventral view of clitellum and genital region (Cl), clitellum; Fm, female pores); C, spermatheca (Sp) (modified after Julka, 1988).

19) *Dichogaster bolaui* (Michaelsen)

1972. *Dichogaster bolaui*, Gates, **Trans. Am. Phil. Soc.** 62: 279.

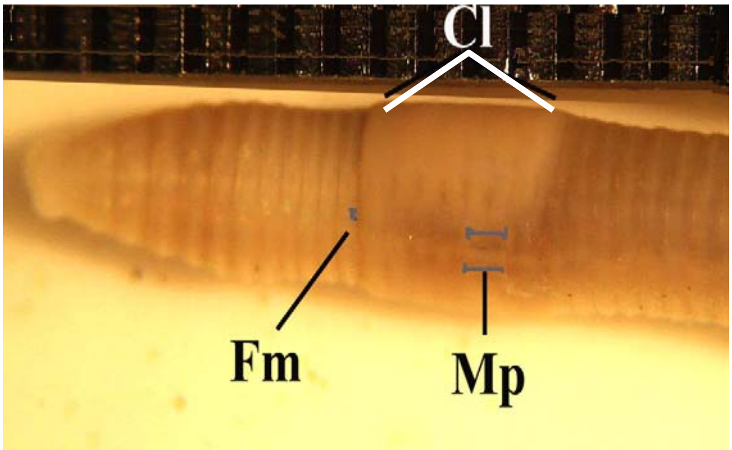
1978. *Dichogaster bolaui bolaui*, Righi *et al.*, **Acta Amazonica.** 8(3), suppl. 1: 38.

1988. *Dichogater bolaui*, Julka, **The fauna of India.** p. 103.

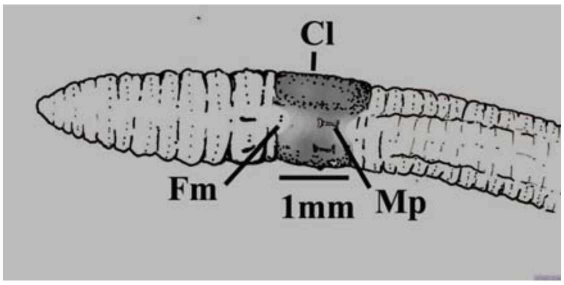
Description

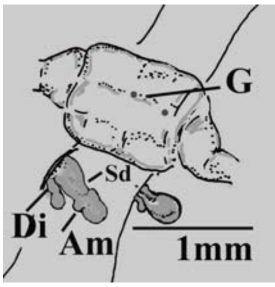
External characters: Length 15-53 mm, diameter 1-3.5 mm, 82-118 segments. Prostomium epilobous, tongue closed. First dorsal pore v/vi, sometimes vi/vii. Clitellum saddle shape in xiii, xiv-xvii, xix, xx, ½ xxi. Setae closely paired, 8 setae per segment. Male pores minute, in seminal grooves on the setal arc of xvii, at a; prostatic pores minute, at the ends of seminal grooves on xvii and xix, at a; seminal grooves slightly concave between the setal arcs of xvii and xix. Female pore single, median, presetal. Spermathecal pores at or ner a. Genital markings absent.

Internal characters: Septa iv/v, vii/viii-xii/xiii slightly muscular, v/vi/vii absent. Gizzards between septa iv/v and vii/viii; typhlosole xxi-xxii to lxviii-lxxvi. last pair of hearts in xii. Testes and male funnels in unpaired sacs, in x and xi, formed by the peripheral apposition of the septa ix/x-xi/xii; seminal vesicles acinous, vestigial, in xi and xii. Prostates 2 pairs, in xvii and xix. Penial setae unornamented or ornamented with a few to several triangular teeth, tip hooked or widened then scalpel, spatula-or spoon-shaped, 0.23-0.4 mm long. 3-7.5 μ diameter. Each spermatheca with a small, digitiform to pyriform, ventrally directed, ental diverticulum, duct rather barrel–shaped, as long as or longer or smaller than ampulla.



A)





B) **C)**

Figure A.18 Photograph and line drawings of *Dichogaster bolaui*: A, ventral anterior view, clitellum (Cl), female pore (Fm), male pores (Mp); B, ventral view of clitellum and genital region, clitellum (Cl), female pores (Fm); C, spermatheca, spermatheca (Sp), gizzard (G), diverticulum (Di).

20) *Dichogaster modiglianii* (Rosa)

1972. *Dichogaster modiglianii*, Gates, **Trans. Am. Phil. Soc.** 62: p. 280.

1978. *Dichogaster modiglianii*, Righi *et al.*, **Acta Amazonica.** 8(3): p. 39.

1988. *Dichogater modiglianii*, Julka, **The fauna of india.** p. 110.

Description

External characters: Length 20-60 mm, diameter 1-2.5 mm, 76-120 segments. prostomium proepilobous. First dorsal pore iv/v or v/vi. Clitellum annular in xii-xx. Setae closely paired, 8 setae per segment. Male pores minute, in seminal grooves on the setal arc of xviii, at or close to a; prostatic pores minute, at the ends of seminal groove, on xvii and xix, at a. Female pores paired, slightly median or posteromedian to a setae. Spermathecal pores minute, at or close to a. Genital markings absent.

Internal characters: Septa iv/v, vii/viii-xii/xiii slightly muscular, v/vi/vii delicate. Gizzards between septa iv/v and vii/viii; typhlosole xxii–xxiii to xxviii-xxxi. Last pair of hearts in xii. Testes and male funnels in unpaired sacs, that of x ventral and that if xi formed by the peripheral apposition of septa x/xi/xii; seminal vesicles vestigial in xii or absent. Prostates 2 pairs, in xvii and xix. Penial setae ornamented with scale-like markings, tip slightly knobbed or truncate or narrowed to a short filament. Each spermatheca with a shortly, staked diverticulum at about the middle of barrel-shaped duct, which is longer than ampulla.

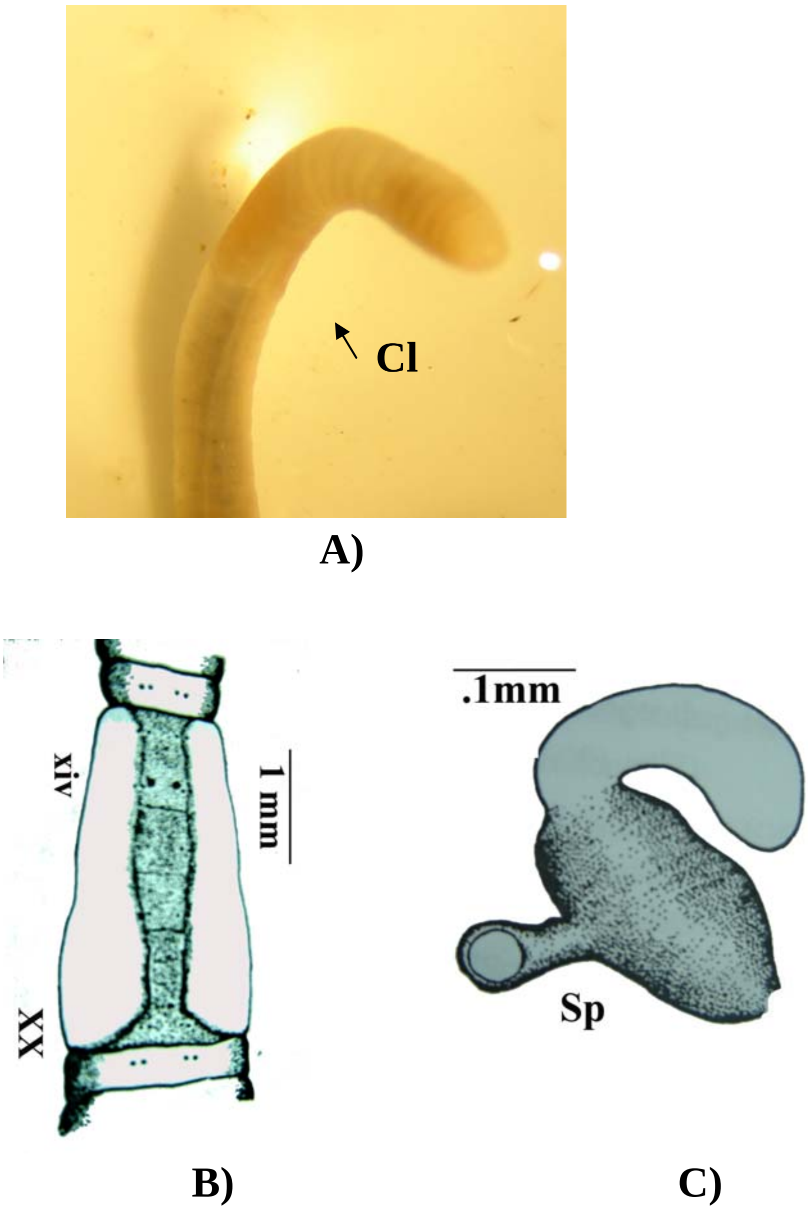


Figure A.19 Photograph and line drawings of *Dichogaster modiglianii*: A, anterior view, clitellum (Cl); B, ventral view of clitellum region, clitellum (Cl), female pores(Fm); C, spermatheca (Sp) (modified after Julka, 1988).

A.5 Family OCNERODRILIDAE

1942. *Onerodrilidae*, Gates, **Bull. Mus. Comp. Zool. Harvard College.** 89: p. 65.

1966. *Ocnerodrilidae*, Gates, **Ann. Mag. Nat. Hist. Ser.** 13, 9: p. 51.

1972. *Ocnerodrilidae*, Gates, **Trans. Am. Phil. Soc.** 62: p. 262.

Diagnosis: Male pores on xvii; prostatic pore one pair, united with the male pores. Spermathecal pores one pair, infurrow vii/viii or viii/ix, or spermathecae and pores absent. No gizzard. One pair of oesophageal sacs in ix, of simple structure. Two pairs and funnels, in x and xi. Spermathecae without diverticula.

Genus *Gordiodrilus*

1963. *Gordiodrilus* (part), Jamieson, **Bull. British Mus. Nat. Hist.** 9: p. 305.

1972. *Gordiodrilus*, Gates, **Trans. Am. Phil. Soc.** 62: 271.

Digestive system, agiceriate, with a ventro-median calciferous gland having a thick wall without large canals (but with canaliculi?) and a small central lumen opening dorsally without a stalk through floor of gut posteriorly in ix, intestinal origin in xii, without typhlosoles and supra-intestinal glands. Nephridia, inconspicuous, in or close to *CD* (throughout?). Setae, closely paired. Dorsal pores and pigment, lacking. Septa, all present from v/vi. Spermathecae, adiverticulate.

21) *Gordiodrilus elegans*

1931. *Gordiodrilus unicus*, Stephenson, **Proc. Zool. Soc. London.** p. 79.

1970. *Gordiodrilus paski*, Soota and Julka, **Proc. Zool. Soc. Calcutta.** 23: p. 205.

Description

Quadrithecal, pores at vii/viii-viii/ix. Seminal grooves, in or close to *AB*. Reproductive apertures, all at or close to *B*. Clitellum, annular, xiii/n-xviii, xix/n, xix, xx/n. Setae, *AB* ca. = *CD*, *AA* slightly < *BC*, *DD* ca. + ½ *C*. Prostomium, epilobous. Segments, 80-98. Size, 26-47 by 1-1 ½ mm. Holandric. Seminal vesicles, in ix and xii. Spermathecae, with intramural seminal chambers in a middle portion of the duct.

Figure A.20 Photograph of *Gordiodrilus elegans*.

A.6 Key to earthworm in Sakaerat Environmental Research Station and adjacent areas

1. Setae lumbricine arrangement..2
   Setae perichaetine arrangement 6
2. Setae of a posterior part of the body in the 'quincunx' arrangement,
   with saddle clitellum..*Pontoscolex corethrurus*
   Setae closely paired arrangement...3
3. Clitellum one segment, or unclearly, or absent..4
   Clitellum more than one segments...5
4. Clitellum annular in ix-xiii, male pore transverse slit at x/xi...*Drawida beddardi*
   Clitellum x-xiv, genital marking at viii near *B* .... *Drawida* sp.2
   Clitellum absent, No genital marking (head white blue tial)........... *Drawida* sp.1
5. Clitellum saddle in xiii-xxii, Female pores paired..................*Dichogaster affinis*
   Clitellum saddle in xiii- xx, Female pore *single*......................*Dichogaster bolaui*
   Clitellum annular, Female pores *pairs*........................... *Dichogaster modiglianii*
6. Spermathecal pore small or absent, Genital marking 3 pairs or more,
   behind male pore, occasionally in xix-*xxiii* .... *Polypheretima elongata*
   Spermathecal pores 2 pairs in vi/vii/viii, with small bump
   genital marking ....*Metaphire planata*
   Spermathecal pores 2 pairs in vi/vii/viii,
   genital marking with penial setae……………………………..*Amynthas* sp.2

Spermathecal pores 2 pairs in vii/viii/ix,

small size (26-47 mm) ....*Gordiodrilus elegans*

Spermathecal pores 3 pairs……………………………………………………7

Spermathecal pores 4 pairs………………………………………………….10

7. Spermathecal pore begin at v/vi/vii/viii,

with cluster of small genital marking.................................. *Amynthas defecta*

Spermathecal pore begin at vi/vii/viii/ix.. 8

8. Spermathecal pores, thick lips, with no genital marking……..*Metaphire houlleti*

Genital marking lacking or larg bump-like.....................*Amynthas seiboldi*-group

Genital marking saugsage-shape, or ellipsoidal in xvii, xix.........*Metaphire bahli*

Genital marking large…………………………..……………………9

9. Genital marking disc-like with cluster, small prostate.....................*Amynthas* sp.3

Genital marking, pairs, widely horse shoes like ....*Amynthas* sp.4

Genital marking 2 pairs with firm glistening

intersegmental at xvii, xix..*Metaphire peguana*

Genital marking 2 pairs intrasegmental at xvii, xix……….*Metaphire posthuma*

10. Spermathecal 4 pairs, with non genital marking in rather circular area

between arms U-shaped..*Amynthas alexandri*

Spermathacal 4 pairs, with genital marking, discs-like, two pairs or more

behind male pores…... *Amynthas* sp.1

APPENDIX B

DEFINITIONS OF KEY TERMS

Aborted — vestigial and functionless, or lacking and having become so during individual development.

Aclitellate — without a clitellum, adult or nearly so but still without clitellar tumescence of the epidermis. The second number in the set of three or four of the usually recognized growth stages.

Adiverticulate — without diverticula, of spermathecae.

Agiceriate — gizzardless, without a gizzard.

Amphigonic — biparental reproduction (cf. amphimictic).

Amphimictic — amphimixis, reproduction involving fertilization of an ovum by a sperm. In megadriles, with the connotation of biparental.

Ampulla — ental portion of an adiverticulate spermatheca in which spermatozoa are stored temporarily or the widened ental portion of the main axis of diverticulate spermatheca and then without such a storage function. Also, when qualified by dorsal or primary, referring to a distal constricted-off portion of a seminal vesicle.

Anandric — anandry, without testes.

Andry — referring to testis containing segments.

Aprostatic — without prostates.

Arsenosomphic — with male terminalia.

Asetal without setae, as in the peristomium and pygomere.

Athecal without spermathecae.

Atrial glandular tissue associated with a cleft or coelomic invagination containing the male pore in the Lumbricidae. Atrial sac, referring in species of the Moniligastrid (*Drawida)*, to the spermathecal diverticulum.

Atrium (plural atria) a diverticulum of a spermatheca in two Moniligastrid genera, *Drawida* and *Moniligaster*, in older contributions of Beddard, Benham, etc., may mean a tubular prostate as in the Acanthodrilidae, Ocnerodrilidae, and Octochetidae or a capsular prostate as in moniligastrids, also certain genital organs in microdriles.

Atyphlosolate without a typhlosole.

Autochthonous native, endemic.

Autogamy reproduction involving fertilization of an animal's ova by its own sperm.

Avesiculate without seminal vesicles when referring to genital system, without a bladder when referring to a nephridium.

Bidiverticulate with two diverticula (of spermathecae).

Bigiceriate with two gizzards.

Biprostatic with two prostates.

Bithecal with two spermathecae.

Blood glands	follicles clustered in region of the pharynx, some species of *Pheretima*, or in a collar on esophagus just behind the gizzard, some species of Pheretima. Function, supposedly production of haemoglobin and of blood corpuscles.
Cephalization	loss of metameric uniformity at anterior end of body involving some or all the following; abortion of septa beginning with ½, of nephridia and setal follicles beginning with ii, of segmental hearts or connectives between dorsal and ventral blood vessels. Sometimes involving total or almost complete abortion of one or more segments.
Chaeta, chaetae	see seta.
Classical System	was defined (Gates, 1959, *Bull. Mus. Comp. Zool. Havuard* 121: p. 235) as the classification of the Oligochaeta, initially presented in vol. 10 of *Das Tierreich* by Michaelsen in 1900 and expressed in its final form by Stephenson (1930) in 'The Oligochaeta' That system crystallized (Gates, 1959, *idem*) around two suppositions. (1) Genera, even subfamilies and families, can be defined and arranged in straight-line phylogenetic sequences of a mother-daughter-granddaughter sort by a very few and simple or generalized characters such as lumbricin and perichaetin, micronephric and meganephric, presence or absence of gizzards and calciferous glands. (2) Other strwcture, including much of the digestive and excretory

as well as all of the vascular and nervous systems, is phylogenetically meaningless and hence of little or no systematic importance. The present author, on the contrary, has attempted to consider each group *de novo*, without preconceptions other than certain general assumptions that were recorded, in 1960 (*Bull. Mus. Comp. Zool.* 123: p. 281). The modern system that is emerging slowly from studies of individual, anomalous, and regenerative variation, as well as of genital and geographic polymorphism, involves much greater emphasis then in the past on somatic characters as well as on various, previously neglected genital characters.

Clitellate — having a clitellum, the age or stage during which the worm has a clitellum.

Clitellum — a regional tumescence of the epidermis, the gland cells of which secrete material to form a cocoon.

Composite — with reference to certain stalked glands, each of which comprises several similar units, in some pheretimas.

Copulatory chamber — an invagination, containing the male pore, that reaches through the body wall into the coelom. Bourses copulatrices, copulatory chambers or pouches of some publications prior to 1900. Previous authors usually did not distinguish between invaginations confined to the parietes and those that reached more or less deeply into the coelomic cavity.

Copulatory pouches spermathecae (some older publications).

Copulatory setae or chaetae those in the same segment as, also near, spermathecae. Occasionally refers to similar setae in an adjacent but athecal segment.

Cosmospolitan a word that should have little use in scientific discussions because it may mean, found in every country, or only, present in more than one country.

Crop a widened portion of the digestive system that lack the muscularity of a gizzard. In the Lumbricidae, at beginning of the intestine and in front of the gizzard.

Cysticercoid larval stage of a cestode (tapeworm).

Decathecal with ten spermathecae, usually in five pairs.

Definitive capable of being used in defining a tazon.

Diagnostic uniquely characterizing a texon.

Diapuase originally charactering a stage in insect development and perhaps with certain cannotations inapplicable to megadriles but now usually meaning a state in which gut is empty and the worm is tightly coiled in a closed off cell. The state has been characterized as obligatory, internally controlled, and also as optional.

Distal away from place of attachment, as in a regenerate, an organ on a septum, the gut, or body wall. A quite different meaning, in some European publications, with respect to the body as a whole, is peripheral.

Diverticulate having a diverticulum, an outgrowth of some sort from the main axis of an organ.

Duodecathecal having 12 spermathecae, usually in 6 pairs.

Ectal ectally, near to or towards the body wall.

Endemic indigenous, native.

Ental entally, away from the body wall, toward the center of the body.

Enteroic, when referring to the excretory system, opening into gut lumen.

Enterosegmental organs paired, segmentally repeated structures of unknown function close to mD on dorsal face of the postgizzard gut in moniligastrids. Each is a bundle of glandular tubes bound together by a delicate connective tissue investment. A tube may be erect, with one end free, or curved into a horseshoe shape. Some tubes are continued ventrally within the lateral wall of the gut nearly to mV but others open directly into gut lumen. Size of the cluster and length of the units decreases posteriorly. The tubes, in preserved material, often are translucent and red, looking like thin-walled blood vessels.

Epilobous epilobic, referring to a prostomium that is continued by a tongue Into the peristomium but without reaching ½.

Epimorphic epimorphosis, Regeneration that results in addition of new tissue at the level of amputation.

Equator a central meridian of latitude of a segment often or usually equivalent to a circumferential line passing across apertures of setal follicles.

Equatorial at of or pertaining to a central meridian of latitude in a segment.

Esophageal when referring to the digestive system, that portion of the gut between the pharynx and the intestine, ending posteriorly in an esophageal valve. When referring to the circulatory system, a heart that opens dorsally into the supra-esopha-geal trunk and beneath the gut into the ventral trunk.

Estivation a state of rest or inactivity during unfavorable summer conditions.

Evaginate evagination, to grow out from, an outgrowth of, as calciferous sacs of the lumbricid esophagus.

Exotic imported, foreign, alien, in contrast to native, endemic, and autochthonous.

Family a taxon usually comprising a number of genera, with a name ending in ae, as Lumbricidae.

Female ducts female gonoducts. Oviducts (q.v.).

Female funnel enlargement of ental end of an oviduct to facilitate entry of ova on their way to the exterior.

Female pores external apertures of the female ducts.

Genital setae *vide* seta.

Genital tumescences in the Lumbricidae, areas of modified epidermis without distinct boundaries and through which follicles of genital setae open.

Giceriate having one or more gizzards in the digestive system.

Gonad gonadal, a testis, ovary, or an organ simultaneously or consecutively producing sperm and ova. Of or pertaining to a gonad.

Gonoducts male, female, ducts or passages that carry gametes from coelomic funnels to or towards the exterior. (*cf.* Sperm ducts, oviducts.) –gyny, the characterization of ovarian location along the main axis, *cf.* holo-, meta- and pro-gyny.

Haemerophilic not averse to culture or some human inte ference with the environment.

Haemerophobic averse to culture and human interference with the environment.

Hearts enlarged, segmental pulsating connectives in an anterior region of the body between the ventral and one or two other longitudinal trunks, the dorsal and supra-esophageal are esophageal, into both are latero-esophageal.

Heterodynamous development indirect because interrupted by a period of rest called diapause.

Heteromorphic with reference to regenerates, a head regenerated instead of a tail or a tail instead of an amputated head.

Hibernation the state of rest or inactivity during unfavorable winter conditions.

Holandric a classical term that now means no more than, testes restricted to x-xi, or a homoeotic equivalent. Andric and gynous characterizations of the past have been applicable only to conditions of, or those derived by reduction from, a supposedly octogonadal megadriles ancestor with testes in x-xi and ovaries in xii-xiii. The terminology was retained, whether unwittingly or not by Stephenson (1930) though his ancestral oligochaete with testes in x-xii and ovaries xiii-xiv nullified the meanings. As there is still need for such terms, they are retained with the meaning implicit in Stephenson's later usage which is now precisely stated. Illustrations of homoerotic equivalents, resulting from suppression of a segment anteriorly, are provided by Nelloscolex and Tonoscolex. These are holandric and metagynous though testes are in ix-x and ovaries are in xii. Holandry, the state or condition of being holandric.

Hologynous a classical term that now means only, ovaries restricted to xii and xiii or a homoeotic equivalent. Hologyny, the state or condition of being hologynous.

Holoic referring to an excretory system, having a pair of stomate, exotic nephridia in each segment of the body except the first and last, referring to a nephridium, having a preseptal nephrostome or funnel opening into the coelomic cavity, a post-septal looped tubule opening to the exterior through a single epidermal nephropore and derived without fragmentation from a single embryonic rudiment.

Holonephridial an unnecessarily long term with same meaning as holoic which avoids tautologies such as 'holonephridial ephridia'.

Homodynamous development direct, i.e., not interrupted by a diapause.

Homoeosis was defined (Gates, 1949 : p. 134) as ordinarily used with reference to megadriles as follows; Presence of an organ, or pairs of organs, or a series of organs, in a segment or series of segments, other than that or those, in which usually or normally found. Reference primarily is to intraspecific variation, secondarily to phylogenetic variation, for a species or genus may be homoeotic with reference to related species or genera. In case of individual homoeosis, the dislocation may involve one or both organs of a segmental pair. The former is asymmetrical, the latter symmetrical homoeosis. Homeotic, the state of being such.

Homomorphic — of regenerates, of the same cephalic or caudalic or caudal nature as the part that was amputated.

Hoplochaetellin — of male terminalia in which one pair of sperm ducts open together with the prostatic ducts of xvii or close to the prostatic pores, the other pair of sperm ducts similarly associated with the prostates of xix.

Hyperandric — having testes additional to those of x-xi. Hyperandry, the state of being such.

Hypergynous — having ovaries additional to those of xii-xiii.

Hypergyny — the state of being such.

Hypomeric of regenerates — with fewer segments than had been removed.

Intersegmental furrow — the boundary between two consecutive segments, almost in a geometrical sense, but actually the level at which the epidermis is thinnest and where color is lacking in pigmented species.

Intrasegmental groove a circumferential depression of strongly contracted specimens that contains the intersegmental furrow. A common failure, in classical writings, to distinguish between groove and furrow resulted in lack of precision with reference to systematically useful characterizations.

Invagination an ingrowth as of the epidermis into the parietes, or of the whole body wall into the coelom.

Juvenile referring to young from time of hatching till appearance of seminal furrows or grooves, genital tumescences, markings and/or pores. The first of the 3 or 4 stages usually recorde when indicating number of specimens from a site or locality.

Lateral on, of pertaining to the sides of a body or of an organ but in connection with the vascular system, a heart join the ventral trunkbelow the gut and the dorsal blood vessel above the gut. Also any segmental commissure with the same relationship to the 2 major trunks.

Lumbricin having 4 setae per segment.

Lymph giands organs on the anterior faces of septa and associated with the dorsal blood vessel, in the intestinal regions of pheretimas (perhaps of some other genera), supposedly functioning in production of phagocytes.

Male ducts male gonoducts, Sperm ducts (q.v.).

Male funnel a funnel or rosette-shaped enlargement of ental end of a sperm duct, with central aperture through which sperm pass into lumen of the duct on their way to the exterior-Sperm, prior to entering the ducts in many species, temporatily aggregate on the funnels in such a way as to reveal their presence by iridescence.

Male pores primarily openings to the exterior of the male ducts. The pores may be superficial, be invaginated into chambers confined to the parietes or reaching more or less extensively into the coelomic cavities, or the apertures of such chambers may be withdrawn into a depression that can be closed off by apposition of its margins. Union of male and prostatic ducts also introduces other complications, i.e., the ducts may unite just beneath the epidermis, deeper within the body wall, or within a chamber invaginated into the coelom which may of may not have a penis or some sort of a porophore in which case male and prostatic pores may still be discrete.

Manicate glove-shaped, usually referring to an intestinal caecum of certain pheretimas in which the organ comprises several anteriorly directed secondary caeca.

Meganephridia meganephridial, meganephridium, large excretory organs, in the classical system often meaning organs now called holoic (q.v.)

Megascolecin in the classical system megascolecine, indicating that the single pair of prostates, tubular or racemose, opened to the

	exterior in xviii, along side of or together with the sperm ducts.
Megascolecoid	of or pertaining to worms or taxa of the classical family megascolecidae which really was at least equivalent of a superfamily.
Meroic, divided	with reference to the excretory system, nephridial tubules formed by longitudinal or transverse fragmentation of the original single pair of embryonic rudiments of each segment. When parietal, often numerous and then said to be 'in forests' almost covering the body wall. Used in place of the classical meronephridial which involved tautologies such as meronephridial nephridia.
Meronephric	meronephridial, see meroic.
Metamere	a segment. Metameric, pertaining to segmentation.
Metandric, metandry	classical terms now meaning only, testes restricted to xi, the state of being such.
Microc	smaller than macroic, substituting for the classical micronephridial, a term often applied to nephridia as large as, or even larger than meganepheridia.
Micronephridia	in classical systematics of the with meaning of meroic (q.v.).
Microscopic	smaller than macroscopic, usually requiring an inverting microscope for elucidation of structure or recognition of whatever characters are involved.
Microscolecin	in classical terminology-microscolecine, provided with a

pair of tubular prostates opening to exterior in xvii along side or together with the sperm ducts.

Monophyletic with a single common ancestry.

Monothecal having only one spermatheca.

Morph with referenc to parthenogenesis, a group of individuals that reproduce parthenogenetically or that have the option to do so, and which share a common anatomy as a result of the degradstions, deletions, or other changes from structure of the ancestral amphimictic population as a result of isolation because of the uniparental reproduction.

Morphallatic morphallaxis, a regenerative process in which the new parts are reorganized from the old in situ instead of being formed anterior or posterior to the level of amputation.

Octoprostatic having 8 prostates.

Octothecal having 8 spermathecae.

Ontogenetic ontogeny, having to do with individual development.

Oviducts ducts or passages carrying female gametes, usually from a coelomic funnel to or toward the exterior.

Parthenogenesis uniparental reproduction in which the ova develop without fertilization by spermatozoa. Parthenogenetic of or pertaining to that manner of reproduction.

Penial setae refer to setae.

Pertonephridia classical term for organs, supposedly modified nephridia, opening into the buccal cavity or pharynx.

Peregrine, exotic — foreign. In the past often with the implication of widely wandering but now usually more accurately characterized as anthropochorous.

Perichaetin — location of the setae, when more than eight per segment, in a more or less complete circle around the equator of a segment.

Periproct — preferred to pygomere (q.v.) by some because of similarity to peristomium.

Peristomium — anteriormost portion of the body, around the mouth and like the anus, lacking major characteristics of a segment though counted as one.

Phylogenetic — phylogeny, having to do with past evolutionary development, as distinct from ontogenetic.

Poly-andric — having testes in more segments than x-xi.

Polydiverticulate — with reference to spermathecae, having more than two diverticula.

Polygiceriate — with several gizzards.

Polyloculate — referring to a spermathecal diverticulum, having several seminal chambers.

Polymorphic — of or pertaining to polymorphism. The latter, with reference to megadriles, is of several kinds, of which the most important for systematics are geographical and parthenogenetic.

Polyphyletic — of mixed evolutionary origin, not derived from a common ancestor.

Polyprostatic — having more than six prostates in three segments or more than eight in two segments.

Polystomate having many mouths, referring to nephridia, with several nephrostomes.

Polytesticulate having more than two pairs testes.

Polythecal having more than one or two pairs of spermathecae per segment.

Porophore any area, protuberance or special structure bearing a pore, usually that of a spermatheca, ovi-or sperm-duct.

Posterobiprostatic with prostaies in xix after loss of a pair in xvii of an acanthodrilin set.

Precis a brief summary of systematically important characters as presently known, sometimes with mention of characters about which needed information is not available. Used rather than diagnosis (a term that seems inapplicable to such summaries) and definition in as much as available data are insufficient to allow characterization to be finally 'definitve'.

Proandric proandry, classical terms that now mean only, testes restricted to x or a homoeotic equivalent, the state of being such.

Progynous a classical term now meaning only, ovaries restricted to xii or a homoeotic equivalent. Progyny, the state of being such.

Prolobic, prolobous, characterizing a prostomium demarcated from and without a tongue in i.

Prostate originally with a meaning in human anatomy that is in applicable to oligochaete organs of a different nature, Moreover, the word has been sued in classical texts, for many different kinds of glands, some of which are not even remotely associated with the male ducts. Now commonly used for tubular glands that open beside the male pores, in acanthodrilids, ocnerodrilids, and octochaetids. Gland ducts and sperm ducts may unite in the coelom or within the parieties. The very same glands may, however, open to the exterior in the segment next in front, or next behind, that of the male pores or even at sites several segments away from the male pores. Exact equivalents of the moniligastrid capsular prostates, and of the eudrilids 'euprostates' but not associated with sperm ducts, also have been found. The function of each of the various kinds of "prostates" is unknown. Usage, in the present text is restricted to stalked glands opening to the exterior in a segment containing the male pores, and as a relict of classical usage, to the same sort of gland opening to the exterior in a segment next in front of or next behind that of the male pore. Lumbricid 'prostates'. without stalks are characterized as 'atrial glands'.

Prostomium a protuberance anteriorly and above the mouth from the first segment. The megadriles equivalent of an elephant's trunk.

Prostandric protandrius, proterandrous, maturing sperm before the ova. Protandry, the state of being such.

Proximal near to towards, place of attachment, as in a regenerate, an organ on a septum, the gut, or body wall.

Pseudogamic of or pertaining to pseudogamy, a method of reproduction in which entrance of the sperm stimulates development of the egg but without involving bigarental heredity.

Pseudvesicles structures on posterior faces of 12/13 or 13/14 that are serially homologous with seminal vesicles. Usually retained from an embryonic or early juvenile state. Function unknown.

Pygomere the terminal portion of the body, sometimes called the anal segment but lacking some of the characters of a metamere.

Quadriprostatic with four prostates.

Quadrithecal with four spermathecae.

Quincunx a pattern involving location of setae of three consecutive segments in a group of five, with one centrally positioned.

Racemose from the latin racemes, meaning bunch, as perhaps of grapes, long used to characterize the lobular kind of prostate present in Pheretima and related genera. Lobulation may or may not be obvious superficially but within those glands a prostatic duct branches repeatedly, the subdivisions usually unrecognizable macroscopically. The finest ductules end in microlobules. Prostatic glands with a central lumen, from which short branches pass out, were believed by classical authorities (*cf.* Stephenson, 1930: p. 369), to be intermediate between the simpler tubular kind (without such branches) and polylobular glands (without a central or macroscopically recognizable lumen). Intermediate stages between a purely mesodermal organ (Stephenson, 1930: p. 368) and one arising as an ectodermal invagination seem improbable if not impossible.

Segment a portion of the body, along the anteroposterior axis, between 2 consecutive intersegmental furrows and the associated septa.

Seminal literally of or pertaining to seeds, but characterizing structures in which sperm are involved, as follows.

Seminal furrows or grooves except in the Lumbricidae, referring to distinct and permanent markings in the epidermis that are associated with male, and sometimes also prostatic, pores, and through which sperm and/or prostatic secretions move at time of copulation.

Seminal receptacles formerly used for spermathecae or occasionally even for seminal vesicles.

Seminal reservoirs in some older publications-seminal vericles.

Seminal vesicles pockets from a septum in which sperm are matured.

A German phrase for testis sacs was consistently mistranslated (Michaelsen, 1909) as seminal vesicles. The German for seminal vesicles was translated as sperm sacs. Supposed seminal vesicles in x, as well sometimes as in xi, species of Pheretima, have been testis sacs, of ocnerodrilid genera have been hypertrophied testes. The septal outgrowth may be simple, tubular and then is posteriorly directed as in Group I megadriles. Vesicles in Group II begadriles are lobed, with connective tissue partitions internally, not posterorly directed primarily though secondary growth may resutly in posterior elongation, in ix and x on anterior faces of the septa, in xi and xii on posterior faces of the septa.

Seta, setae from Latin meaning bristle, hence more appropriate than chaeta from Greek meaning hair or mane. Also note, setole (Italian), soie (French), cedas (Spanish), cerda (Portuguese), Solid rods, secreted by cell at ental end of a tubular epidermal in growth, the setal follicle. Follicles are provided with protractor and retractor muscles so that the seta can be partially protruded beyond the epidermis or retracted. A normal, unspecialized seta has a slight double curvature providing a shape called sigmoid, a pointed outer end called the base. Specialized setae, usually on longer sigmoid, often ornamented in one or more of several ways, if associated more or less closely with male or prostatic pores are called penial, but copulatory if associated with spermathecae. Modified setae asscciated with genital tumescences and/or with special glands but not especially with the male, female, prostatic or spermathecal pores are designated only as genital. Setae often are variously modified in shape and may be sculptured (ornamented) ectally in numerous ways. Ornamentation by circles of fine spines or teeth thus may characterize enlarged setae at either end of the body.

Sexprostatic with 6 prostates in 3 consecutive segments.

Sexthecal with 3 pairs of spermathecae.

Salivary gland in classical writings a term for organs, opening in to buccal cavity or the pharynx, that sometimes were thought to be modified excretory organs = peptonephridia.

Somatic of or pertaining to any portion of the anatomy except the reproductive organs.

Spermatheca	spermathecal, an organ in which sperm received from a copulatory partner are stored until extrusion during laying.
Sperm ducts	ducts or tubes that carry sperm from the male funnels to or towards the exterior.
Spermiducal	glands, spermiducal pores, of older texts now are called prostates, prostatic or male pores.
Sperm sacs	in writing of some classical authorities, seminal vesicles, or sometimes referring to testis sacs or spermathecae.
Stomate	havng a mouth, referring to a nephridium, with a funnel. A nephridium with a funnel sometimes is said to be ‘open’
Sulcate	having seminal furrows of grooves.
Tanylobous	characterizing a prostomium with a tongue that Reaches all the way through segment i to ½.
Taxon	any unit in a system of classifying plants or animals.
Testicular chamber	testis sac.
Testicular vesicle	testis sac or some part of it.
Testicular sac	sometimes mistaken, when enlarged in parthenogenetic morphs for seminal vesicles.
Testis sac	usually a closed off coelomic space containing one or both testis and male funnels of a segment.
Thecal	having spermathecae.
Trabeculate	characterizing megadrile seminal vesicles that develop as connective tissue proliferations from a septum so as to have numerous irregular spaces that remain inconsiderable until spermatogonia begin to enter.

Troglophile cave-loving, but sometimes used to characterize animals living permanently and reproducing in caves. Various species earthworms can be called troglophile but none of them are confined to caves, i.e., they are not obligatory troglohiles.

Typhlosole any longitudinal fold of gut wall, especially if projecting into gut lumen from the roof at mD or the floor at mV. Lateral typhlosoles (in the intestine) usually are rudimentary.

Unidiverticulate having one diverticulum, as of spermathecae.

Uniloculate having only one seminal chamber, as of spermathecal diverticulum.

Vas deferens plural, vasa deferentia. Sperm duct(s).

Vesicle referring to the excretory sysyem, the bladder, referring to the reproductive system, asteriorly or posteriorly directed pockets of a septum in which male germ cells mature.

Vesiculate with reference to a nephridium-provided with a bladder, with referenceto a reproductive system-having seminal vesicles, with reference to tissue or organ structure-having small spaces.

Vermicompost compost generate from the processing of organic waste materials by earthworms.

Vermiculture the intensive cultivation of earthworms for used as fish bait, feed supplement, or as by product of vermicomposting.

Zygolobous a prostromium that is not in any way demarcated from the first segment.

APPENDIX C

RAW DATA OF EARTHWORMS AND ENVIRONMENTAL FACTORS IN SAKAERAT ENVIRONMENTAL RESEARCH STATION AND ADJACENT AREAS

DATA FOR CHAPTER III

Table C.1 Data of earthworm (number, density), climate factor, soil factor, soil nutrient and litter, in different sites in June, 2006.

sites	earthworm		Climate factor			Soil factor			Soil nutrient						Litter			
	No. (ind/site)	density (ind/m^2)	temperature mean(°C)	rainfall (mm)	Rh%	miosture (%)	pH	temperature (°C)	N (g/kg)	P (g/kg)	K (g/kg)	CaO (g/kg)	OM (%)	C/N	OM (%)	OC (%)	total N (%)	C/N
DE1	13	144.44	28.4	33.4	84.57	19.08	5.12	24.5	1.633	0.015	0.43	0.538	2.710	9.624	59.763	34.67	1.839	18.85
DE2	0	0.00	27.5	54.8	85	18.11	5.6	24.5	1.486	0.005	0.38	0.283	1.332	5.199	59.63	34.59	1.629	21.23
DE3	2	22.22	27.6	173.2	81.83	19.52	4.79	24	2.404	0.024	0.28	0.564	3.663	8.837	55.55	32.22	1.755	18.36
DE4	2	22.22	27.6	173.2	81.83	19.92	8.61	22.5	2.082	0.015	0.63	0.712	2.359	6.574	63.555	36.87	1.912	19.28
DIF1	0	0.00	28.2	59.9	87	9.36	6.91	27	1.573	0.017	0.37	1.181	1.501	5.536	79.21	45.95	2.78	16.53
DIF2	0	0.00	28.2	59.9	87	13.03	5.19	27	0.896	0.013	0.2	0.416	1.137	7.359	74.119	42.99	0.869	49.49
DIF3	6	66.67	28.2	59.9	87	19.32	5.98	27	1.016	0.012	0.44	0.779	1.228	7.009	69.361	40.38	2.159	18.7
DIF4	0	0.00	28.2	59.9	87	5.29	7.73	26	1.126	0.005	0.39	0.987	1.436	7.400	40.218	23.33	1.571	14.85
DINF1	0	0.00	28.2	43.6	83.77	13.23	7.39	25.5	1.910	0.012	0.52	0.834	2.904	8.821	61.868	35.89	1.994	18
DINF2	0	0.00	28.2	43.6	83.77	11.33	4.88	28	1.793	0.009	0.26	0.518	1.705	5.517	72.228	41.9	2.118	19.78
DINF3	3	33.33	28.2	43.6	83.77	16.67	6.12	27	1.017	0.003	0.37	0.457	1.232	7.024	42.769	24.81	1.347	18.41
DINF4	0	0.00	28.2	43.6	83.77	8.38	4.77	25	1.468	0.015	0.49	1.346	2.597	10.264	73.999	42.92	1.722	24.93
PL1	13	144.44	27.6	173.2	81.83	25.88	5.93	25.5	2.031	0.017	0.37	0.547	2.218	6.335	36.528	21.19	1.631	12.99
PL2	5	55.56	27.6	173.2	81.83	20.11	5.15	25	2.153	0.004	0.41	0.662	2.281	6.146	70.409	40.84	1.936	21.09
PL3	16	177.78	27.6	173.2	81.83	19.44	4.97	23.5	1.938	0.004	0.5	0.566	2.454	7.346	82.608	47.92	2.515	19.05
PL4	6	66.67	27.6	173.2	81.83	14.04	4.42	25	1.799	0.013	0.55	0.362	2.360	7.611	46.969	27.24	1.931	14.11
G1	14	155.56	27.6	173.2	81.83	23.41	5.42	25	1.470	0.006	0.3	0.275	1.654	6.526	81.765	47.43	2.277	20.83
G2	12	133.33	27.6	173.2	81.83	24.55	5.89	25.5	1.800	0.01	0.52	0.906	2.223	7.162	56.087	32.53	2.004	16.23
G3	3	33.33	27.6	173.2	81.83	26.37	5.53	26.5	2.476	7E-05	0.6	0.541	3.775	8.843	70.296	40.78	1.939	21.03
G4	5	55.56	27.6	173.2	81.83	22.56	5.52	25	1.909	0.003	0.38	0.715	2.163	6.571	66.804	38.75	1.103	35.12
R1	0	0.00	28.2	59.9	87	12.23	6.65	29	1.300	0.071	0.26	1.586	0.784	3.498	29.382	17.04	0.132	129.1
R2	8	88.89	28.2	59.9	87	15.68	5.7	27.5	1.250	0.008	0.32	0.935	0.657	3.049	20.549	11.92	0.171	69.7
R3	13	144.44	28.2	59.9	87	20.34	6.64	28	1.290	0.024	0.2	1.098	0.562	2.527	59.162	34.32	0.898	38.21
R4	19	211.11	28.2	59.9	87	29.98	5.99	28.5	0.850	0.088	0.54	1.810	2.147	14.651	54.616	31.68	0.778	40.72
S1	14	155.56	28.2	59.9	87	15.96	4.84	27	2.150	0.144	1.17	1.409	1.173	3.165	20.412	11.84	1.552	7.63
S2	56	622.22	28.2	59.9	87	15.71	7.62	31	2.170	0.036	0.56	0.792	0.383	1.024	55.858	32.4	1.014	31.95
S3	12	133.33	28.2	59.9	87	21.35	5.24	29.5	0.840	0.03	0.3	0.520	0.892	6.160	61.904	35.91	2.537	14.15
S4	8	88.89	28.2	59.9	87	21.49	6.08	30	1.260	0.057	0.26	1.035	0.886	4.079	28.081	16.29	2.231	7.3

Table C.1 Data of earthworm (number, density), climate factor, soil factor, soil nutrient and litter, in different sites in June, 2006 (Continued).

sites	earthworm		Climate factor			Soil factor			Soil nutrient						Litter			
	No. (ind/site)	density (ind/m^2)	temperature mean(°C)	rainfall (mm)	Rh%	miosture (%)	pH	temperature (°C)	N (g/kg)	P (g/kg)	K (g/kg)	CaO (g/kg)	OM (%)	C/N	OM (%)	OC (%)	total N (%)	C/N
C1	9	100.00	28.2	59.9	87	10.65	6.55	26	1.270	0.031	0.08	0.683	0.810	3.700	12.664	7.345	0.495	14.84
C2	28	311.11	28.2	59.9	87	9.68	5.63	28	1.680	0.027	0.14	0.979	0.722	2.493	42.435	24.61	1.411	17.44
C3	10	111.11	28.2	59.9	87	20.08	6.72	29	1.280	0.053	0.21	0.817	0.895	4.056	47.947	27.81	1.524	18.25
C4	0	0.00	28.2	59.9	87	16.84	4.84	27	1.290	0.042	0.08	0.774	0.889	3.997	69.133	40.1	1.172	34.22
M1	0	0.00	28.2	59.9	87	11.43	5.77	26	0.361	0.163	0.31	0.493	1.555	24.981	80.718	46.82	0.611	76.7
M2	39	433.33	28.2	59.9	87	22.58	6.34	25	1.425	0.701	0.7	1.996	4.296	17.488	65.104	37.76	0.635	59.45
M3	4	44.44	28.2	59.9	87	15.17	6.23	26	0.685	0.345	0.43	0.948	1.907	16.148	66.135	38.36	0.695	55.23
M4	20	222.22	28.2	59.9	87	18.63	5.39	26	0.220	0.165	0.25	0.334	0.800	21.098	77.491	44.95	0.647	69.45
H1	0	0.00	28.2	59.9	87	17.72	8.09	26	0.858	0.222	0.19	1.877	1.213	8.200	n/a	n/a	n/a	n/a
H2	11	122.22	28.2	59.9	87	13.24	8.95	28	1.280	0.138	1.45	0.937	1.225	5.551	n/a	n/a	n/a	n/a
H3	6	66.67	28.2	59.9	87	20.12	8.87	26	1.680	0.28	0.51	1.900	1.863	6.432	n/a	n/a	n/a	n/a
H4	17	188.89	28.2	59.9	87	18.46	7.84	26	1.270	0.121	0.13	1.075	0.760	3.471	n/a	n/a	n/a	n/a
SERS1	3	33.33	28.2	43.6	83.77	10.99	7.73	25	0.633	0.283	0.7	1.597	1.307	11.976	n/a	n/a	n/a	n/a
SERS2	0	0.00	28.2	43.6	83.77	16.67	7.74	23.5	1.163	0.34	0.43	0.027	1.789	8.924	n/a	n/a	n/a	n/a
SERS3	0	0.00	28.2	43.6	83.77	16.16	8	24.5	1.165	0.333	0.46	2.637	1.700	8.466	n/a	n/a	n/a	n/a
SERS4	0	0.00	28.2	43.6	83.77	10.73	7.55	25	0.720	0.306	0.7	1.836	1.307	10.528	n/a	n/a	n/a	n/a
SRS1	1	11.11	27.6	173.2	81.83	24.27	6.92	25	1.892	0.938	0.66	5.219	3.567	10.934	n/a	n/a	n/a	n/a
SRS2	0	0.00	27.6	173.2	81.83	22.78	5.82	25	1.512	0.063	0.44	2.410	2.667	10.232	n/a	n/a	n/a	n/a
SRS3	21	233.33	27.6	173.2	81.83	22.59	7.04	25.5	1.094	0.079	0.36	1.462	1.816	9.626	n/a	n/a	n/a	n/a
SRS4	4	44.44	27.6	173.2	81.83	17.02	7.14	25.5	0.695	0.133	0.45	1.285	1.006	8.395	n/a	n/a	n/a	n/a

Table C.2 Data of earthworm (number, density), climate factor, soil factor, soil nutrient and litter, in different sites in August, 2006.

sites	earthworm		Climate factor			Soil factor			Soil nutrient						Litter			
	No. (ind/site)	density (ind/m^2)	temperature mean(°C)	rainfall (mm)	Rh%	miosture (%)	pH	temperature (°C)	N (g/kg)	P (g/kg)	K (g/kg)	CaO (g/kg)	OM (%)	C/N	OM (%)	OC (%)	total N (%)	C/N
DE1	16	177.78	27.9	104.1	85	25.19	4.94	25	2.719	0.036	0.41	1.168	4.546	9.699	81.795	47.45	2.419	19.62
DE2	22	244.44	26.9	85.2	86	17.64	6.15	25	3.110	0.014	0.51	3.137	5.121	9.551	64.598	37.47	1.761	21.28
DE3	6	66.67	26.7	135	81.95	21.19	5.17	25	2.113	0.011	0.29	0.887	3.270	8.979	79.21	45.95	1.528	30.06
DE4	15	166.67	26.7	135	81.95	19.40	4.96	23	1.685	0.016	0.58	0.600	2.241	7.715	56.306	32.66	1.915	17.06
DIF1	1	11.11	27.4	82.7	87	3.71	5.35	28.5	1.446	0.013	0.2	0.614	2.301	9.228	56.971	33.05	1.69	19.55
DIF2	0	0.00	27.4	82.7	87	23.71	5.35	28.5	1.603	0.022	0.28	0.600	2.740	9.915	74.795	43.39	1.814	23.92
DIF3	3	33.33	27.4	82.7	87	6.37	5.97	28	1.181	0.004	0.22	0.377	1.412	6.933	68.923	39.98	1.987	20.12
DIF4	8	88.89	27.4	82.7	87	7.11	6.08	30	1.016	0.005	0.38	0.703	1.236	7.056	62.343	36.16	2.473	14.62
DINF1	0	0.00	27.9	93.4	85	5.79	5.11	26	1.780	0.019	0.46	0.871	3.585	11.682	51.017	29.59	0.824	35.89
DINF2	0	0.00	27.9	93.4	85	3.33	5.18	27	1.268	0.01	0.42	0.329	1.864	8.525	56.842	32.97	1.188	27.75
DINF3	0	0.00	27.9	93.4	85	6.49	5.28	28	1.434	0.013	0.35	0.394	1.690	6.837	52.638	30.53	0.75	40.71
DINF4	0	0.00	27.9	93.4	85	9.62	5.56	26	1.855	0.023	0.32	0.555	1.276	3.991	72.394	41.99	1.795	23.39
PL1	36	400.00	26.7	135	81.95	9.67	5.05	26	2.110	0.004	0.46	1.202	2.302	6.329	59.665	34.61	2.068	16.73
PL2	21	233.33	26.7	135	81.95	11.60	5.4	25	2.709	0.009	0.32	0.915	3.659	7.834	63.941	37.09	2.859	12.97
PL3	4	44.44	26.7	135	81.95	11.38	5.12	25	2.282	0.016	0.67	0.626	2.835	7.206	48.745	28.27	1.407	20.1
PL4	9	100.00	26.7	135	81.95	26.43	4.4	25	2.034	0.022	0.31	0.516	3.054	8.710	54.597	31.67	1.814	17.46
G1	19	211.11	26.7	135	81.95	25.66	5.97	26	1.351	0.009	0.22	0.455	0.384	1.649	63.157	36.63	2.001	18.31
G2	24	266.67	26.7	135	81.95	22.93	6.04	26	1.690	0.006	0.35	0.717	1.910	6.556	61.722	35.8	1.59	22.51
G3	21	233.33	26.7	135	81.95	30.88	5.53	23	2.287	0.006	0.44	0.840	3.056	7.752	38.838	22.53	1.668	13.51
G4	29	322.22	26.7	135	81.95	29.94	5.56	24	2.700	0.007	0.5	0.778	2.926	6.285	51.103	29.64	0.568	52.2
R1	19	211.11	27.4	82.7	87	12.94	7.11	28	1.710	0.024	0.17	2.388	1.343	4.556	30.38	17.62	0.67	26.3
R2	10	111.11	27.4	82.7	87	24.72	5.84	28	2.090	0.019	0.23	1.867	1.264	3.508	24.395	14.15	0.809	17.49
R3	10	111.11	27.4	82.7	87	12.05	6.7	27	2.140	0.088	0.33	0.833	1.146	3.106	65.856	38.2	1.292	23.57
R4	8	88.89	27.4	82.7	87	19.92	5.31	27	1.290	0.022	0.12	0.300	0.583	2.621	52.413	30.4	0.732	41.53
S1	12	133.33	27.4	82.7	87	16.24	5.38	29	1.250	0.252	0.29	1.301	0.817	3.791	22.093	12.82	0.729	17.58
S2	36	400.00	27.4	82.7	87	18.04	5.66	29	1.270	0.156	0.28	0.721	0.750	3.425	49.069	28.46	2.875	9.9
S3	5	55.56	27.4	82.7	87	17.21	5.21	29	1.270	0.05	0.14	0.461	0.763	3.485	32.811	19.03	0.59	32.26
S4	8	88.89	27.4	82.7	87	6.98	6.99	27	1.240	0.096	0.28	0.948	0.309	1.445	31.193	18.09	0.491	36.85

Table C.2 Data of earthworm (number, density), climate factor, soil factor, soil nutrient and litter, in different sites in August, 2006 (Continued).

sites	earthworm		Climate factor			Soil factor			Soil nutrient						Litter			
	No. (ind/site)	density (ind/m^2)	temperature mean(°C)	rainfall (mm)	Rh%	miosture (%)	pH	temperature (°C)	N (g/kg)	P (g/kg)	K (g/kg)	CaO (g/kg)	OM (%)	C/N	OM (%)	OC (%)	total N (%)	C/N
C1	8	88.89	27.4	82.7	87	14.86	6.54	28	1.280	0.049	0.12	1.624	0.730	3.308	40.046	23.23	0.645	36.01
C2	3	33.33	27.4	82.7	87	13.69	5.84	29	1.280	0.031	0.11	0.429	0.423	1.917	65.644	38.08	2.219	17.16
C3	6	66.67	27.4	82.7	87	8.62	5.52	25	1.300	0.029	0.13	0.931	0.809	3.610	61.904	35.91	0.82	43.79
C4	21	233.33	27.4	82.7	87	10.77	4.91	26	1.290	0.037	0.12	0.636	0.711	3.197	72.144	41.85	2.099	19.94
M1	3	33.33	27.4	82.7	87	13.73	4.49	26	0.743	0.474	0.28	0.359	1.140	8.897	67.742	39.29	0.572	68.7469
M2	27	300.00	27.4	82.7	87	16.13	6.76	26	0.764	0.364	0.46	0.924	1.021	7.754	74.194	43.04	0.435	98.9439
M3	1	11.11	27.4	82.7	87	9.26	6.72	26	0.928	0.424	0.5	1.847	1.242	7.766	72.503	42.05	0.716	58.699
M4	10	111.11	27.4	82.7	87	7.29	5.54	28	0.532	0.075	0.15	0.631	0.913	9.950	70.53	40.91	0.795	51.4363
H1	16	177.78	27.4	82.7	87	16.39	6.59	28	1.680	0.364	0.17	1.430	0.842	2.907	n/a	n/a	n/a	n/a
H2	0	0.00	27.4	82.7	87	16.49	7.05	25	1.260	0.19	0.96	0.990	1.194	5.497	n/a	n/a	n/a	n/a
H3	6	66.67	27.4	82.7	87	25.99	6.87	25	1.660	0.075	0.3	1.960	1.961	6.852	n/a	n/a	n/a	n/a
H4	26	288.89	27.4	82.7	87	29.41	6.44	25	2.140	0.298	0.12	2.053	1.502	4.071	n/a	n/a	n/a	n/a
SERS1	0	0.00	27.9	93.4	85	14.69	6.73	25	2.176	0.991	0.65	3.257	3.416	9.107	n/a	n/a	n/a	n/a
SERS2	0	0.00	27.9	93.4	85	9.91	6.71	24	1.876	0.164	0.3	3.286	3.123	9.657	n/a	n/a	n/a	n/a
SERS3	21	233.33	27.9	93.4	85	25.50	6.56	24	2.350	0.321	0.29	3.230	3.333	8.228	n/a	n/a	n/a	n/a
SERS4	70	777.78	27.9	93.4	85	9.05	6.54	27	1.765	0.274	0.6	2.983	2.772	9.108	n/a	n/a	n/a	n/a
SRS1	3	33.33	26.7	135	81.95	22.59	6.46	24	1.135	0.149	0.49	2.695	1.421	7.260	n/a	n/a	n/a	n/a
SRS2	9	100.00	26.7	135	81.95	17.14	5.99	26	0.895	0.047	0.29	1.393	1.301	8.433	n/a	n/a	n/a	n/a
SRS3	20	222.22	26.7	135	81.95	19.79	5.61	27	1.437	0.064	0.32	1.441	1.933	7.802	n/a	n/a	n/a	n/a
SRS4	22	244.44	26.7	135	81.95	22.13	6.1	27	0.925	0.14	0.56	1.361	1.595	9.999	n/a	n/a	n/a	n/a

Table C.3 Data of earthworm (number, density), climate factor, soil factor, soil nutrient and litter, in different sites in October, 2006.

sites	earthworm		Climate factor			Soil factor			Soil nutrient						Litter			
	No. (ind/site)	density (ind/m^2)	temperature mean(°C)	rainfall (mm)	Rh%	miosture (%)	pH	temperature (°C)	N (g/kg)	P (g/kg)	K (g/kg)	CaO (g/kg)	OM (%)	C/N	OM (%)	OC (%)	total N (%)	C/N
DE1	15	166.67	26.9	140.5	92	15.01	5.3	25	1.766	0.016	0.4	0.711	2.757	9.054	58.212	33.76	1.951	17.31
DE2	7	77.78	25.3	170.5	93	21.63	5.56	23	3.045	0.011	0.3	2.341	4.764	9.075	60.35	35.01	1.837	19.06
DE3	1	11.11	25.8	138.6	86.53	12.70	4.87	23	2.452	0.022	0.3	0.749	3.937	9.313	71.626	41.55	1.85	22.45
DE4	5	55.56	25.8	138.6	86.53	18.89	4.64	23	2.453	0.023	0.44	0.618	7.892	18.662	75.393	43.73	2.207	19.82
DIF1	5	55.56	25.5	179.5	93	3.73	5.5	30	2.698	0.009	0.41	0.425	1.089	2.342	57.699	33.47	2.089	16.02
DIF2	2	22.22	25.5	179.5	93	9.11	5.5	30	1.947	0.02	0.28	0.673	3.419	10.187	66.463	38.55	1.996	19.32
DIF3	4	44.44	25.5	179.5	93	7.34	5.43	25	1.352	0.008	0.43	1.245	1.917	8.224	54.169	31.42	2.194	14.32
DIF4	11	122.22	25.5	179.5	93	18.71	5.66	27	1.106	0.004	0.06	0.076	1.252	6.567	52.628	30.53	2.37	12.88
DINF 1	7	77.78	27.3	204.9	91	9.98	6.04	25	2.799	0.016	0.38	2.024	4.462	9.248	61.946	35.93	2.1	17.11
DINF 2	0	0.00	27.3	204.9	91	7.66	4.92	24	1.606	0.01	0.24	0.344	1.233	4.455	42.066	24.4	1.859	13.13
DINF 3	10	111.11	27.3	204.9	91	5.51	6.11	27	0.766	0.009	0.24	0.306	0.778	5.891	73.499	42.63	0.635	67.11
DINF 4	18	200.00	27.3	204.9	91	8.47	5.09	24	2.449	0.032	0.24	0.785	4.325	10.245	47.932	27.8	2.065	13.47
PL1	21	233.33	25.8	138.6	86.53	12.86	4.08	25	1.682	0.005	0.33	0.333	1.975	6.810	79.847	46.32	2.43	19.06
PL2	62	688.89	25.8	138.6	86.53	33.53	4.8	21	2.188	0.005	0.35	0.530	2.226	5.903	6.242	39.58	1.078	36.72
PL3	6	66.67	25.8	138.6	86.53	14.81	5.09	23	1.849	0.034	0.43	0.779	2.195	6.885	75.48	43.78	2.246	19.49
PL4	13	144.44	25.8	138.6	86.53	11.18	4.73	25	1.957	0.016	0.48	0.276	1.369	4.058	66.338	38.48	1.537	25.04
G1	19	211.11	25.8	138.6	86.53	16.76	5.24	23	1.276	0.005	0.25	0.285	1.734	7.882	87.897	50.99	2.071	24.62
G2	19	211.11	25.8	138.6	86.53	17.26	5.48	23	1.269	0.007	0.48	0.460	2.493	11.393	75.214	43.63	2.042	21.37
G3	23	255.56	25.8	138.6	86.53	29.66	5.53	25	2.191	0.005	0.59	1.116	3.455	9.146	82.256	47.71	4.051	11.78
G4	22	244.44	25.8	138.6	86.53	15.68	5.35	23	1.281	0.003	0.36	0.638	1.663	7.528	82.256	47.71	2.426	19.66
R1	15	166.67	25.5	179.5	93	23.32	6.38	28	1.720	0.123	0.23	2.466	1.222	4.121	29.018	16.83	0.396	42.51
R2	12	133.33	25.5	179.5	93	35.06	6.4	30	1.690	0.049	0.1	1.814	1.300	4.462	54.343	31.52	0.437	72.13
R3	6	66.67	25.5	179.5	93	17.49	6.09	27	1.670	0.082	0.25	0.699	0.607	2.108	71.504	41.48	1.343	30.88
R4	17	188.89	25.5	179.5	93	29.71	6.81	27	1.300	0.025	0.12	0.261	0.639	2.851	36.268	21.04	2.021	10.41
S1	20	222.22	25.5	179.5	93	2.40	6.05	27	1.290	0.008	0.06	0.134	0.057	0.256	17.839	10.35	0.619	16.72
S2	0	0.00	25.5	179.5	93	20.75	6.41	28	1.290	0.337	0.99	1.127	0.907	4.078	57.522	33.37	2.642	12.63
S3	8	88.89	25.5	179.5	93	17.23	5.28	30	1.280	0.116	0.28	0.485	0.872	3.952	39.423	22.87	0.324	70.58
S4	8	88.89	25.5	179.5	93	21.18	6.31	27	1.280	0.185	0.22	1.796	1.014	4.595	72.916	42.3	1.58	26.77

Table C.3 Data of earthworm (number, density), climate factor, soil factor, soil nutrient and litter, in different sites in October, 2006 (Continued).

sites	earthworm		Climate factor			Soil factor			Soil nutrient						Litter			
	No. (ind/site)	density (ind/m^2)	temperature mean(°C)	rainfall (mm)	Rh%	miosture (%)	pH	temperature (°C)	N (g/kg)	P (g/kg)	K (g/kg)	CaO (g/kg)	OM (%)	C/N	OM (%)	OC (%)	total N (%)	C/N
C1	13	144.44	25.5	179.5	93	19.26	6.06	29	1.720	0.027	0.13	1.252	0.720	2.428	36.168	20.98	0.608	34.5
C2	10	111.11	25.5	179.5	93	3.60	5.46	27	1.670	0.023	0.08	0.645	0.479	1.664	47.494	27.55	1.464	18.82
C3	5	55.56	25.5	179.5	93	7.21	5.68	30	2.150	0.039	0.17	0.648	0.820	2.212	69.146	40.11	1.228	32.66
C4	10	111.11	25.5	179.5	93	22.26	5.22	29	2.130	0.041	0.14	0.708	0.851	2.317	46.248	26.83	1.215	22.08
M1	9	100.00	25.5	179.5	93	12.16	6.02	25	0.707	0.103	0.18	0.691	0.925	7.591	70.441	40.86	0.783	52.1908
M2	8	88.89	25.5	179.5	93	17.80	6.08	25	1.067	0.414	0.32	1.423	1.415	7.694	74.194	43.04	0.788	54.618
M3	4	44.44	25.5	179.5	93	16.97	6.58	26	1.138	0.66	0.39	2.289	2.319	11.821	75.587	43.84	0.875	50.0915
M4	41	455.56	25.5	179.5	93	17.02	6.79	24	0.479	0.069	0.26	0.961	1.012	12.252	65.093	37.76	0.694	54.4197
H1	21	233.33	25.5	179.5	93	17.21	6.64	29	1.280	0.235	0.14	1.407	1.009	4.572	n/a	n/a	n/a	n/a
H2	6	66.67	25.5	179.5	93	14.37	6.82	25	1.260	0.548	0.2	1.423	2.211	10.178	n/a	n/a	n/a	n/a
H3	11	122.22	25.5	179.5	93	16.90	5.54	26	1.730	0.147	0.18	0.616	0.831	2.786	n/a	n/a	n/a	n/a
H4	28	311.11	25.5	179.5	93	24.76	6.75	24	1.250	0.286	0.29	7.588	2.034	9.439	n/a	n/a	n/a	n/a
SERS1	84	933.33	27.3	204.9	91	16.84	7.43	25	4.456	0.471	1.01	5.809	6.247	8.132	n/a	n/a	n/a	n/a
SERS2	33	366.67	27.3	204.9	91	29.34	7.39	25	1.436	0.244	0.21	4.295	2.848	11.504	n/a	n/a	n/a	n/a
SERS3	57	633.33	27.3	204.9	91	24.19	7.52	25	1.362	0.231	0.35	2.720	2.514	10.707	n/a	n/a	n/a	n/a
SERS4	46	511.11	27.3	204.9	91	16.80	6.64	25	1.440	0.199	0.57	2.852	2.765	11.136	n/a	n/a	n/a	n/a
SRS1	23	255.56	25.8	138.6	86.53	15.43	7.55	26	2.531	1.617	0.51	5.678	5.722	13.113	n/a	n/a	n/a	n/a
SRS2	42	466.67	25.8	138.6	86.53	9.49	7.13	25	1.588	0.08	0.36	1.829	2.375	8.675	n/a	n/a	n/a	n/a
SRS3	55	611.11	25.8	138.6	86.53	15.86	6.97	29	1.022	0.098	0.38	1.783	1.722	9.771	n/a	n/a	n/a	n/a
SRS4	9	100.00	25.8	138.6	86.53	9.91	6.85	29	0.960	0.147	0.98	1.341	1.411	8.525	n/a	n/a	n/a	n/a

Table C.4 The number of earthworm in different land used in June, 2006.

Earthworm	Forest types				Agricultural land used				Residential areas			**total**
Families/species	DEF	DIF	G	PL	M	R	S	C	H	SERS	SRS	
MEGASCOLECIDAE												
Amynthas alexandri	-	-	-	-	-	-	-	2	-	1	-	**3**
A. defecta	-	-	-	-	-	-	-	-	-	-	-	**0**
A. sieboldi-group	-	-	-	-	-	-	-	-	-	-	-	**0**
Amynthas sp. 1	-	-	-	-	-	-	-	-	-	-	-	**0**
Amynthas sp. 2	-	-	-	-	-	-	-	-	-	-	-	**0**
Amynthas sp. 3	-	3	-	-	-	-	-	1	-	-	-	**4**
Amynthas sp. 4	-	-	-	-	-	-	-	-	-	-	-	**0**
Metaphire bahli	-	-	-	-	3	-	-	-	-	-	-	**3**
M. houletti	-	-	-	-	-	2	14	8	-	-	-	**24**
M. peguana	-	-	-	-	-	-	-	-	-	-	-	**0**
M. planata	-	-	-	-	3	12	7	-	4	-	31	**57**
M. posthuma	-	-	-	-	1	-	17	-	6	-	-	**24**
Polypheretima elongata	-	-	-	-	-	-	47	-	-	-	-	**47**
GLOSSOSCOLECIDAE												
Pontoscolex corethrurus	14	-	21	36	56	17	-	34	20	2	7	**207**
MONILIGASTRIDAE												
Drawida beddardi	-	-	2	2	-	-	-	-	-	-	-	**4**
Drawida sp. 1	-	-	-	-	-	-	-	-	-	-	-	**0**
Drawida sp. 2	-	-	-	-	-	8	-	-	-	-	-	**8**
OCTOCHAETIDAE												
Dichogaster affinis	-	-	4	2	-	1	5	2	-	-	-	**14**
Di. modiglianii	2	-	7	-	-	-	-	-	-	-	1	**10**
Di. bolaui	-	3	-	-	-	-	-	-	-	-	-	**3**
OCNERODRILIDAE												
Gordiodrilus elegans	-	-	-	-	-	-	-	-	-	-	-	**0**

Table C.5 The number of earthworm in different land used in August, 2006.

Earthworm	Forest types				Agricultural land used				Residential areas			**Total**
Families/species	DEF	DIF	G	PL	M	R	S	C	H	SERS	SRS	
MEGASCOLECIDAE												
Amynthas alexandri	-	-	4	-	-	-	3	-	-	-	-	**7**
A. defecta	-	-	-	-	-	-	-	-	-	-	-	**0**
A. sieboldi-group	-	-	-	-	-	-	-	-	-	-	-	**0**
Amynthas sp. 1	-	-	1	-	-	-	-	-	-	-	-	**1**
Amynthas sp. 2	1	-	-	-	-	-	-	-	-	-	-	**1**
Amynthas sp. 3	-	12	-	-	-	4	-	-	-	-	-	**16**
Amynthas sp. 4	-	-	-	-	-	-	-	-	-	-	1	**1**
Metaphire bahli	-	-	-	-	7	-	1	-	-	-	6	**14**
M. houletti	1	-	-	-	-	7	-	-	-	-	1	**9**
M. peguana	-	-	-	-	-	-	-	-	2	2	8	**12**
M. planata	-	-	-	-	3	8	15	3	4	-	-	**33**
M. posthuma	-	-	5	-	-	9	12	1	11	-	-	**38**
Polypheretima elongata	-	-	-	-	-	-	24	-	-	-	-	**24**
GLOSSOSCOLECIDAE												
Pontoscolex corethrurus	32	-	41	61	29	1	-	24	26	64	23	**301**
MONILIGASTRIDAE												
Drawida beddardi	-	-	22	-	1	-	-	-	-	-	-	**23**
Drawida sp. 1	16	-	-	1	-	-	-	-	1	-	3	**21**
Drawida sp. 2	-	-	-	-	-	1	-	6	-	16	-	**23**
OCTOCHAETIDAE												
Dichogaster affinis	1	-	-	-	-	-	-	-	-	-	-	**1**
Di. modiglianii	8	-	8	8	-	1	-	1	-	3	1	**30**
Di. bolaui	-	-	-	-	-	-	-	-	-	-	-	**0**
OCNERODRILIDAE												
Gordiodrilus elegans	-	-	-	-	-	-	-	-	143	-	-	**143**

Table C.6 The number of earthworm in different land used in October, 2006.

Earthworm Families/species	Forest types				Agricultural land used				Residential areas			Total
	DEF	DIF	G	PL	M	R	S	C	H	SERS	SRS	
MEGASCOLECIDAE												
Amynthas alexandri	1	-	-	-	-	-	3	-	2	-	3	**9**
A. defecta	-	-	-	-	-	-	-	-	-	-	-	**0**
A. sieboldi-group	-	-	-	-	-	-	-	-	-	-	-	**0**
Amynthas sp. 1	-	-	-	-	-	-	-	-	-	-	-	**0**
Amynthas sp. 2	-	-	-	-	-	-	-	-	-	-	-	**0**
Amynthas sp. 3	-	15	-	-	-	-	-	1	-	-	-	**16**
Amynthas sp. 4	4	-	-	-	-	-	-	-	-	-	-	**4**
Metaphire bahli	-	-	-	-	15	-	12	-	9	39	30	**105**
M. houletti	3	-	-	1	-	-	-	-	-	-	-	**4**
M. peguana	-	7	1	-	3	-	-	1	-	52	6	**70**
M. planata	-	-	-	-	6	20	15	18	1	-	9	**69**
M. posthuma	-	-	-	-	2	11	5	-	21	-	1	**40**
Polypheretima elongata	-	-	-	-	-	-	-	-	-	-	-	**0**
GLOSSOSCOLECIDAE												
Pontoscolex corethrurus	14	-	47	100	30	15	-	9	30	94	77	**416**
MONILIGASTRIDAE												
Drawida beddardi	2	-	7	-	2	-	1	-	-	27	-	**39**
Drawida sp1	-	-	-	-	-	-	-	-	-	-	-	**0**
Drawida sp2	-	-	-	-	-	4	-	6	-	-	-	**10**
OCTOCHAETIDAE												
Dichogaster affinis	1	-	15	-	-	-	-	-	-	8	3	**27**
Di. modiglianii	3	-	11	-	-	-	-	3	-	-	-	**17**
OCNERODRILIDAE												
Gordiodrilus elegans	-	-	-	-	-	-	-	-	-	-	-	**0**

Table C.7 Total number of earthworm in different land used in 2006.

Earthworm	Forest types				Agricultural land used				Residential areas			Total
Families/species	DEF	DIF	G	PL	M	R	S	C	H	SERS	SRS	
MEGASCOLECIDAE												
Amynthas alexandri	1	-	4	-	-	-	6	2	2	1	3	**19**
A. defecta	-	-	-	-	-	-	-	-	-	-	-	**0**
A. sieboldi-group	-	-	-	-	-	-	-	-	-	-	-	**0**
Amynthas sp. 1	-	-	1	-	-	-	-	-	-	-	-	**1**
Amynthas sp. 2	1	-	-	-	-	-	-	-	-	-	-	**1**
Amynthas sp. 3	-	30	-	-	-	4	-	2	-	-	-	**36**
Amynthas sp. 4	4	-	-	-	-	-	-	-	-	-	1	**5**
Metaphire bahli	-	-	-	-	25	-	13	-	9	39	36	**122**
M. houletti	4	-	-	1	-	9	14	8	2	-	1	**39**
M. peguana	-	7	1	-	3	0	-	1	-	54	14	**80**
M. planata	-	-	-	-	12	40	37	21	9	-	40	**159**
M. posthuma	-	-	5	-	3	20	34	1	38	-	1	**102**
Polypheretima elongata	-	-	-	-	-	-	71	-	-	-	-	**71**
GLOSSOSCOLECIDAE												
Pontoscolex corethrurus	60	-	109	197	115	33	-	67	76	160	107	**924**
MONILIGASTRIDAE												
Drawida beddardi	2	-	31	2	3	-	1	-	-	27	-	**66**
Drawida sp. 1	16	-	-	1	-	-	-	-	1	-	3	**21**
Drawida sp. 2	-	-	-	-	-	13	-	12	-	16	-	**41**
OCTOCHAETIDAE												
Dichogaster affinis	2	-	19	2	-	1	5	2	-	8	3	**42**
Di. modiglianii	13	-	26	8	-	1	-	4	-	3	2	**57**
Di. bolaui	-	3	-	-	-	-	-	-	-	-	-	**3**
OCNERODRILIDAE												
Gordiodrilus elegans	-	-	-	-	-	-	-	-	143	-	-	**143**

DATA FOR CHAPTER IV

Table C.8 Data of environmental factors and earthworm density in dry evergreen forest.

		Earthworm	Soil								Litter		Climate		
Month	Site	(ind/m^2)	N (g/kg)	P (g/kg)	K (g/kg)	CaO (g/kg)	OM (%)	Moisture (%)	pH	Temp (°C)	OM(%)	C/N	T-Ave	Rain(mm)	Rh%
JAN	DEF1	0.00	2.221	0.035	0.275	0.533	3.08	5.86	5.14	26	41.52	55.59	24.40	0	78.5
JAN	DEF2	0.00	1.777	0.015	0.272	0.194	2.24	7.32	5.84	26	47.97	28.53	22.15	0	80.4
JAN	DEF3	33.33	1.530	0.014	0.453	0.271	1.86	7.43	5.42	24	26.19	17.66	25.53	0	87.11
JAN	DEF4	0.00	2.365	0.026	0.577	0.675	3.13	8.40	6.3	24	20.03	11.77	25.53	0	87.11
FEB	DEF1	0.00	1.951	0.033	0.283	0.561	2.41	5.78	5.1	24	39.34	16.19	26.35	0	79
FEB	DEF2	0.00	1.709	0.012	0.401	0.410	2.24	7.52	5.55	24	48.77	27.58	26.55	0	80
FEB	DEF3	0.00	2.046	0.022	0.255	0.253	2.77	8.04	4.38	24	45.79	19.57	27.59	6.8	81.71
FEB	DEF4	0.00	2.633	0.027	0.493	1.409	2.89	8.77	5.94	24	43.24	22.48	27.59	6.8	81.71
MAR	DEF1	33.33	2.116	0.033	0.412	0.659	2.75	21.65	4.77	25	43.31	20.52	27.90	88.2	84
MAR	DEF2	0.00	1.623	0.012	0.308	0.285	1.73	15.20	4.41	25	45.21	28.89	26.85	88.3	86
MAR	DEF3	0.00	2.042	0.022	0.240	0.203	2.94	10.08	4.36	25	48.68	33.08	29.61	112.6	80.87
MAR	DEF4	0.00	2.203	0.028	0.521	0.648	2.53	11.35	5.64	25	42.3	14.33	29.61	112.6	80.87
ARP	DEF1	22.22	0.935	0.027	0.338	0.687	2.83	24.38	5.13	25.5	31.94	16.82	25.49	35.6	90.3
ARP	DEF2	0.00	1.268	0.007	0.543	1.418	1.56	13.73	4.51	25.5	39.09	19.43	21.13	42	92
ARP	DEF3	0.00	1.858	0.018	0.323	0.359	2.32	12.68	4.64	25.5	36.66	21.84	30.76	31	76.4
ARP	DEF4	0.00	1.864	0.024	0.405	0.637	0.15	12.59	4.82	25	42.46	38.2	30.76	31	76.4
MAY	DEF1	33.33	1.855	0.014	0.582	0.703	0.13	21.65	4.77	25	43.86	32.72	28.73	44.3	86.16
MAY	DEF2	0.00	1.690	0.003	0.545	0.229	0.09	15.20	4.41	25	39.71	48.55	27.18	38.3	86.94
MAY	DEF3	0.00	1.525	0.011	0.658	0.232	0.00	10.08	4.36	25	64.64	16.26	29.94	100.4	75.07
MAY	DEF4	0.00	2.370	0.022	0.254	0.756	0.12	10.23	4.87	25	81.8	21.43	29.94	100.4	75.07
JUN	DEF1	144.44	1.633	0.015	0.432	0.538	2.71	19.08	5.12	24.5	34.67	18.85	28.39	33.4	84.57
JUN	DEF2	0.00	1.486	0.005	0.383	0.283	1.33	18.11	5.6	24.5	34.59	21.23	27.45	54.8	85
JUN	DEF3	22.22	2.404	0.024	0.282	0.564	3.66	19.52	4.79	24	32.22	18.36	27.56	173.2	81.83
JUN	DEF4	22.22	2.082	0.015	0.626	0.712	2.36	19.92	8.61	22.5	36.87	19.28	27.56	173.2	81.83
JUL	DEF1	188.89	1.020	0.021	0.293	0.558	0.07	8.62	5.31	25	55.81	17.19	27.33	47.2	86.19
JUL	DEF2	33.33	3.131	0.024	0.425	1.483	0.24	19.33	5.3	23.5	70.41	18.26	27.05	45.9	86
JUL	DEF3	55.56	1.618	0.017	0.378	0.207	0.09	11.21	4.79	24	57.03	22.26	28.16	164.9	82.83
JUL	DEF4	100.00	2.361	0.022	0.402	0.998	0.15	12.33	5.3	23.5	54.74	19.08	28.16	164.9	82.83
AUG	DEF1	177.78	2.719	0.036	0.414	1.168	4.55	19.08	4.94	25	47.45	19.62	27.85	76.9	85
AUG	DEF2	244.44	3.110	0.014	0.511	3.137	5.12	18.11	6.15	25	37.47	21.28	26.85	85.2	86
AUG	DEF3	66.67	2.113	0.011	0.291	0.887	3.27	19.52	5.17	25	45.95	30.06	26.75	135	81.95
AUG	DEF4	166.67	1.685	0.016	0.575	0.600	2.24	19.92	4.96	23	32.66	17.06	26.75	135	81.95
SEP	DEF1	200.00	2.974	0.025	0.330	1.331	0.23	26.96	5.81	23	48.61	9.22	27.77	258.6	94.53
SEP	DEF2	100.00	2.954	0.012	0.451	2.754	0.26	35.45	6.1	23	54.12	10	25.57	284.1	95.2
SEP	DEF3	33.33	1.862	0.009	0.296	0.327	0.12	24.02	5.49	22.5	63.37	22.13	29.13	211.1	86.88
SEP	DEF4	188.89	2.210	0.013	0.363	0.288	0.11	23.18	3.95	24	52.11	17.39	29.13	211.1	86.88
OCT	DEF1	166.67	1.766	0.016	0.403	0.711	2.76	15.01	5.3	25	33.76	17.31	26.90	140.2	92
OCT	DEF2	77.78	3.045	0.011	0.304	2.341	4.76	21.63	5.56	23	35.01	19.06	25.25	170.5	93
OCT	DEF3	11.11	2.452	0.022	0.298	0.749	3.94	12.70	4.87	23	41.55	22.45	25.78	138.6	86.53
OCT	DEF4	55.56	2.453	0.023	0.441	0.618	7.89	18.89	4.64	23	43.73	19.82	25.78	138.6	86.53
NOV	DEF1	33.33	1.350	0.013	0.214	1.826	0.07	9.12	6.61	24	73.04	28.8	25.98	31.8	91.53
NOV	DEF2	11.11	2.467	0.009	0.222	2.469	0.22	6.98	6.86	23	61.61	12.83	23.97	16.3	91.33
NOV	DEF3	11.11	2.536	0.019	0.281	0.591	0.15	9.35	4.75	24.5	80.52	13.43	28.56	41.4	86.77
NOV	DEF4	0.00	1.535	0.011	0.214	0.221	0.10	17.41	5.36	23	70.85	13.59	28.56	41.4	86.77
DEC	DEF1	0.00	2.729	0.021	0.397	1.218	0.20	6.42	6.56	21	84.15	22.58	22.99	0	90.32
DEC	DEF2	0.00	2.625	0.012	0.532	2.252	0.28	9.74	7.27	20	78.23	22.57	21.13	0	92
DEC	DEF3	0.00	2.644	0.017	0.404	0.529	0.20	6.86	6.02	20	80.59	13.99	25.09	0	80.2
DEC	DEF4	0.00	1.704	0.012	0.482	0.502	0.11	9.18	6.03	29	102.7	20.54	25.09	0	80.2

Table C.9 Data of earthworm density and environmental factors in dry dipterocarp forest.

		Earthworm	Soil								Litter		Climate		
Month	Site	(ind/m^2)	N (g/kg)	P (g/kg)	K (g/kg)	CaO (g/kg)	OM (%)	Moisture (%)	pH	Temp (°C)	OM(%)	C/N	T-Ave	Rain(mm)	Rh%
JAN	DEF1	0.00	2.191	0.006	0.553	2.331	2.07	15.13	5.93	29	50.48	24.3	23.55	0	81
JAN	DEF2	0.00	1.697	0.028	0.331	0.670	2.15	8.43	6.09	28	61.26	33.06	23.55	0	81
JAN	DEF3	0.00	1.103	0.019	0.275	0.364	1.15	4.97	5.89	28	24.05	13.74	24.40	0	79
JAN	DEF4	0.00	2.477	0.025	0.596	0.646	2.20	9.31	5.46	27	52.76	23.1	29.40	0	79
FEB	DEF1	0.00	1.624	0.019	0.257	0.554	1.50	5.13	5.9	30	54.26	26.54	25.90	0	83
FEB	DEF2	0.00	1.017	0.012	0.238	0.375	1.34	8.24	5.28	28	50.51	31.25	25.90	0	83
FEB	DEF3	0.00	0.929	0.018	0.283	0.485	1.46	4.10	5.62	25	52.34	65.2	26.65	0	81
FEB	DEF4	0.00	1.025	0.017	0.225	0.247	1.34	4.47	5.48	25	53.75	22.9	26.65	0	81
MAR	DEF1	0.00	1.615	0.019	0.305	0.567	1.47	10.18	5.25	26	55.31	27.32	27.90	90.7	87
MAR	DEF2	0.00	1.194	0.058	0.251	0.409	1.46	10.38	4.88	28	41.27	17.63	27.90	90.7	87
MAR	DEF3	0.00	1.701	0.014	0.776	0.806	1.83	9.39	4.87	27	49.75	21.26	28.60	82.1	85
MAR	DEF4	0.00	2.123	0.017	0.454	0.294	1.20	6.15	5.83	27	49.66	22.78	28.60	82.1	85
ARP	DEF1	55.56	1.101	0.019	0.285	0.596	0.02	18.71	5.04	28	36.25	21.07	28.10	41.7	86.07
ARP	DEF2	22.22	1.101	0.015	0.293	0.482	0.08	19.14	5	28	46.51	20.49	28.10	41.7	86.07
ARP	DEF3	22.22	1.442	0.028	0.171	0.427	0.10	13.37	5.31	30	39.27	24.87	28.93	36.5	82.27
ARP	DEF4	0.00	1.350	0.023	0.273	0.396	0.06	15.19	6.12	28	45.79	30.54	28.93	36.5	82.27
MAY	DEF1	0.00	1.447	0.014	0.208	0.392	0.09	10.18	5.25	26	66.39	17.23	27.50	54.3	87.48
MAY	DEF2	0.00	1.271	0.015	0.233	0.432	0.05	10.38	4.88	28	69.47	18.31	27.50	54.3	87.48
MAY	DEF3	0.00	1.529	0.030	0.225	0.527	0.11	9.39	4.87	27	56.87	25.34	27.88	40.2	86.26
MAY	DEF4	0.00	1.188	0.013	0.224	0.246	0.06	9.29	4.89	26	74.27	21.43	27.88	40.2	86.26
JUN	DEF1	0.00	1.573	0.017	0.374	1.181	1.50	9.36	6.91	27	45.95	16.53	28.20	59.9	87
JUN	DEF2	0.00	0.896	0.013	0.198	0.416	1.14	13.03	5.19	27	42.99	49.49	28.17	59.9	83.77
JUN	DEF3	0.00	1.910	0.012	0.515	0.834	2.90	13.23	7.39	25.5	35.89	18	28.20	43.6	87
JUN	DEF4	33.33	1.017	0.003	0.375	0.457	1.23	16.67	6.12	27	24.81	18.41	28.20	43.6	87
JUL	DEF1	0.00	1.532	0.022	0.351	0.373	0.11	4.45	5.31	28	70.23	20.05	27.31	51	88.6
JUL	DEF2	0.00	1.783	0.020	0.310	0.823	0.13	4.30	5.2	27	47.92	25.73	27.31	51	88.6
JUL	DEF3	0.00	1.953	0.026	0.261	0.800	0.03	4.31	5.82	34.5	73.68	13.14	27.60	48.3	85.97
JUL	DEF4	0.00	1.104	0.021	0.295	0.338	0.09	6.51	6.4	24.5	38.91	12.97	27.60	48.3	85.97
AUG	DEF1	11.11	1.446	0.013	0.200	0.614	2.30	9.36	5.35	28.5	33.05	19.55	27.40	82.7	87
AUG	DEF2	0.00	1.603	0.022	0.279	0.600	2.74	13.03	5.7	28	43.39	23.92	27.90	82.7	85
AUG	DEF3	0.00	1.780	0.019	0.460	0.871	3.59	13.23	5.11	26	29.59	35.89	27.40	93.4	87
AUG	DEF4	0.00	1.434	0.013	0.351	0.394	1.69	16.67	5.28	28	30.53	40.71	27.40	93.4	87
SEP	DEF1	22.22	1.855	0.023	0.423	0.751	0.06	14.99	5.97	26	55.42	19.08	26.17	281.9	92.67
SEP	DEF2	44.44	0.764	0.010	0.358	0.320	0.03	22.80	4.78	25	43.59	10.45	26.17	281.9	92.67
SEP	DEF3	66.67	1.788	0.039	0.608	1.181	0.11	23.10	5.62	25	61.76	17.62	27.35	215.8	94.1
SEP	DEF4	66.67	1.447	0.009	0.242	0.642	0.07	20.77	6.3	25	37.32	15.05	27.35	215.8	94.1
OCT	DEF1	55.56	2.698	0.009	0.408	0.425	1.09	3.73	5.5	30	33.47	16.02	25.50	179.5	93
OCT	DEF2	22.22	1.947	0.020	0.280	0.673	3.42	9.11	5.26	30	38.55	19.32	27.30	179.5	91
OCT	DEF3	77.78	2.799	0.016	0.379	2.024	4.46	9.98	6.04	25	35.93	17.11	25.50	204.9	93
OCT	DEF4	111.1	0.766	0.009	0.240	0.306	0.78	5.51	6.11	27	42.63	67.11	25.50	204.9	93
NOV	DEF1	0.00	1.176	0.010	0.244	0.353	0.07	2.23	5.79	27	73.93	15.6	24.90	3.3	91.9
NOV	DEF2	0.00	1.441	0.019	0.257	0.428	0.10	4.54	5.32	27	72.28	10.3	24.90	3.3	91.9
NOV	DEF3	0.00	2.274	0.018	0.260	0.972	0.17	9.95	5.72	27	61.22	13.62	26.48	51.9	90.7
NOV	DEF4	33.33	1.015	0.006	0.281	0.170	0.05	12.72	5.51	27	76.75	15.42	26.48	51.9	90.7
DEC	DEF1	0.00	1.367	0.012	0.558	0.620	0.10	2.89	5.6	24	85.4	15.81	22.05	0	91.4
DEC	DEF2	0.00	1.698	0.022	0.318	0.583	0.11	4.41	6.18	26	82.98	15.34	22.05	0	91.4
DEC	DEF3	0.00	2.204	0.015	0.177	1.143	0.17	6.26	7.37	25	73.37	12.16	23.39	0	90.48
DEC	DEF4	0.00	0.851	0.009	0.242	0.237	0.02	4.49	6.79	28	85.71	20.4	23.39	0	90.48

Table C.10 The number of earthworms in dry evergreen forest (DEF) and dry dipterocarp forest (DIF) in 2006.

Earthworm	January		March		April		May		June		July		August		September		October		November		
Family/species	DEF	DIF	DEF	DIF	DEF	DIF	DEF	DIF	DEF	DIF	DEF	DIF	DEF	DIF	DEF	DIF	DEF	DIF	DEF	DIF	total
GLOSSOSCOLECIDAE																					
Pontoscolex corethrurus	-	-	3	-	-	-	3	-	14	-	13	-	32	-	32	-	14	-	2	-	113
MEGASCOLECIDAE																					
Amynthas alexandri	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	-	1	-	-	-	5
A.defecta	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
A. sieboldi-group	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	3
Amynthas sp. 2	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1
Amynthas sp. 3	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	2		2	-	3	8
Amynthas sp. 4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	7	-	-	11
M. houletti	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	3	-	-	-	4
M. peguana	-	-	-	-	-	4	-	-	-	3	-	-	-	-	-	3	-	11	-	-	21
M. planata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1
MONILIGASTRIDAE																					
Drawida beddardi	-	-	-	-	-	-	-	-	-	-	11	-	16	-	4	3	2	2	3	-	41
OCTOCHAETIDAE																					
Dichogaster affinis	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	1	1	1	-	-	5
D. modiglianii	1	-	-	-	-	1	-	-	2	-	1	-	8	-	7	2	3	-	-	-	25
UNKNOWN	-	-	-	-	2	3	-	-	1	-	9	-	-	-	-	4	-	-	-	-	19

Remark: No earthworm sample in February and December

APPENDIX D

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The Diversity and Distribution of Terrestrial Earthworms in Sakaerat Environmental Research Station and Adjacent Areas, Nakhon Ratchasima, Thailand

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Abstract: The distributions of terrestrial earthworms were studied in the Sakaerat Environmental Research Station (SERS) and adjacent areas. The earthworms and soil samples were collected in the same 30×30×30 cm^3 sampling sites from four vegetation types (dry evergreen forest, dry dipterocarp forest, forest plantation and grassland) four agricultural lands (rice paddy, sugarcane, cassava and mango) and three types of residential areas (household, SERS building area and Silvicultural Research Station area). The digging and hand sorting method was used to collect the earthworms, three times during rainy season (June, August and October) in 2006. Identification of terrestrial earthworms was based on external and internal morphology. Nineteen species of five families were found in studied areas. *Pontoscolex corethrurus*, the only member of the Glossoscolecidae, had the highest population density followed, by 11 species of Megascolecidae, three species of Moniligastridae, three species of Octochaetidae and finally, *Gordiodrilus elegans*, the only species of Ocnerodrilidae, was found in only a household area. Most earthworms collected were adults. Highest population densities were found in residential areas followed by agricultural lands and forest types. The earthworm density was highly significant different in October. The highest density was in SERS (611.1 ind/m^2) and the lowest was in DIF (61.1 ind/m^2). The highest species diversity was 11 in SRS but the highest diversity index was 1.71 in rice paddy.

Key words: Terrestrial earthworm • Diversity • Sakaerat Environmental Research Station • Forest types • Agricultural lands • Residential areas

INTRODUCTION

Earthworms have important roles in soil physical, chemical and biological properties [1]. Earthworms eat soil organic matter and litter and increase availability of plant nutrients in their casts [2]. The nutrients can increase plant growth and yield of crops as the result [3]. These are good indications that earthworm activities and behavior interact strongly with physical, chemical and biological properties of soil. But there is still inadequate knowledge of the basic biology and ecology of earthworms, especially in Thailand. Therefore, this study will give new information on earthworms in Thailand and will be valuable resources (species richness, population distributions) for future basic and applied earthworm research and also increase knowledge and understanding about earthworms for people who work in the field of ecology, agriculture and environmental science.

MATERIALS AND METHODS

Study Site: The Sakaerat Environmental Research Station (SERS) is the UNESCO biosphere reserve. It was established in 1967, primarily as a site for research on dry evergreen and dry dipterocarp tropical forest and was supported by the UNESCO/MAB Programme since 1978. Other vegetation types in SERS are bamboo, forest plantation and grassland. SERS is administered by the Thailand Institute of Scientific and Technological Research aiming to be a natural laboratory for students

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and providing training and seminars in ecological and environmental research. SERS is located at 14°30 'N and 101°55'E at an altitude of 280-762 m above sea level, covering 78 km^2 on the edge of Thailand's Khorat Plateau about 300 km north-east of Bangkok. The average annual temperature is 26°C, the average annual rainfall is 1,260 ml and average relative humidity is 81.9%. There are three seasons: the rainy season (May to October), winter (November to February) and Summer (March to mid- May). The wettest month is September and the driest months are from January to March.

Some 5,300 people live around SERS in 1999. They make their living from growing crops and rice but also using the forest for food and wood gathering. That leads to illegal hunting and tree cutting in the area.

The study sites (as shown in Fig. 1) consisted of four types of forest in SERS, namely dry evergreen forest (DE), dry dipterocarp forest (DIF= fired, DINF=non fired), forest plantation (PL), a grassland site (G), four types of agricultural land, including mango plantation (M), sugarcane plantation (S), cassava plantation (C) and rice paddy (R) and three types of residential areas, including house area (H), SERS building area (SERS) and Silvicultural Research Station area (SRS).

Earthworms and Soil Sampling: Earthworm and soil samples were collected in 30×30×30 cm^3 by hand sorting method in June, August and October during rainy season of 2006. There are four replications per site. The external morphology keys of Gates [4] and Sims and Easton [5] were used for earthworm identifications.

Soil samples (500 g) were taken to measure pH, moisture, organic matter, N, P and K. Soil pH were determined in a water suspension at a 2:5 soil:water ratio, on fresh samples. Soil moisture was determined by percent of the weight of fresh soil sample after dried at 105°C for 24 h [6]. The organic matter was determined following Walkley and Black [7]. Total N was analysed by the micro Kjeldahl method [6]. Available phosphorus was measured colourimetrically, based on the reaction with ammonium molybdate and development of the 'Molybdenum Blue' colour [8]. Exchangeable K was extracted by the Mehlich-3 procedure and determined by atomic absorption spectrophotometry and flame emission [9].

Data Analysis: Evenness and Shannon-Wiener index [10] were use to compare the diversity of earthworms among sites. Differences in earthworm numbers and species abundance among land use types were analyzed with ANOVA. The Pearson correlation was employed to find relationship among soil parameters, environmental factors and earthworm density. All data were calculated by using SPSS version 14.0 program for windows.

RESULTS AND DISCUSSION

Diversity and Distribution: Nineteen species of five families (Glossoscolecidae, Megascolecidae, Moniligastridae, Octochaetidae and Ocnerodrilidae) were found in this study (Table 1). Interestingly, *Pontoscolex corethrurus*, the only species of Glossoscolecidae, had the highest number of individuals and was distributed all over the areas except in dipterocarp forest and sugarcane plantation.

Many earthworm species were present in many places. Three earthworms (*P. corethrurus*, *Drawida beddardi* and *Dichogaster affinis*) were found in nine habitats. Whereas, five species (*Amynthas alexandri*, *Metaphire peguana*, *Metaphire planata*, *Metaphire posthuma* and *Dichogaster modigliani*) were present in seven habitats. In contrast, five earthworms were very site-specific species such as *Polypheretima elongata* in sugarcane plantation, *Dichogaster bolaui* in dry dipterocarp forest (fired), *Gordiodrilus elegans* in household area, *A. corticis* in grassland and *A. tokioensis* species – group in dry evergreen forest.

The Southeast Asian earthworm fauna is dominated by species of Megascolecidae, Moniligastridae and some Ocnerodrilidae. The most diverse and successful group of earthworm species in this region is the pheretimoid-related genera *Pheretima, Polypheretima, Metaphire* and *Amynthas*. In both natural and disturbed ecosystems, the exotic *P. corethrurus or Polypheretima elongata* are generally dominant [11].

SRS was the most diverse habitat for earthworms, containing 11 species, while the lowest was DIF which had only three species (Table 2). The greatest species evenness was 0.80 in DINF. The highest Shannon-Wiener index (H') was 1.71 in rice paddy and the lowest was 0.95 in mango plantation.

The species richness of all area types ranged from 3 to 11 species. They were not different from other tropical rainforests that contained 4 to 14 species. Edwards and Bohlen [3] stated that earthworm diversity ranged from 1 to 15 species, while most earthworm communities contained around 3-6 species. Generally, more species of earthworm were found in residential and agricultural areas than in the forests. Because the residential and agricultural areas are more subject to

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Table 1: Distribution and density of earthworm

Earthworm Family/species	Forest habitats				Agricultural habitats					Residential habitats			
	DE	DIF	DINF	PL	G	R	S	C	M	H	SERS	SRS	Average
Glossoscolecidae													
Pontoscolex corethrurus	55.6	0.0	0.0	182.4	100.9	30.6	0.0	62.0	106.5	70.4	148.2	99.1	71.3
Megascolecidae													
Amynthas alexandri	0.9	0.0	0.0	0.0	3.7	0.0	2.8	1.9	0.0	1.9	0.9	2.8	1.2
Amynthas corticis	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Amynthas tokioensis													
species- group	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Amynthas sp1	0.0	27.8	2.8	0.0	0.0	3.7	0.0	1.9	0.0	0.0	0.0	0.9	3.1
Amynthas sp2	3.7	0.0	6.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8
Metaphire bahli	0.0	0.0	0.0	0.0	0.0	0.0	12.0	0.0	23.2	13.9	36.1	33.3	9.9
Metaphire houlleti	3.7	0.0	0.0	0.9	0.0	8.3	13.0	7.4	0.0	0.0	0.0	0.9	2.9
Metaphire peguana	0.0	6.5	6.5	0.0	0.9	0.0	0.0	0.9	2.8	0.0	50.0	13.0	6.7
Metaphire planata	0.0	0.0	0.9	0.0	0.0	37.0	34.3	19.4	11.1	4.6	0.0	37.0	12.0
Metaphire posthuma	0.0	0.0	0.0	0.0	4.6	18.5	31.5	0.9	2.8	35.2	0.0	0.9	7.9
Polypheretima elongata	0.0	0.0	0.0	0.0	0.0	0.0	65.7	0.0	0.0	0.0	0.0	0.0	5.5
Moniligastridae													
Drawida beddardi	16.7	0.0	1.9	2.8	28.7	0.0	0.9	0.0	2.8	0.9	17.6	2.8	6.3
Drawida sp1	0.0	0.0	0.0	0.0	0.0	7.4	0.0	11.1	0.0	0.0	0.0	0.0	1.5
Drawida sp2	0.0	0.0	0.0	0.0	0.0	4.6	0.0	0.0	0.0	0.0	22.2	0.0	2.2
Octochaetidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dichogaster affinis	1.9	0.0	16.7	1.9	17.6	0.9	4.6	1.9	0.0	0.0	7.4	2.8	4.6
Dichohaster modiglianii	11.1	0.0	0.0	7.4	24.1	0.9	0.0	3.7	0.0	0.0	2.8	1.9	4.3
Dichogaster bolaui	0.0	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Ocnerdrilidae													
Gordiodrilus elegans	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	132.4	0.0	0.0	11.0
Juvenile and unknown	1.9	0.0	0.0	0.9	13.0	14.8	8.3	2.8	4.6	10.2	5.6	10.2	6.0

DE = dry evergreen forest, DIF = dry dipterocarp forest-fired, DINF= dry dipterocarp forest-non fired, PL = forest plantation, G = grass land, M = mango plantation, S = sugarcane plantation, C = cassava plantation, R= rice paddy, H= household area, SERS = SERS office building area and SRS = office building area of Sakaerat Silvicultural Research Station

Table 2: Species Diversity and evenness of earthworms in different habitats

Index	Forest habitats					Agriculture habitats				Residence habitats		
	DE	DIF	DINF	PL	G	R	S	C	M	H	SERS	SRS
Species richness	8.00	3.00	6.00	5.00	8.00	9.00	8.00	10.00	6.00	6.00	8.00	11.00
Eveness	0.64	0.65	0.80	0.59	0.68	0.78	0.77	0.63	0.53	0.67	0.70	0.62
Species Diversity('H)	1.33	0.72	1.43	0.96	1.41	1.71	1.60	1.45	0.95	1.20	1.45	1.50

DE = dry evergreen forest, DIF = dry dipterocarp forest-fired, DINF= dry dipterocarp forest-non fired, PL = forest plantation, G = grass land, M = mango plantation, S = sugarcane plantation, C = cassava plantation, R= rice paddy, H= household area, SERS = SERS office building area and SRS = office building area of Sakaerat Silvicultural Research Station

Table 3: The Earthworm Density in Sakaerat Environmental Research Station and Adjacent Areas, 2006

Area types	June		August		October		
	Ind/m^2	S.E	Ind/m^2	S.E	Ind/m^2	S.E	Average
DE	47.2	32.8	163.9	36.7	77.78c	32.7	96.3
DIF	16.7	16.7	33.3	19.8	61.11c	21.5	37.0
DINF	8.3	8.3	0.0	0.0	97.22c	41.4	35.2
PL	111.1	29.8	194.4	79.2	283.33bc	139.4	196.3
G	94.4	29.6	258.3	24.2	230.56bc	11.5	194.4
R	111.1	44.7	130.6	27.4	138.89bc	26.6	126.9
S	250.0	124.9	169.4	78.5	100.00c	45.8	173.2
C	130.6	65.2	105.6	44.1	105.56c	18.4	113.9
M	175.0	98.6	113.9	65.6	172.22bc	95.2	153.7
H	94.4	40.2	133.3	63.5	183.33bc	54.9	137.0
SERS	8.3	8.3	252.8	183.4	611.11a	120.4	290.7
SRS	72.2	54.5	150.0	50.2	358.33b	112.9	193.5
Average	93.3	17.6	142.1	21.1	201.6	28.8	145.7

DE = dry evergreen forest, DIF = dry dipterocarp forest-fired, DINF= dry dipterocarp forest-non fired, PL = forest plantation, G = grass land, M = mango plantation, S = sugarcane plantation, C = cassava plantation, R= rice paddy, H= household area, SERS = SERS office building area and SRS = office building area of Sakaerat Silvicultural Research Station

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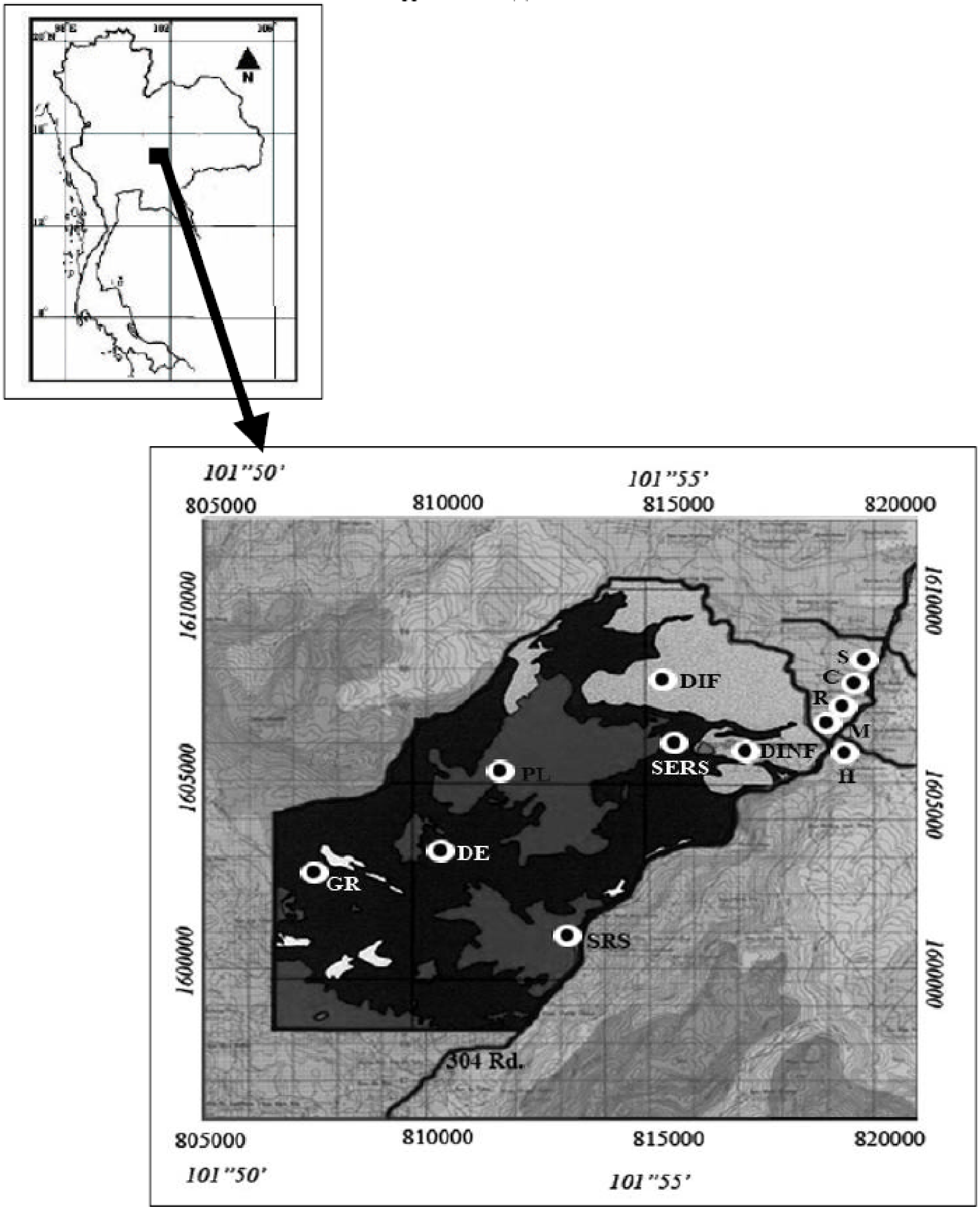

Fig. 1: SERS Location and Earthworm Collecting Sites
DE = dry evergreen forest, DIF = dry dipterocarp forest-fired, DINF= dry dipterocarp forest-non fired, PL = forest plantation, G = grass land, M = mango plantation, S = sugarcane plantation, C = cassava plantation, R= rice paddy, H= household area, SERS = SERS office building area, and SRS = office building area of Sakaerat Silvicultural Research Station

Table 4: The Correlations among Earthworm Density and Environmental Factors

	Earthworm density	Soil Moisture	Soil pH	Temperature	Rain fall	N	P	K	Soil OM
Soil Moisture	0.24**								
Soil pH	0.14	0.05							
Temperature	-0.15	-0.08	0.19*						
Rainfall	0.20**	0.17*	-0.14	-0.70**					
N	0.23**	0.16	-0.18*	-0.15	0.29**				
P	0.1	0.06	0.39**	-0.01	-0.01	-0.01			
K	0.11	0.02	0.25**	0.17*	-0.06	0.19*	0.25**		
Soil OM	0.17*	0.17*	-0.11	-0.06*	0.23**	0.66**	0.24**	0.32**	
Soil C/N	0.05	0.07	0.01	-0.39**	-0.02	-0.14	0.30**	0.26**	0.52**

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

species introduction, so they get the exotic species. Nevertheless, these habitats might have many kinds of food resources which supported many earthworm species.

Earthworm Density: A total of 2,044 earthworms were collected in all studied areas. Of these, 1,966 individuals were identified to species and 78 were unidentified. All earthworm specimens were divided into 3 age groups, adult (1,382 individuals), juveniles (393 individuals) and sub-adults (269 individuals).

The highest earthworm density was *P. corethrurus* (average 71.3 ind/m^2; Table 1.) followed by *Metaphire planata* (average 12.0 ind/m^2) and *Metaphire bahli* (average 9.9 ind/m^2). The lowest were *Amynthas corticis* and *Amynthas tokioensis* species-group (average 0.1 ind/m^2).

As shown in Table 3, the numbers of earthworm were highest in October (201.6 ind/m^2) followed by August (142.1 ind/m^2) and June (93.3 ind/m^2) respectively. Edwards and Bohlen [15] stated that when the rain began, the population consisted of juvenile individuals. The mature earthworms were found one month later and predominated to the end of wet season.

Earthworm densities were highest in residential areas followed by agricultural lands and forest types. The earthworm density was significantly different in October. The highest density was in SERS (611.1 ind/m^2) and the lowest was in DIF (61.1 ind/m^2), as shown in Table 3.

The earthworm densities were positively significant correlated ($p < 0.05$) with soil moisture, rainfall, total nitrogen and organic matter (Table 4). However, they were not correlated with temperature, phosphorus, potassium and C/N ratio.

Environmental factors cannot explain the earthworm density in our sites. The differences depend on earthworm species in each habitat, especially an exotic one. The density of *P. corethrurus*, which is well adapted to human disturbed areas, was 24% in rice paddy and up to 92% in forest plantation. This species alone contributed to the high earthworm density in residential, agricultural, grassland and forest plantation areas.

CONCLUSION

A total 2,044 individuals of 19 earthworm species were found in this study. They belonged to the following five families: Glossoscolecidae, Megascolecidae, Moniligastridae, Octochaetidae and Ocnerodrilidae. The 19 species were *P. corethrurus, A. alexandri, A. corticis, A. tokioensis* species-group, *Amynthas sp1, Amynthas sp2, M. bahli, M. houlleti, M. peguana, M. planata, M. posthuma, P. elongata, D. beddardi, Drawida sp.1, Drawida sp.2, Di. affinis, Di. modiglianii, Di. bolaui and Gordiodrilus elegans*. The most abundant was *P. corethrurus*, which was present in every forest type except dipterocarp forest. The rarest were *A. corticis* and *A. tokioensis* species-group, found only in grassland and dry evergreen forest respectively. The adult stage was most abundant, followed by juveniles and sub-adults. Population densities were highest in October followed by August and June. The earthworm density was highest in residential areas followed by agricultural lands and forests. The earthworm density was significantly different among sites in October. The highest density was in SERS (611.1 ind/m^2) and the lowest was in DIF (61.1 ind/m^2). The highest species diversity and species richness of earthworms were found in rice paddy and around the Silvicultural Research Station offices respectively. The evenness of earthworm was highest in unburned dipterocarp forest. The exotic *P. corethrurus* was found in every habitat except in dry dipterocarp forest and sugarcane plantation. *Polypheretima elongata* was found only in sugarcane plantation while *Gordiodrilus elegans* was found only in household area. Environmental factors, such as soil moisture, rainfall, total nitrogen and organic matter, were very important for earthworm management.

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