SPECIES DIVERSITY OF TERRESTRIAL EARTHWORMS IN KHAO YAI NATIONAL PARK

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ไส้เดือนดิน 13 ชนิดใน 3 วงศ์ที่พบในป่า 5 ชนิดของอุทยานแห่งชาติเขาใหญ่ ได้แก่ วงศ์ Glossoscolecidae (*Pontoscolex corethrurus*) วงศ์ Megascolecidae (*Perionyx excavatus*, *Pithemera bicincta*, *Amynthas alexandri*, *A. fucosus*, *A. longicauliculatus*, *Amynthas* sp.1, *Amynthas* sp.2, *Amynthas* sp.3, *Metaphire peguana*, *M. houlleti* และ *Metaphire* sp.1) และวงศ์ Moniligastridae (*Drawida beddardi*) มี 3 ชนิดที่คาดว่าจะเป็นชนิดใหม่ คือ *Amynthas* sp.1, *Amynthas* sp.2 และ *Metaphire* sp.1 และที่พบเป็นครั้งแรกของประเทศไทย คือ *A. fucosus* ความชุกชุมของไส้เดือนดินสูงที่สุดในเดือนกันยายน 2545 และ 2546 ความหนาแน่นของไส้เดือนดินสูงที่สุดในป่าดิบชื้นและต่ำที่สุดในป่าเบญจพรรณ ความหลากหลายของชนิด ความมากชนิดและความสม่ำเสมอของชนิดไส้เดือนดินสูงที่สุดในป่าดิบแล้ง ปัจจัยที่มีความสัมพันธ์กับสังคมของไส้เดือนดินอย่างมีนัยสำคัญ ได้แก่ ความเป็นกรด-ด่างของดิน ความชื้นของดิน ลิตเตอร์ อุณหภูมิ ความชื้นสัมพัทธ์และไนโตรเจน

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PRASUK KOSAVITITKUL : SPECIES DIVERSITY OF TERRESTRIAL EARTHWORMS IN KHAO YAI NATIONAL PARK. THESIS ADVISOR : ASST. PROF. PANEE WANNITIKUL, Ph.D. 180 PP. ISBN 974-533-516-9

EARTHWORM/IDENTIFICATION/SPECIES DIVERSITY/ENVIRONMENTAL FACTORS/KHAO YAI NATIONAL PARK

A total of thirteen earthworm species belonging to three families was found in five forest types in Khao Yai National Park: Glossoscolecidae (*Pontoscolex corethrurus*), Megascolecidae (*Perionyx excavatus*, *Pithemera bicincta*, *Amynthas alexandri*, *A. fucosus*, *A. longicauliculatus*, *Amynthas* sp.1, *Amynthas* sp.2, *Amynthas* sp.3, *Metaphire peguana*, *M. houlleti* and *Metaphire* sp.1), and Moniligastridae (*Drawida beddardi*). Three species i.e. *Amynthas* sp.1, *Amynthas* sp.2 and *Metaphire* sp.1 were supposed to be new species, and *A. fucosus* was a new recorded species of Thailand. Earthworm abundance was highest in September 2002 and 2003. Earthworm density was highest in moist evergreen forest and lowest in the mix deciduous forest. The highest species diversity, richness and evenness of earthworms were found in dry evergreen forest. Earthworm communities were significantly correlated with soil pH, soil moisture, litter, temperature, relative humidity and nitrogen.

School of Biology

Academic Year 2005

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

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CHAPTER I

INTRODUCTION

1.1 The importance of problems

Earthworms are classified in phylum Annelida, class Oligochaeta. They are presumably the most ancient soil dwellers and were found earlier as in sediments of the Pre-Cambrian and Ordovician (Miller and Harley, 1999). The most recent data account for 3627 species described worldwide (Reynolds, 1994).

Charles Darwin was one of the first scientists to give credence to the conventional wisdom from earlier civilizations about the importance of earthworms to soil fertility. Recently there has been resurgence in interest in earthworms, driven by environmental and economic concerns, particularly the need to understand and utilize their functions in sustainable agriculture, and to exploit their potential for recycling of organic wastes (Lee, 1985; Sims and Garard, 1985). Earthworms are important in the breakdown of organic matter to inorganic matter. The action of the digestive fluids and increased microbial activity in the casts tends to solubilize inorganic plant nutrient elements. The extensive burrowing of the earthworm improves soil aeration and increases water penetration into soil. Upon further microbial decomposition of the partially digested residues, plant nutrient elements are released (Edwards, 1998).

Thailand is located in the tropical region which encompasses diverse kinds of natural ecosystems. These natural habitats are homes to some of the world’s richest and unique plants and animals, resulting in a high diversity of earthworms. However, the studies in biology and ecology dealing with earthworms in Thailand have been lagging behind due to the limited knowledge of both their morphology and taxonomy.

This investigation will provide information of earthworms on species compositions, quantities, abundance, earthworm diversity, seasonal variation and some ecological factors effecting earthworm compositions. Information from this study will also increase knowledge and understanding of ecosystem changes, and be making its primary contributions to the work of people whose interests line in ecology, agriculture, and other fields in need of a coherent classification of earthworm species.

1.2 The objectives of study

1.2.1 To investigate species diversity of terrestrial earthworms in different vegetation types (mixed deciduous forest, dry evergreen forest, moist evergreen forest, hill evergreen forest and grassland) in Khao Yai National Park.

1.2.2 To investigate relationships between terrestrial earthworm species and environmental factors.

1.3 The scope and limitations of study

1.3.1 The scope of the study area

This research was conducted in Khao Yai National Park. It covers four provinces as Saraburi, Nakhon Nayok, Prachinburi and Nakhon Ratchasima. Sample areas were selected from different vegetation types; mixed deciduous forest, dry evergreen forest, moist evergreen forest, hill evergreen forest and grassland.

1.3.2 The scope of time

Earthworm samplings were conducted every month from July – December 2002 and June – December 2003 (during early rainy season to mid winter).

1.4 Key words

Species diversity, Earthworm, Identification, Environmental factors, Khao Yai National Park

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

1.4.2 Earthworm is a common name referring to the segmented worms, phylum Annelida, class Oligochaeta (Miller and Harley, 1999).

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

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

1.4.5 Khao Yai National Park (see 1.5)

1.5 Details of the study area

1.5.1 Location

Khao Yai National Park was gazetted on 18 September 1962. It covers four provinces in central, eastern and northeastern Thailand including Saraburi, Nakhon Nayok, Prachinburi and Nakhon Ratchasima (Figure 3.1). It is situated between latitude 14° 05′ to 14° 15′ N and longitude 101° 05′ to 101° 50′ E. It covers an area of 2,168 Km^2 or 1,356,500 rai, making it the third largest national park of Thailand following Kaeng Krachan National Park and Tab Lan National Park (Phoonjumpa, 2002).

1.5.2 Geography and Soil

The park is generally mountainous, although the east is characterized by lower, undulating terrain. Mountains in the north slope gently to the northern boundary while those in the south and west are characterized by a steep escarpment which drops to agricultural plains outside the Park. The north-east is bounded by the long, wall-like Khao Kamphaeng mountain. Underlying bedrock comprises Palaeozoic sediments of the Kanchanaburi series. During the Permian period this was overlain by limestone and shale, forming the Ratburi series. Granitic and grandioritic intrusions caused the Kanchanaburi and Ratburi beds to fold and uplift to form mountains that subsequently eroded to form the red sandstone, shale, gypsum and salt Korat series which now forms the western edge of the Korat plateau. However, the majority of the park substrate comprises eroded rhyolitic flows from more recent volcanic activity. Soils throughout the bulk of the park are from the Kabin Buri, Chieng Mai, Chatturat, Korat, Khao Yai and Lam Narai series. These are mostly red-yellow podzols and reddish-brown laterites, characterized by a sandy texture, moderate to good drainage and moderate soil fertility. Pak Chong series soils, comprising very fine clayey kaolinite of reddish-brown laterites is found to the north and is generally deep, well-drained, with a high water-holding capacity but only moderate fertility. Muak Lek series soils found in the north and east are loamy skeletals of non-calcic brown soils. This series is well-drained, shallow, low fertility and highly susceptible to erosion (National Park Division, 1987; Srikosamatara and Hansel, 2000).

1.5.3 Climate

The park experiences both the south-west and north-east monsoons and the distribution of rainfall is influenced by topography. Mean annual rainfall at the headquarters is 2270 mm. The south, and a limited area in the north-east, tend to be wetter with more than 3000 mm in the Klong Tha Dan basin, below Khao Khieo and Khao Rom. The extreme west and south-east are the driest with mean annual rainfall of 1600 mm. Most precipitation falls during the mid-May to October south-west monsoon, with an annual mean of 1917 mm falling during this period at the headquarters. The driest months are December and January which average just 15mm rain monthly. Several perennial watercourses, punctuated by waterfalls such as Heo Suwat, Heo Narok and Wang Heo, drain the park and there are four major watersheds, with an annual run-off discharge of about 1,889 million m^3. Nakhon Nayok watershed covers 660 km^2 in the west and south; Prachin Buri watershed covers 1,122 km^2 in the south, east and central regions; Lam Thakhong watershed covers 201 km^2 in the north and round the headquarters; and Lam Phra Phloeng watershed covers 114 km^2in the north-east. Mean annual temperature is 23ºC, increasing to 28ºC in April and May and decreasing to 17ºC during December and January (National Park Division, 1987; Srikosamatara and Hansel, 2000).

1.5.4 Vegetation

Khao Yai National Park is more than 80% forested. The dominant vegetation type is moist evergreen forest with the height of 500–1,000 meters above sea level, covering more than 60% of the park. Other forest types include: dry evergreen forest (200–400 meters on the east and south slopes), dry mixed deciduous forest (300–600 meters on the northern edge of the park), and hill evergreen forest (above 1,000 meters on Khao Khieo ridge). Grasslands and secondary growth make up the remaining vegetation types (Srikosamatara and Hansel, 2000).

CHAPTER II

LITERATURE REVIEW

Earthworms are among the most ancient of terrestrial animal groups. They play a vital role in the formation and maintenance of fertile soils and are thus paramount for primary production of forest ecology. This chapter deals with an overview of the external characteristics, internal anatomy and function, earthworm diversity and geographical distribution, earthworm ecology and influence of environmental factors on earthworms.

2.1 External characteristics

The principal systematic features of earthworms are bilaterally external and internal segmentation. They have no skeleton and a thinly pigmented cuticle, bearing setae on all segments except the first and end segment. They are hermaphrodite and have relatively few gonads, which are situated in definite segmental positions. When mature, a swollen area of the epidermis called a clitellum, and this is then passed over the anterior segment. The eggs are usually fertilized and the young develop within the eggs without a free larval stage, the newly hatched worms resembling adults (Edwards and Bohlen, 1996). Diagrams of external anatomy, which are basic to classification, are provided in Figure 2.1.

2.1.1 Segmentation

Earthworms are divided eternally into bands or segments along the length of the body by furrows or intersegmental grooves. Often the external segments are subdivided

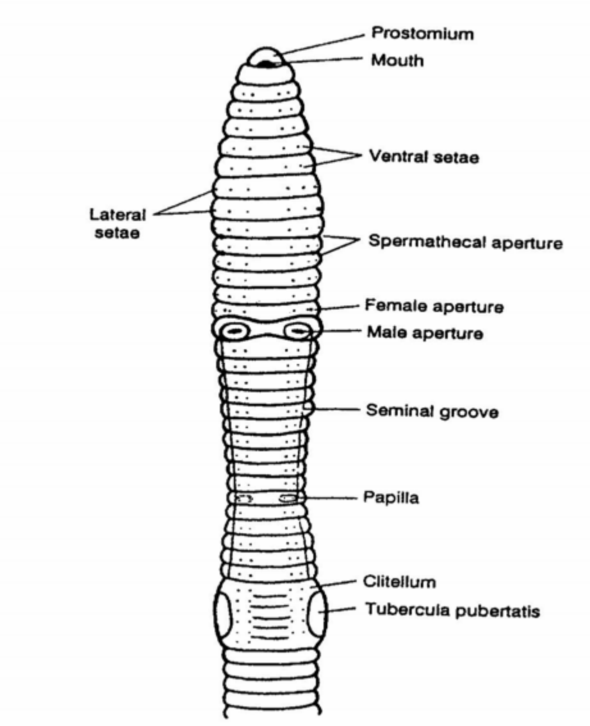

Figure 2.1 Ventral view of external anatomy of earthworms (Edwards and Bohlen, 1996).

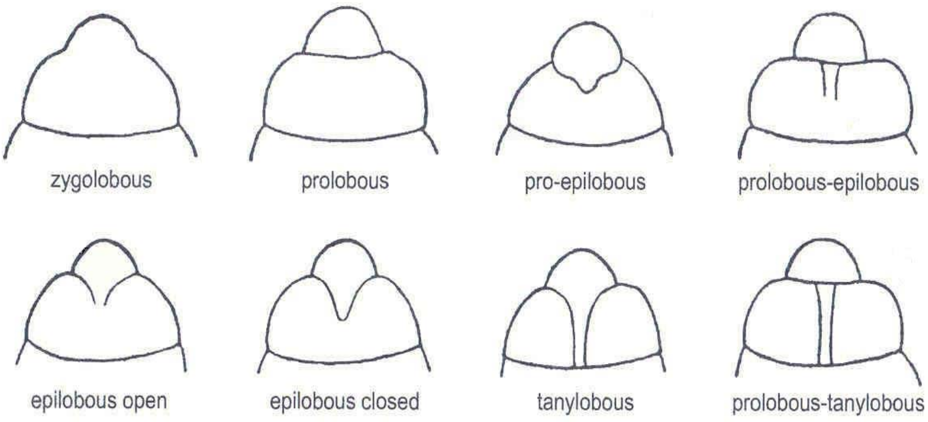

Figure 2.2 Various forms of prostomium (Michaelsen, 1928).

by one or two secondary grooves, particularly in the anterior part, but these are superficial divisions which are not reflected in the internal anatomy. The mouth opens on the first segment, or peristomium, which bears on its dorsal surface the prostomium, a lobe overhanging the mouth. The peristomium and prostomium are joined difference between species and is a useful systematic character (Figure 2.2). The connection is termed zygolobous, prolobous, epilobous and tanylobous, depending on the demarcation of the prostomium (Edwards and Bohlen, 1996).

2.1.2 Setae

The setae are bristle-like structures borne in follicles on the exterior of the body wall, can be extended or retracted by means of protractor and retractor muscles. Different species of oligochaetes have setae of varying shapes and position. The setae are arranged in a single ring around the periphery of each segment, their number and distribution being four typically are termed closely paired, widely paired, distant paired and perichaetine arrangement (Figure 2.3). The setae are designated by the letters a, b, c, d – beginning with the most ventral one 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 (Edward and Bohlen, 1996).

Modified setae with a function in reproduction are termed genital setae. Those at the male and/or prostatic pores are distinguished as penial setae as there is evidence that during copulation they are protruded into the spermathecal orifices of the partner. Other genital setae may occur in association with glandular modifications of the epidermis. Those in the vicinity of the spermathecae are spermathecal setae. They are seen in the Kynotidae, Hormogastridae, Microchaetidae, Lumbricidae, Glossoscolecidae, Eudrilidae and Megascolecidae (Figure 2.4). In *Pontoscolex*

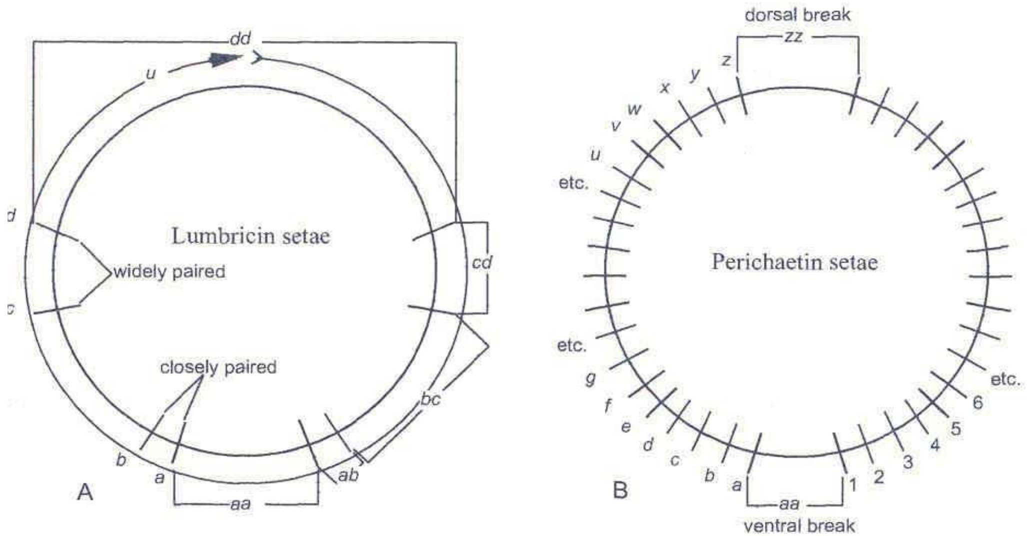

Figure 2.3 Arrangement of setae in Oligochaeta. Lumbricine arrangement (A), and perichaetine arrangement (B) (Jamieson, 1997).

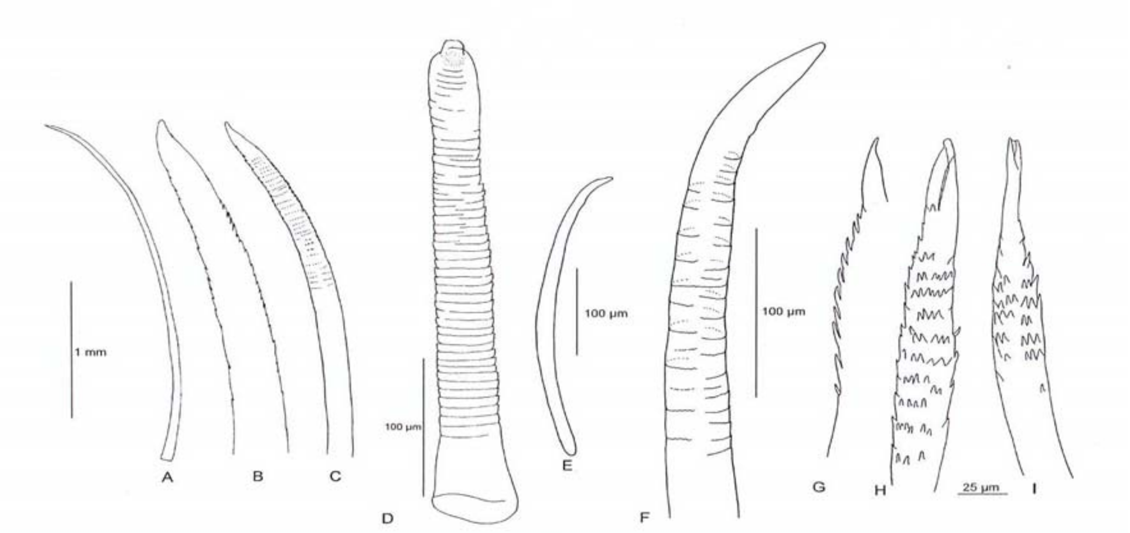

Figure 2.4 Penial setae of some Australian Megascolecidae. A-C: *Heteroporodrilus mediterreus*. D: *Notoscolex camdensis*. E-F: *Cryptodrilus polynephricus*. G-I: *Digaster armifera* (Jamieson, 1972).

corethrurus one or both setae of the ventral couples in some of segments 14-22 are modified as genital setae with longitudinal rows of grooves (Gates, 1972).

2.1.3 Dorsal pores

Dorsal pores are small openings located in intersegmental furrows on the mid-dorsal line leading to the coelomic cavity. They are present in most earthworms, but are usually absent in worms with subaquatic habitats. They function in permitting discharge of coelomic fluid to the exterior which enables lubrication of the burrow and they may play a secondary role in releasing coelomocytes to the exterior which in some worms have a bioluminescent, excretory or protective role (Jamieson and Wampler, 1979; Wampler and Jamieson, 1986).

2.1.4 Clitellum

The clitellum is a specialization of the epidermis for secretion the cocoon in which the eggs are deposited and into which spermatozoa received into spermathecae from the partner are exuded to bring about fertilization. The clitellate condition is interpreted as a modification allowing increased secretion of nutrients materials into the cocoon, a change correlated with a great reduction in yolk content, and size, of the eggs and increasing dependence of the embryo for its nutrition on the fluid contained in the cocoon (Figure 2.5). The clitellum is anterior to the male pores for most or all of its length in the Megascolecidae (Edward and Bohlen, 1996).

2.1.5 Male pores and accessory markings

The position of the male pores and their relationship to the openings of the prostates is of great importance taxonomically from the specific to the subfamilial level. At the specific level, the position of pores relative to setal rows is much used. At higher levels the numbers of prostates pores and their locations relative to the male pores are important. In the Megascolecidae, two pairs are still seen in the acanthodrilin condition, in which two pairs of prostate pores lie on segments XVII and XIX (Figure 2.5), and the male pores are on segment XVIII, which are usually absent from lumbricid species (Edward and Bohlen, 1996; Jamieson, 1974).

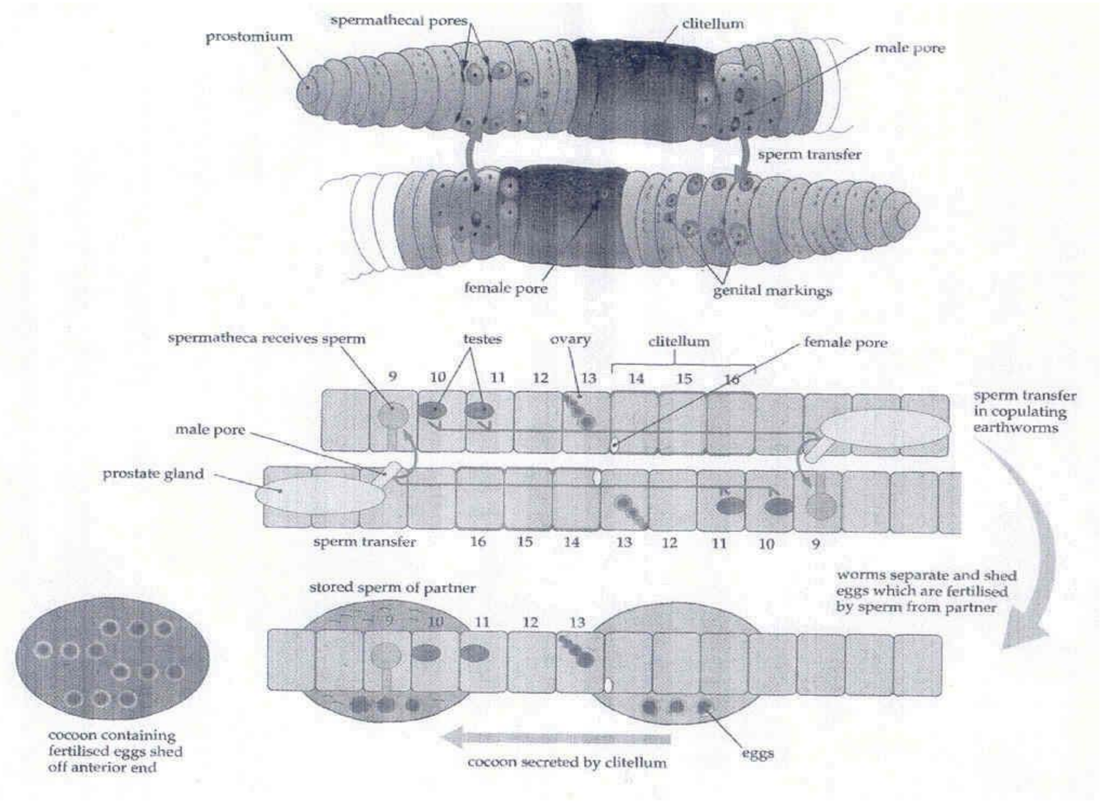

Figure 2.5 Cocoon formation and arrangement of male and prostatic pores in the Megascolecidae (Jamieson, 1974).

Both the male and prostatic pores may be on raised papillae or ridges, or may open directly on to the surface. The male and prostatic 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. In the Megascolecidae, more than any other oligochaete groups, so-called accessory genital markings, are well developed. These usually have the form of paired and/or single pit-shaped or protuberant, segmental and/or intersegmental glandular modifications of the epidermis which may be circular, elliptical or ridge-like or have other forms. They rarely form elongate structures over two or more segments somewhat resembling the tubercular pubertatis of lumbricids. Their function is imperfectly understood but it is likely that they have a role in species recognition and that they may have a key in the lock function in copulation, not by mutual insertion, but by precise apposition to structures on the partner(Jamieson, 1974). An example in megascolecine is illustrated in Figure 2.5.

The worms lie with their anterior regions in contact, facing in opposite directions. The male pore deposit sperm in spermathecal diverticula of the partner. The partners separate. Eggs pass out of the female genital pore(s) into a cocoon which is secreted by the clitellum. The worm wriggles backward out of the cocoon which effectively moves forward and receives spermatozoa from the spermathecae. Eggs are fertilized and the cocoon is shed off the anterior end of the body (Jamieson, 1994).

2.1.6 Female pores

The female pores are always located in the segment behind the corresponding ovaries. Predominantly, there is only one pair of female pores as there is only one pair of ovaries in most microdriles. There are one or two pairs in the Lumbriculata (Lumbriculidae). Female pores are usually inconspicuous and this is so in the Megascolecidae. The location of the female pores relative to setal lines has some value in taxonomy of megascolecids (Edward and Bohlen, 1996). In the Lumbricidae, Megascolecidae and Glossoscolecidae they are on segment 14. Sometimes the female pores are united into a single median pore (Figure 2.6) (Jamieson, 1974).

2.1.7 Spermathecal pores

Spermathecal pores 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 (Figure 2.6). Usually earthworms have two or more pairs of spermathecal pores, with a maximum of seven pairs in some species (Edwards and Bohlen, 1996; Jamieson, 1974).

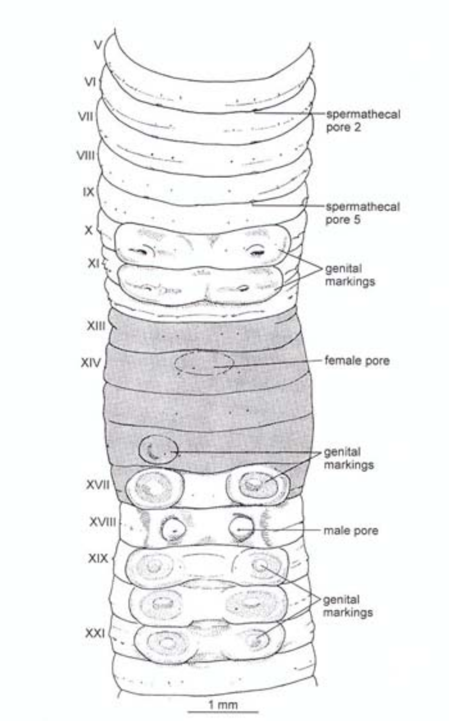

Figure 2.6 An example of a megascolecine genital field, *Spenceriella penolaensis.* (Jamieson, 1974).

2.1.8 Body wall

The body wall of oligochaetes consists of an integument, consisting of cuticle and epidermis, overlying musculature which typically consists of an outer a circular and inner longitudinal muscle layer, and a peritoneal epithelium, the whole enclosing the coelom. The epidermis is a monolayered epithelium and contains supportive, secretory and sensory cells, though, rarely, non-sensory ciliary cells are present. The cuticle is permeable to respiratory gases but protects the epidermis from abrasion. It is also permeable to certain not-gaseous molecules. The body wall musculature of oligochaetes is arranged in two concentric coats, a thin outer coat consisting of fibers with their long axes concentric to the long axis of the worm, forming the circular muscle, and a thicker inner coat of longitudinal fibers (Jamieson, 1992).

2.2 Internal anatomy and function

2.2.1 The coelom

The coelom is a large cavity that extends through the length of the body, and is filled with coelomic fluid. It is surrounded on the outer side by the peritoneum of the body wall and on the inner side by the peritoneum covering the alimentary canal. Transverse septa divide it into segmental portions. The peritoneum covering these septa is similar in structure to that covering the inner surface of the muscle layers; in a few species the peritoneum on the septa is so very much thickened that it almost fills the coelom in this region. The septa usually correspond to the external segmental grooves but often do not occur in the first few segments of the body, and in some species they are missing in other parts. Some species have septa that do not correspond with the intersegmental grooves in the anterior end but are displaced backwards. The septa differ in thickness, depending on their position in the body, those in the anterior of the body being markedly thickened and more muscular. Septa are constructed from muscle fibers, mostly derived from the longitudinal muscle layer, together with some circular muscles on the posterior face, with connecting tissue and blood vessels. The coelomic fluid is a milky white liquid which is sometimes colored yellow by eleocyted. 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. The coelomic fluid contains many different kinds of particles in suspension. The inorganic inclusions are mainly crystals of calcium carbonate, but the corpuscular bodies in the coelomic fluid of lumbricid worms include phagocytic amoebocytes, which feed on waste materials; vacuolar lymphocytes; and mucocytes. Many earthworms eject coelomic fluid through the dorsal pores, in response to mechanical or chemical irritation, or when subjected to extremes of heat or cold (Edwards and Bohlen, 1996; Jamieson, 1997).

2.2.2 Feeding and digestive system

The alimentary canal of megadrile oligochaetes is typically differentiated into a buccal cavity, pharynx, oesophagus, intestine and rectum. The oesophagus frequently has one or more muscular thickenings, the gizzards, and often bears diverticula which may be differentiated as calciferous glands. The oesophageal (megascolecids) or intestinal gizzard (lumbricids) may be preceded by a less muscular enlargement, the crop (Figure 2.7). The intestine may show muscular thickenings, in one or more of its initial segments, which may be differentiated, as in the megascolecines, *Hickmaniella* and *Retrovescus*, in each segment as a gizzard. It also may have anteriorly directed diverticula near it anterior limit, and it is frequently internally infolded as one or more typhlosoles (Edwards and Bohlen, 1996).

2.2.2.1 Buccal cavity and pharynx

The earthworm buccal cavity is usually visible and occupies the first two segments. The pharynx in oligochaetes is strongly thickened owing to glandular and muscular tissue (Figure 2.7). The pharynx is generally either a symmetrical axial structure or has a ventral buccal organ or diverticulum (Edwards and Bohlen, 1996).

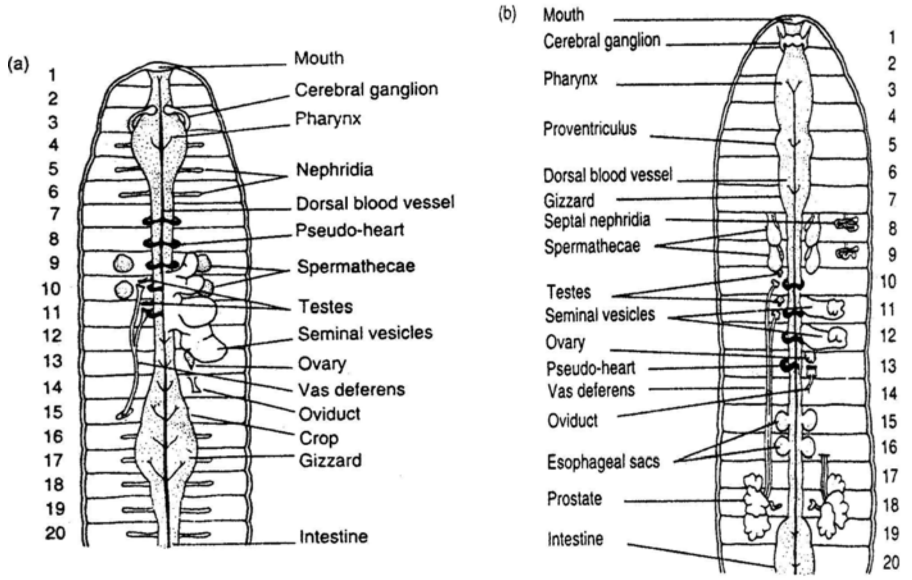

Figure 2.7 Digestive, circulatory and reproductive systems of earthworms a) *L. terrestris* b) *Pheretima* spp. (Edwards and Bohlen, 1996).

2.2.2.2 Oesophagus

The megadrile oesophagus consists of a relatively straight tube traversing several segments, with or without appended calciferous glands and other Diverticula (Figure 2.7). Oesophageal diverticula are well developed in many Megascolecidae (Edwards and Bohlen, 1996).

2.2.2.3 Calciferous glands

Oesophageal diverticula are usually termed calciferous glands particularly where well demarcated from the oesophagus irrespective of whether a calciferous function has been demonstrated. Figure 2.8 shows the calciferous glands of some Australian Megascolecidae as *Heteroporodrilus* and *Spenceriella* species. The vascularization of the glands is shown and it is seen that in *Heteroporodrilus* and *Plutellus* the glands are supplied by branches from the supar-oesophageal vessel and that blood passes from the glands to paired or single suboesophageal vessels (Jamieson and Bradbury, 1972).

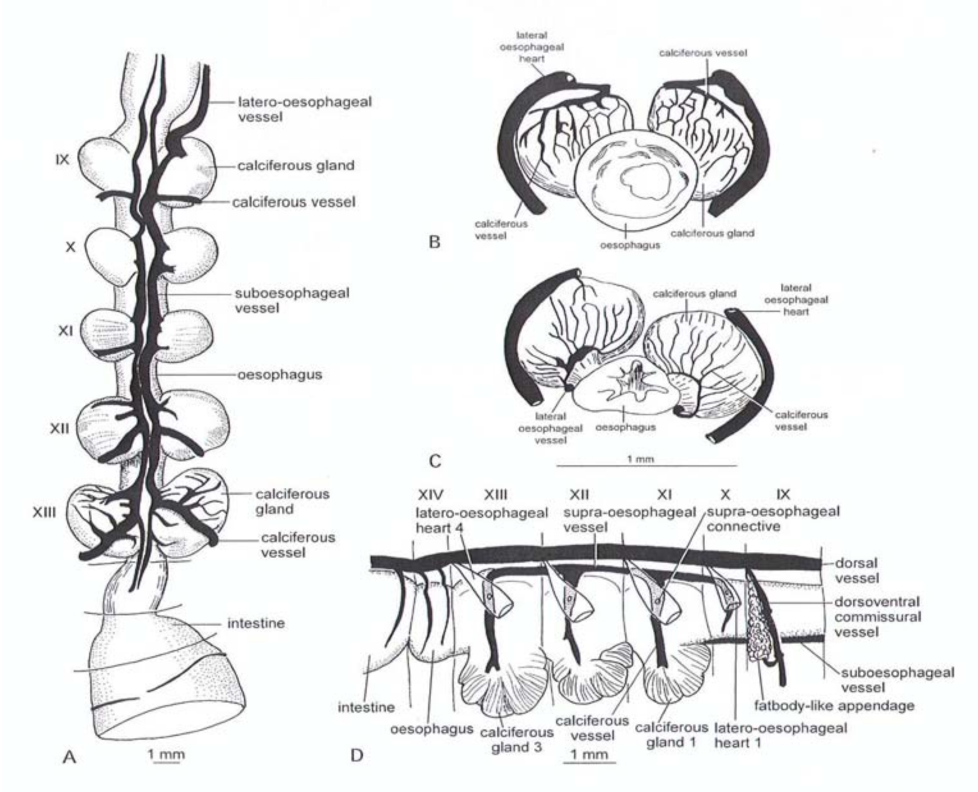

Figure 2.8 Calciferous glands and their vascularization in some Australian Megascolecidae. A: Ventral view of five pairs of calciferous glands of *heteroporodrilus tryoni*. B and C: Anterior and posterior views of gland of X in *Spenceriella* (*Spenceriella*) *notabilis*. D: Lateral view of gland of *Heteroporodrilus oxleyensis* (Jamieson and Bradbury, 1972).

2.2.3 The vascular system

Earthworms have a closed vascular system, it is not possible to distinguish arteries and veins. 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 (Edwards and Bohlen, 1996). Megascolecid and some glossosclecid earthworms, but not lumbricids, have a supra-intestinal vessel; this lies along the dorsal wall of the gut in the anterior segments and is part of the complex of blood vessels serving the alimentary canal (Figure 2.9) (Jamieson and Bradbury, 1972).

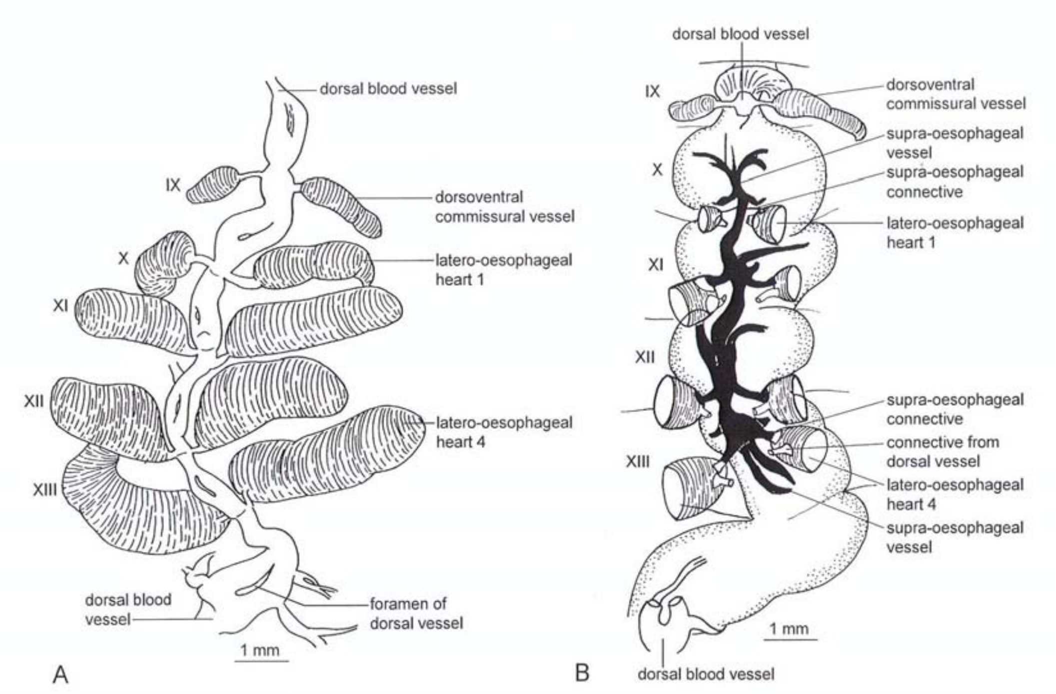

Figure 2.9 Vascular system. Dorsal blood vessel and connections in the oesophageal region of Megascolecidae exemplified by *Didymogaster sylvaticus*. A: Showing the hearts. B: Hearts removed to reveal the supra-oesophageal connectives (Jamieson and Bradbury, 1972).

2.2.4 The respiratory system

Earthworms 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. The gas exchange depends upon a network of small blood vessels buried in the body wall of 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 the blood and passed around the body. The hemoglobin in earthworms has a very high affinity for oxygen (Edwards and Bohlen, 1996; Jamieson, 1992).

2.2.5 Excretion

The principal excretory organs in earthworms are the nephridia, which extract waste materials from the coelomic fluid in which they lie, and excrete them to the exterior, as urine consisting mainly of ammonia and urea, through the nephridiopores. There are at least two nephridia in each segment, but in some species there are many more (Edwards and Bohlen, 1996). The nephridia open from the coelom by funnel-like nephrostomes and are termed metanephridia. Metanephridia occurring as a single pair in each segment are termed holonephridia. Alternatively ontogenetic subdivision of the nephridia rudiments may produce more than one pair of nephridia, then known as meronephridial, in each segment. The nephridia obviously act as differential filters, because there is much more urea and ammonia, but less of protein, in the urine they produce than in the coelomic fluid.

2.2.6 Sense organs and nervous system

In oligochaetes, the brain is united with the segmentally ganglionated ventral nerve cord by a pair of commissures. The annelid brain is reasonably supposed to be the equivalent of the combined protocerebrum and deutocerebrum of arthropods. In earthworms, ganglia of the first two segments have become incorporated into the circumpharyngeal commissures, and the ganglia of the subsequent two segments form the subpharyngeal ganglion. Each segmental ganglion, posterior to these, has two to four pairs of nerves (Jamieson, 1992).

2.2.6.1 Photoreceptors

Earthworms do not have recognizable eyes, but possess sensory cells with a lens-like structure in regions of the epidermis and dermis, particularly on the prostomium. The middle part of the body is rather less sensitive to light and the posterior is also slightly sensitive (Edwards and Bohlen, 1996).

2.2.6.2 Chemoreceptor

Most of the sense organs, which react to chemical stimuli, are on the prostomium or the buccal epithelium which comes into contact with substances when the buccal chamber is exerted during feeding. Different earthworm species differ in their tolerance to soil acidity, but all have a threshold of pH below which they cannot live for long, so the ability to detect pH is essential for survival. Laverack demonstrated that *Aporrectodea longa* will not burrow into soil with a pH below 4.5 and *L. terrestris* into soil with a pH below 4.1 (Laverack, 1961, quoted in Edwards and Bohlen, 1996).

2.2.7 Reproductive system

Oligochaetes are hermaphrodite, and have more complicated genital systems than most unisexual animals. The reproductive 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. The paired ovaries 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 (Edwards and Bohlen, 1996).

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 Ocnerodrilidae have only a single pair in 10 (proandric) or 11 (Metandric). The testes are lobed organs attached to the posterior faces of septa 9/10 and 10/11 of *Lumbricus* and projecting from the septal walls into two median testis sacs, one in segment 10 and one in segment 11 (Figure 2.10). The testis sacs are filled with nutrient fluid in which lie the developing male cells. These sacs communicate with the seminal vesicles which are storage sacs for the developing male cells (Edwards and Bohlen, 1996; Jamieson and Bradbury, 1972).

The seminal vesicles are the largest and most conspicuous organs of the reproductive system, and are immediately obvious when earthworms are dissected as white masses on either side of the alimentary canal. They are sacs, for the most part divided by connective tissue into intercommunicating compartments. The Megascolecidae have from one to four pairs of seminal vesicles, *Pheretima* spp. having two pair (Edwards and Bohlen, 1996).

The prostates or prostatic glands are large glands associated with the posterior ends of the vas deferent. 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 and finger-like or convolute tubes (Edwards and Bohlen, 1996).

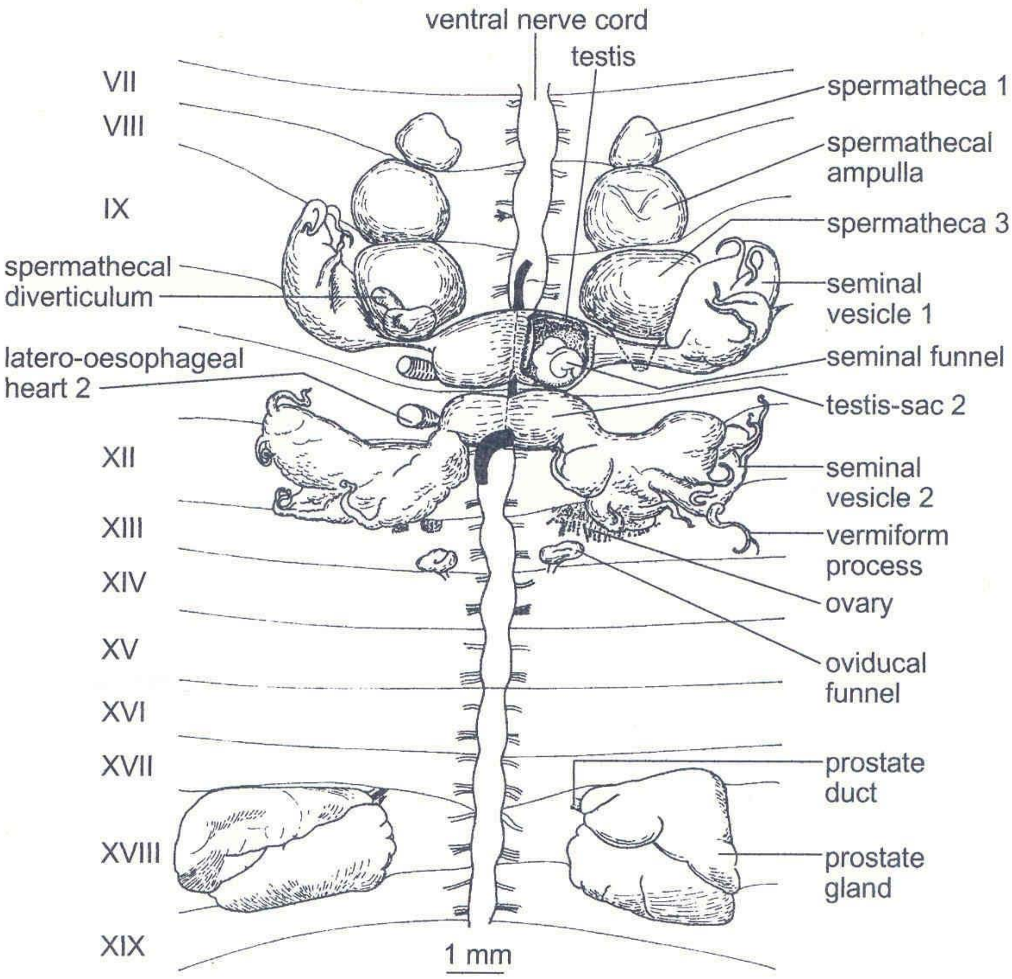

Figure 2.10 The genital organs of a megascolecine (Jamieson and Bradbury, (1972).

2.3 Earthworm diversity and geographical distribution.

2.3.1 Earthworm diversity

Earthworms belong to the class Oligochaeta and are related to the Polychaeta (bristle worms) and the Hirudinea (leeches). The early oligochaetes probable 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) (Edward and Bohlen, 1996).

Many authors have produced classifications of the Oligochaeta, but it was not until 1900 that Michaelsen produced the Oligochaeta system on the basis of the modern taxonomy and divided them into 11 families, containing about 152 genera and 1,200 species (Edward and Bohlen, 1996).

In 1930, Stephenson simplified Michaelsen's system of classification into 14 families. Stephenson's families, Aeolosomatidae, Naididae, Tubificidae, Pheodrilidae, Enchytraeidae, Lumbriculidae and Branchiobdellidae, were placed in Microdrili group and Alluroididae, Haplotaxidae, Moniligastridae, Megascolecidae, Eudrilidae, Glossoscolecidae, and Lumbricidae are placed in Megadrili group. (Stephenson, 1930, quoted in Edwards and Bohlen, 1996).

Gates (1959) recognized several somatic characters which were markedly resistant variation and evolutionary conservation. Gates's classification of the megadrile families were as follows: Moniligastridae, Megascolecidae, Ocnerodrilidae, Acanthodrilidae, Octochaetidae, Eudrilidae, Glossoscolecidae, Sparganophilidae, Microchaetidae, Hormogastridae, Criodrilidae, and Lumbricidae.

Jamieson (1988) reviewed the overall phylogeny and higher classification of the Oligochaeta based 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 superfamilies, Ocnerodriloidea (family Ocnerodrilidae), Eudriloidea (family Eudrilidae), Lumbricoidea (family Kynotidae, Komarekionidae, Ailoscolecidae, Microchaetidae, Hormogastridae, Glossoscolecidae, and Lumbricidae), and Megascolecoidea (family Megascolecidae).

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

1. Order Moniligastrida
            - Family Moniligastridae
2. Order Haplotaxida
    - Suborder Enchytraeina
        - Superfamily Enchytraeoidea
            - Family Enchytraeidae
            - Family Propappidae
    - Suborder Lumbricina
        - Superfamily Alluroidoidea
            - Family Alluroididae
        - Superfamily Criodriloidea
            - Family Criodrilidae
        - Superfamily Lumbricoidea
            - Family Lumbricidae
            - Family Komarekionidae
            - Family Diporochaetidae
            - Family Ailoscolecidae
            - Family Hormogastridae
            - Family Lobatocerebridae
        - Superfamily Sparganophiloidea
            - Family Sparganophilidae
        - Superfamily Biwadriloidea
            - Family Biwadrilidae

Superfamily Glossoscolecoidea
    Family Glossoscolecidae
    Family Kynotidae
    Family Microchaetidae
Superfamily Almoidea
    Family Almidae
    Family Lutodrilidae
Superfamily Megascolecoidea
    Family Megascolecidae
    Family Acanthodrilidae
    Family Octochaetidae
    Family Eudrilidae
Superfamily Ocnerodriloidea
    Family Ocnerodrilidae

The two most important families in Europe, North America, Australia and Asia are Lumbricidae and Megascolecidae. 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, with two genera, *Pheretima* and *Dichogaster*, that together probably contain more species than any other oligochaete genera (Edwards and Bohlen, 1996).

Sims and Easton (1972) reviewed the genus *Pheretima* and divided it into eight genera: *Archipheretima*, *Pithemera*, *Ephemitra*, *Metapheretima*, *Planapheretima*, *Amynthas*, *Metaphire* and *Pheretima*.

2.3.2 Geographical distribution

In considering the possibilities and the modes of migration the Oligochaeta may be divided into three groups: the limnic, littoral, and terrestrial. The limnic Oligochaeta have abundant means of dispersal. They may spread directly throughout a river system. The littoral forms live on the shore, exposed at times to submersion in salt water. They have a wide distribution. They can be transported in masses of seaweed or more commonly their cocoons are transported, entangled in masses of weed or other detritus. For terrestrial forms the means of spreading are more limited, earthworms have to depend on their own activities for reaching new regions. There are other barriers to the migration of earthworms. Mountain ranges may be a barrier, through lack of vegetation and the presence of snow and ice. Desert tracts are still more effective; earthworms cannot live in soil which does not contain moisture and organic matter. The sea is a barrier to most species of earthworms, because they cannot tolerate salt water even for short periods. Climate is importance to some, though not to all genera, the genus *Pheretima*, though it has been unable to establish itself except in the warmer zones. Regions which are covered for considerable periods of the year with ice and snow harbor no earthworms, though this rule is hardly absolute (Stephenson, 1930). Michaelsen has used the term peregrine to describe such species, whereas the other species that do not seen able to spread successful to other areas to any great extent have been termed endemic species (Edward and Bohlen, 1996). In the remaining megadrile families that have not been discussed so far have a wide-ranging distribution and can be endemic as well as peregrine; they are based mainly in eastern countries. The family Moniligastridae has a very large range, encompassing South-East and Eastern Asia, South India, Japan, Philippines, Borneo and Sumatra. South-East Asia and Australasia are dominated by earthworms belonging to the classical Megascolecidae, i.e. the families Megascolecidae, Acanthodrilidae, Ocnerodrilidae and Octochaetidae. Megascolecid earthworms of the genus *Pheretima* (indigenous in China, Philippines, Malaysia, Indonesia and Papua New Guinea) have also been transported to many tropical, subtropical and temperate regions (Edward and Bohlen, 1996). The most widespread peregrine species are confined to man-modified habitats. Gates distinguished these as anthropochorous species, contrasting them with allochthonous species that are not so constrained, and attributing their success to their rather unusual ability not only to withstand but also to take advantage of human disturbance of the environment. It is these species, more than any others, that are important in maintaining soil fertility in agricultural soils (Gates, 1970).

Fragoso, Kanyonyo, Lavelle, and Moreno (1992) provided data on 176 earthworm species and 60 earthworm communities from tropical America (six countries) and Africa (two countries). Peregrine species with pantropical distributions were dominant in disturbed environments because they had greater tolerances than native species towards environmental factors. Nevertheless, a few native species with rather broad regional distributions were able to live in the disturbed environments. In many of the disturbed environments, earthworm communities had a lower diversity but larger biomass due to the colonization of a few peregrine species, e.g. *Pontoscolex corethrurus*.

In China, about 105 species of terrestrial earthworms have been recorded. Five families of earthworms in China i.e. Moniligastridae, Lumbricidae, Megascolecidae, Octochaetidae and Ocnerodrilidae were reported by many research works. (Chen, 1930, 1931, 1933, 1935, 1936, 1938; Chen, Hsu, Yang, and Fong.

1975; Gates, 1935, 1939a; Tsai, Shen, and Tsai, 2000).

In Japan, about 77 species of terrestrial earthworms have been recorded. They are placed in Moniligastridae, Lumbricidae, Biwadrilidae, Megascolecidae, Acanthodrilidae, Octochaetidae and Ocnerodrilidae (Blakemore, 2003; Easton, 1980; Hatai, 1930a, 1930b; Hatai and Ohfuchi, 1936, 1937; Ishizuka, 1999; Kobayashi, 1941; Ohfuchi, 1935, 1937, 1938, 1941; Tsai, Shen, and Tsai, 2000).

In Korea, there is a total 55 species distributed in Moniligastridae, Lumbricidae and Megascolecidae (Gates, 1972; Hong and James, 2001; Hong, Lee, and Kim, 2001; Kobayashi, 1934, 1936, 1938a; Tsai, Shen, and Tsai, 2000).

In Taiwan, there is a total 44 species distributed in Moniligastridae, Lumbricidae, Glossoscolecidae, Megascolecidae and Octochaetidae (Gates, 1959; Kobayashi, 1938b; Shen and Tsai, 2002; Shen, Tsai, and Tsai, 2005: Shih, Chang, and Chen, 1999; Tsai, Shen, and Tsai, 2000, 2001, 2002).

In Vietnam, there is a total 40 species distributed in Moniligastridae, Lumbricidae and Octochaetidae (Thai, 1982,1984).

In Myanmar, Gates (1972) published the “Burmese Earthworms and Introduction to the Systematics and Biology of Megadrile Oligochaetes with Special Reference to Southeast Asia”. He found 232 earthworm species belonging to Moniligastridae, Lumbricidae, Glossoscolecidae, Microchaetidae, Megascolecidae, Acanthodrilidae, Ocnerodrilidae and Octochaetidae.

In Thailand, the first report of 24 species of Megascolecidae has been presented in “The Journal of the Thailand Research Society Natural History Supplement” (Gates, 1939b). Then in 1972, some earthworms of Thailand, 25 species, have been reported in the “Burmese Earthworms” by Gates. These earthworms have been placed in Glossoscolecidae (*Pontoscolex corethrurus*), 23 species in Megascolecidae [*Lampito* (*L. mauritii*), *Perionyx* (*P. excavatus*), 9 species of *Amynthas* (*A. alexandri*, *A. compta*, *A. longicavlicalata*, *A. exigua*, *A. austrina*, *A. fluvialis*, *A. hupbonensis*, *A. manicata*, *A. decorosa*), 9 species of *Metaphire* (*M. anomala*, *M. bipora*, *M. elongata*, *M. houlleti*, *M. malayana*. *M. peguana*, *M. planata*, *M. posthuma*, *M. virgo*), 3 species of *Pheretima* (*P. hawayana*, *P. morrisi* and *P. papulosa*)], and 1 species in Octochaetidae (*Dichogaster affinis*) (Gates, 1939b, 1937).

2.4. Earthworm ecology

2.4.1 Populations

Earthworm population can be expressed either in terms of numbers or biomass. The use of numbers is sometimes misleading because it does not differentiate between very small and large individuals, which have very different influences on soil processes. It is best to express populations both as numbers and biomass. The numbers of earthworms in regularly cultivated arable soils are usually very variable, and populations are intermediate in size between the more sterile habitats and those in pastures and natural grasslands which can support large numbers of earthworms. The populations in coniferous forests tend to be lower and those in deciduous temperate forests and tropical forests rather larger than those in arable land. There is great variability in earthworm populations, although grassland seems able to support higher populations than most other habitats, presumably due to the availability of large quantities of organic matter (Edwards and Bohlen, 1996). Satchell (1969) and Collins (1992) described a method for calculating the live weight of earthworms that had been kept in 10% formalin solution. They plotted a regression of the live weights of worms against their weight after being kept in 10% formalin, then oven-dried them at 105ºC, and reweighed them. They obtained the expression: 1 g dry weight = 5.5 g live weight.

McCredie, Parker, and Abbott (1992) reported from Australia that the abundance of *Allolobophora trapezoides* increased from 58 per m^2 at the time of the opening rains to 170 per m^2 after 10.5 weeks. Near the end of the wet season, in October, the density was 37 per m^2. At the time when the rains began, the population consisted of juvenile and immature individuals. The mature earthworms were found 1 month later and predominated from August, 10.5 weeks, to the end of the season. The cocoons occurred from August through October, and those incubated in the laboratory at 16ºC hatched on average after 42 days and produced about two juveniles each. Juvenile and immature earthworms collected from a quiescent state at the end of summer, matured within 1 month when reared in moist soil in the laboratory.

Guild (1952, quoted in Edwards and Bohlen, 1996) classified the possible factors that were likely to be responsible for variability in horizontal distributions as: physioco-chemical (soil temperature, moisture, pH, inorganic salts, aeration and texture); food available (litter, organic matter); reproductive potential and historical factors (colonization of new habitats).

Boyd (1958, quoted in Edwards and Bohlen, 1996) reported that earthworms in pasture, populations of *Dendrobaena octaedra* and *Lumbricus rubellus* were aggregated significantly beneath dung-pats in spring. Satchell (1955, quoted in Edwards and Bohlen, 1996) showed that *Lumbricus castaneus* and *Aporrectodea rosea* were greatly aggregated in a relatively uniform pasture which had not been grazed. He suggested that aggregations might occur when earthworms are reproducing more rapidly than the offspring can disperse from the breeding site. Satchell calculated indices of dispersion for adults and immatures, he found that the adults were nearly randomly dispersed but the immatures were aggregated significantly. On this assumption, a species with distinct seasonal changes in abundance can be expected to pass from a very aggregated phase in the breeding season in early summer to a more randomly distributed phase in winter.

Many workers introduced earthworms to new habitats and studied their rate of multiplication and spread. For instance, Rhee (1969a,b) inoculated a new polder in the Netherlands with 4664 individuals of *Aporrectodea caliginosa* and reported that they had multiplied to 384,740 individuals 1 year later. At the same site 2558 individuals of *Allolobophora chlorotica* increased to 121,660 in the same period. He calculated a horizontal rate of spread of the population of *A. caliginosa* of 6 m/yr and 4 m/yr for *A. chlorotica*. Stockdill (1982) inoculated *A. caliginosa* into New Zealand pastures at a spacing of 10 m and reported that the whole area became colonized after 8-10 years. Hoogerkamp, Rogaar, and Eijsackers (1983, quoted in Edwards and Bohlen, 1996) reported an annual dispersal rate of about 9 m for *A. caliginosa* and 4 m for *Lumbricus terrestris*. The spread of earthworms in inoculated polder soils was calculated by Stein, Bekker, Blom, and Rogaar (1992) to be from 10 to 13 m/yr.

Different species of lumbricids inhabit different depth zones in the soil, but the vertical distribution of each species changes considerably with the time of year. The seasonal vertical distributions of earthworms in a Rothamsted pasture. Species such as *Dendrobaena octaedra* and *Bimastos eiseni* live in the surface organic horizon of soil for most of the year. *A. caliginosa*, *A. chlorotica*, *A. rosea*, *Lumbricus castaneus* and *L. rubellus* occur commonly within 8 cm of the soil surface, as do immature individuals of *Octolasion lacteum*, *O. cyaneum*, *Aporrectodea longa*, *Allolobophora nocturna* and *L. terrestris*. Most adult and nearly mature individuals of *O. cyaneum* are in the top 15 cm. *A. longa* and *A. nocturna* have fairly permanent burrows which usually penetrate as deep as about 45 cm, but the deeper vertical burrows of *L. terrestris* go down to a depth of 1-2.5 m. (Edwards and Bohlen, 1996). Gerard (1967) studied the changes in vertical distribution of common earthworms at different times of the year in England. Most earthworms were below 7.5 cm deep in January and February, when the soil temperature was about 0ºC, but by March when the soil temperature had risen to 5ºC at a depth of 10 cm. the most individuals of *A. chlorotica*, *A. caliginosa* and *A. rosea*, and small and medium sized individuals of *A. longa*, *A. nocturna* and *L. terrestris*, had moved into top 7.5 cm of soil, although most of the larger worms were still deeper in the soil. Form June to October, earthworms of most species were below the top 7.5 cm again. In November, December and the following April, most earthworms had returned to the top 7.5 cm. The two factors influencing movement to deeper soil, seemed to be very cold or very dry surface soil

2.4.2 Communities

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 stratification in soil. These major ecological groups represent functional adaptations to the soil environment that allow different species of earthworms to coexist by exploiting different food resources and habitat space. Earthworm communities nearly always include species that pursue different ecological strategies, and a familiarity with these strategies is essential to an understanding of the structure of earthworm communities (Edwards and Bohlen, 1996).

Lee (1959, quoted in Edwards and Bohlen, 1996) recognized three main ecological groups of earthworms among New Zealand Megascolecidae, base on the soil horizons in which the earthworms were commonly found: i.e. litter, topsoil and subsoil. The litter species form no burrows, are generally heavily pigmented dorsally and ventrally and feed on decomposing litter. The top soil species live in permanent burrows that descend into the mineral horizon. They are unpigmented ventrally and feed on decomposing litter on the soil surface and some soil. The subsoil species have constantly extending burrow systems and are unpigmented or lightly pigmented. They feed on soil and organic matter in the soil.

Bouche (1971, 1977, quoted in Edwards and Bohlen, 1996) recognized three major ecological groups, which he termed: epigeics, anecics and endogeics. Epigeics are small pigmented earthworms that rarely burrow into the soil and live in the litter layer feeding on decaying organic matter. These species are common in forested areas but are rarely found in agricultural fields because of inadequate residue cover and surface moisture. This group is represented by *L. rubellus*, *D. octaedra* and *L. castaneus*. Anecic earthworm species fall into the same general category as the Lee's topsoil species. They form permanent or semi-permanent vertical borrows in the soil, which descend into the mineral horizon and open at the surface, where the earthworm emerges to feed, primarily on dead leaves and other decaying organic materials. This group includes *L. terrestris*, *A. longa* and *Nicodrilus longus* which are the major European representatives of this group. Anecic earthworms are more predominant among European lumbricids than among New Zealand megascolecids. Endogeic earthworm species, like Lee’s subsoil species, inhabit the mineral soil horizons. They consume more soil than do either epigeic or anecic species and derive their nourishment from more humified organic matter, although some species will occasionally come to the surface to feed beneath the litter layer.

2.5 The influence of environmental factors on earthworms

2.5.1 Moisture

Earthworms are thin-skinned invertebrates with little protection against the changes in moisture and temperature of soil (Edwards and Bohlen, 1996). Water constitutes 75-90% of the body weight of earthworms, so prevention of water loss is a major factor in earthworm survival. Grant (1955, quoted in Edwards and Bohlen, 1996) considered that most lumbricids worms could sustain a water loss of at least 50%. Earthworm activity also depends upon adequate availability of soil moisture, but not all species have the same moisture requirements and within a species, the moisture requirements for earthworm populations from different regions of the world can be quite different. In Europe, *A. caliginosa* goes into diapauses at soil moisture content below 25-30% and does not survival well below 20% soil moisture (Baltzer, 1956, quoted in Edwards and Bohlen, 1996). In Argentina, *A. caliginosa* and *A. rosea* are active in soils with moisture content as low as 15% (Ljungstrom, Orellana, and Priano, 1973). Madge (1969 quoted in Edwards and Bohlen, 1996) placed earthworms of the species *Helodrilus africanus* in moisture gradients, and reported that they preferred soil between 12.5 and 17.2% moisture content. Soil with a moisture content of about 23.3% appeared to be optimal for them to produce casts. *A. caliginosa* and *Metaphire californica* seemed to prefer soil moisture contents of 20-45% and 35-55%.

Soil moisture can influence the numbers and biomass of earthworms at any given location. Olson (1928 quoted in Edwards and Bohlen, 1996) surveyed areas of Ohio, USA, for earthworms, and reported that the largest numbers of earthworms occurred in soils containing between 12% and 30% moisture. El-Duweini and Ghabbour (1965, quoted in Edwards and Bohlen, 1996) investigated the survival of *A. caliginosa* in relation to soil moisture content in Egypt, reported that in soils with 5-85% gravel and sand, an increase in moisture content of from 15 to 34% was associated with an increase in numbers of *A. caliginosa*, but above 34% extra moisture had no effect.

2.5.2 Temperature

Temperature and moisture are usually inversely related and high surface temperatures and dry soils are much more limiting to earthworms than low temperatures and waterlogged soils (Nordstrom and Rundgren, 1974). The optimum temperature for cocoon production by *L. terrestris* was 15ºC with 25.3 cocoons produced per annum. Cocoon of *L. terrestris* hatched more rapidly at 20ºC than other temperatures (Butt, 1991). The growth period from hatching to sexual maturity is also dependent on temperature; for instance, *A. chlorotica* took 29-42 weeks to mature (Evans and Guild, 1948, quoted in Edwards and Bohlen, 1996), 17-19 weeks at 15ºC (Graff, 1953, quoted in Edwards and Bohlen, 1996) and 13 weeks at 18ºC (Michon, 1954, quoted in Edwards and Bohlen, 1996). *Eisenia fetida* took 9.5 weeks to mature at 18ºC and 6.5 weeks at 28ºC (Michon, 1954, quoted in Edwards and Bohlen, 1996). Viljoen, Reinecke, and Hartman (1992) reported that *Dendrobaena veneta* completed its life cycle in 107 days at 15ºC and in 151 days at 25ºC. Lee (1985, quoted in Edwards and Bohlen, 1996) reported that the optimal temperature for growth of indigenous populations of Lumbricidae in Europe ranges from 10 to 15ºC. Daughberger (1988) verified these temperature optima in laboratory experiments, the temperature preference of *L. terrestris* was 10ºC, and that of both *Aporrectodea caliginosa* and *A. longa* was between 10 and 15ºC. Grant (1955, quoted in Edwards and Bohlen, 1996) showed that the temperature optimum was 15-23ºC for *Pheretima hupeiensis*, 15.7-23.2ºC for *Eisenia fetida*, and 10-23.2ºC for *A. caliginosa*, 24.1-25.6ºC for *Eisenia rosea*.

2.5.3 pH

Soil pH is a limiting factor of earthworm species, numbers and distribution. Some species are intolerant for acid soil conditions, and many species can tolerate a wide range of pH (Edwards and Bohlen, 1996). Spiers *et al.* (1986) studied an acid-tolerant earthworm species, *Arctiostrotus* sp., endemic to the organic horizons of coniferous podzols of Canada. These earthworms occurred in organic soil horizons with pH ranges from 2.6 to 6.2 and were most abundant at a site with a pH of 2.9. Satchell (1955, quoted in Edwards and Bohlen, 1996) reported that *Bimastos eiseni*, *Dendrobaena octaedra* and *Dendrobaena rubida* were acid-tolerant species, and *A. caliginosa*, *Allolobophora nocturna*, *A. chlorotica*, *A. longa* and *A. rosea* were acid intolerant. Guild (1951, quoted in Edwards and Bohlen, 1996) and Richardson (1938, quoted in Edwards and Bohlen, 1996) reported that *L. rubellus*, *L. terrestris*, *Lumbricus castaneus*, *Octolasion cyaneum* and *Dendrobaena subrubicunda* were not very sensitive to pH. El-Duweini and Ghabbour (1965, quoted in Edwards and Bohlen, 1996) reported that an increase of pH from 7.25 to 8.25 was associated with a decrease in numbers of earthworms in 14 Egyptian soils. Bouche (1972, quoted in Edwards and Bohlen, 1996) related the distribution of 67 taxa of Lumbricidae in France in relation to the pH of soil. Most species occurred in soils with a pH range of 7.0-7.4. Twenty six acid-tolerant species were found in soils with a pH below 4.0 and 4 species were found only in soils with a pH above 6.6.

2.5.4 Soil type

Earthworms are influenced by soil type and texture, although there have been relatively few studies of the direct influence of soil type on earthworm populations. Guild (1948, 1951, quoted in Edwards and Bohlen, 1996) made a survey of the main soil types in Scotland and reported that there were differences both in total numbers and relative numbers of each species in soil of different textural composition. Light and medium loam had greater total populations of worms than heavier clays or more open gravelly sands and alluvial soils. *A. caliginosa* was the dominant species in all soil types, and *A. longa* was less important in open soils, gravelly sands and alluvial soils. Boyd (1957, quoted in Edwards and Bohlen, 1996) compared the relative abundance of earthworm species in light soils with those in calcareous sand and dark peat soils. Six species were more abundant on the light soils and six on the dark ones. In particular, *A. caliginosa* and *L. castaneus* were much numerous in the light soils, and *B. eiseni* and *D. octaedra* in the dark soils. El-Duweini and Ghabbour (1965, quoted in Edwards and Bohlen, 1996) showed that populations of *A. caliginosa* in Egypt decreases with increasing proportions of gravel and sand in soils. This relationship did not hold in soils that had higher water contents, indicating that some of the effects of texture were due to its influence on soil moisture. In pasture and heath-lands in Sweden, Nordstrom and Rundgren (1974) found a significant positive correlation between earthworm abundance and soil clay content in soils that were categorized as having 0-5%, 5-15% or 15-25% clay. In particular, populations of *A. caliginosa*, *A. longa*, *A. rosea* and *L. terrestris* were correlated positively with clay content at 0-60 cm. Hendrix *et al*. (1992) studied the distribution of earthworms at site representing various ecosystem types, management practices, landscape positions, soil texture and soil erosion status on the Georgia piedmont in south-eastern USA. Moderately and severely eroded sandy clay loam supported significantly more earthworms and greater biomass than slightly eroded soil with a higher sand content. Of the soil texture variables, the silt content of the soil was correlated most with earthworm abundance. These results may have been due to the lower organic matter content and water-holding capacity of the sandy soils.

Fragoso and Lavelle (1992) showed that earthworm communities dominated by geophagus species are characteristic of nutrient-rich soils, whereas those dominated by litter-feeding, epigeic species and normally present in nutrient-poor soils. They showed that the percentage dominance of epigeic species in the earthworm community was negatively correlates with the amounts of calcium, magnesium and nitrogen in the soil.

2.5.5 Organic matter

The distribution of organic matter in soil influences the distribution of earthworms greatly. In Sweden, Nordstrom and Rundgren (1974) found significant co-relations between the organic matter content and clay content of soils and the abundance of deep-burrowing species of earthworms. Large amounts of dead roots and other organic matter in pasture usually coincide with large number of earthworms. Decaying leaves in woodlands are also a source of organic matter that usually favors earthworm multiplication. Earthworms can remove a large part of the annual leaf fall in a woodland or orchard if populations are large and the leaf litter is of a species that is palatable to the worms present. Hendrix *et al*. (1992) reported a strong positive correlation between earthworm population density and soil organic matter content across 10 sites, which included conventional and no-tillage agroecosystems, grass meadows and a mixed deciduous forest, in the south-eastern USA.

2.5.6 Food supply

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. Evans and Guild (1948, quoted in Edwards and Bohlen, 1996) investigated the influence of food on earthworm cocoon production, and showed clearly that more cocoons were produced by worms that were provided with decaying animal organic matter, than by those provided with fresh plant material. They also showed that earthworms fed on any nitrogen-rich diets grew faster and produced more cocoons than those with little nitrogen available. Guild (1955, quoted in Edwards and Bohlen, 1996) stated that most species of earthworms prefer dung or succulent herbage to tree leaves, and that pine needles are preferred least of all. He estimated that mature individuals of *A. longa* can ingest 35-40 g, *A. caliginosa* 20-24 g and *L. rubellus* 16-20 g dry weight of dung per annum. Piearce (1972) reported the diets and gut contents of *A. caliginosa* and *L. rubellus* in deciduous woodland. The *L. rubellus* is primarily a litter-feeder, whereas *A. caliginosa* consumes organic matter in a more advanced state of decomposition. The material ingested by *L. rubellus* was richer in calcium than that consumed by *A. caliginosa*, and the former species has a mechanism for excreting calcium. Piearce (1978) examined the gut contents of six species of Lumbricidae in a pasture in North Wales, UK, and identified different ecological groups of worms based on gut contents and feeding behavior. *L. castaneus* and *L. rubellus* consumed material rich in relatively undecomposed plant remains, whereas *A. caliginosa* and *A. chlorotica* fed mainly on well-decomposed organic detritus; *A. longa* and *Dendrobaena mammalis* were intermediate in their dietary requirements.

Bostrom and Lofs-Holmin (1986) reported that the growth of *A. caliginosa* depended, not only on the type of food available, but also on the particle size of the food material. Earthworms grew best with shoots of meadow fescue, followed by provision of alfalfa shoots and roots. Earthworms provided with barley straw fragments smaller than 0.2 mm gained more than twice as much weight during 150 days as earthworms provided with fragments ranging from 0.2-1.0 mm in size, indicating the importance of food particle size to the nutritional quality of food material. Lowe and Butt (2003) reported that the growth of *A. chlorotica* and *L. terrestris* were significantly enhanced by decreased food particle size and this effect was size specific. The intensity of competitive interactions was influenced by food particle size and stage of earthworm development. Werff, Noordhuis, and Dekkers (1998) reported that, differences between effects of manorial treatments were not significant, whereas crop and cultivation direction significantly influenced earthworm distribution. Hendriksen (1990) used litterbags in experiments with 10 different types of litter in a pasture and observed that detritivore earthworm species (*Lumbricus* spp.) preferred ash, basswood and predecomposed elm and beech litter to undecomposed beech litter. The number of litter feeding earthworms found beneath the litterbags were correlated negatively with the C : N ratio and final polyphenol concentration of the litter. Briones, Mascato, and Mato (1992) reported that a group of species *A. caliginosa*, *D. mammalis*, *L. rubellus*, *E. tetraedra* and *D. rubida* could be separated from *A. rosea* and *A. chlorotica* by combined preferences for organic matter, soil texture and moisture content. Gonzalez, Zou, Sabat, and Fetcher (1999) observed that the plant species composition could produce differences in earthworm abundance and distribution in tropical wet forests.

CHAPTER III

RESEARCH METHOD

3.1 Study site description

This study was conducted at Khao Yai National Park, which situated between latitude 14º 05´ to 14º 15´ N and longitude 101º 05´ to 101º 50´ E. Earthworm sampling areas were selected from 5 different forest types: mix deciduous forest (MD), dry evergreen forest (DE), moist evergreen forest (ME), hill evergreen forest (HE) and grassland (GL) as shown in Figure 3.1. Each forest type consists of dominant plant species which differ from forest to forest.

The sampling area of mixed deciduous forest was situated at an altitude of 170 m, 14º 14' 48″ N, 101º 26' 57″ E. This sampling area was selected as a representative of the major forest areas and was in the least disturbed area. The area includes good stands of mixed deciduous forest and consists of dominant plant species such as *Afzelia xylocarpa* (Kurz) Craib, *Perocarpus macrocarpus* Kurz, *Lagerstroemia calyculata* Kurz, *Pterocymbium javanicum* R. Br., *Gmelina arborea* Roxb., *Adina cordifolia* Hook.F., *Vitex pinnata* Linn. *Terminalia bellerica* (Gaertn.) Roxb., *Garuga pinnata* Roxb., *Bambusa arundinacea* Willd. and grass.

The sampling area of dry evergreen forest was situated at an altitude of 812 m, 14º 26' 42″ N, 101º 22' 26″ E. The area includes good stands of dry evergreen forest and dominated by *Dipterocarpus alatus* Roxb., *D. turbinatus* Gaertn.f., *Vatica cinerea*

King., *Shorea roxburghii* G. Don, *Lagerstroemia calyculata* Kurz, *Hopea odorata* Roxb., *H. Ferrea* Pierrre., some family of Marantaceae, Zingiberaceae and some species of *Musa acuminate* Colla and *Pandanus* sp.

The sampling area of moist evergreen forest was situated at an altitude of 761 m, 14º 26' 23″ N, 101º 22' 18″ E. This are the majority plant community of the whole area. The dominant plant species found are *Dipterocarpus dyeri* Pierre, *D. baudii* Korth., *Anisoptera costata* Korth., *Duabanga grandiflora* (Roxb. Ex Dc.) Walp. Herbs found are *Embelia ribes* Burmf., *Viburnum punctuatum* Ham.& Don. and *Rubus cochinchinensis* Tratt.

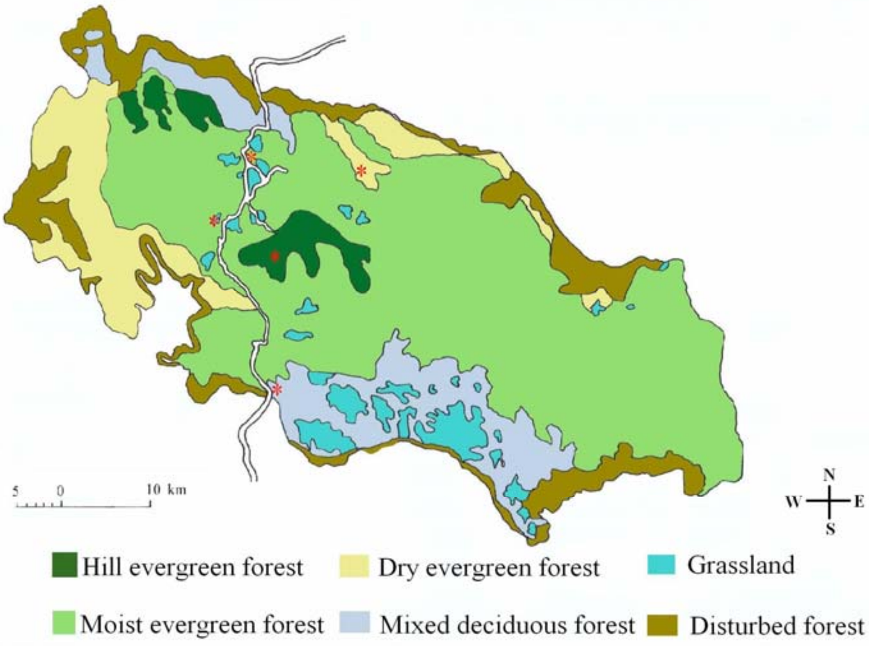

Figure 3.1 The map of Khao Yai National Park shows 5 different sampling areas (Source: Adapted from map of Khao Yai National Park).

The sampling area of hill evergreen forest was situated at an altitude of 1073 m, 14º 20' 40″ N, 101º 23' 55″ E. The hill evergreen forest in Khao Yai National Park is found over 1,000 m above mean sea level. The dominant plant species found are *Podocarpus neriifolius* D. Don, *P. imbricatus* Bl. *Dacrydium elaum* (Roxb.) Wall., *Olea maritime* Wall., *Toxicodendron succedanea* (Linn.) Moldenke. The forest floor is covered with shrubs, climbers, grasses and seedlings. Mosses, ferns, other epiphytes and orchids are frequently found as coverings on tress, rocks and the ground.

The sampling area of grassland was situated at an altitude of 782 m, 14º 22' 55″ N, 101º 20' 45″ E. In the previous times, this area used to be covered with the very dense forest, and because of the deforestation for shifting cultivation and the roads in national park in the recent year caused them to become the grass land as seen in the present. This sampling area is dominated by tall grass such as *Imperaa cylindrical* Beauv., *Saccharum spontaneum* Linn., *Thysanolaena maxima* O.Ktze., *Cicranopteris linearis* (Linn.), some small shrubs and herbaceous species.

3.2 Climate

The physical parameters of environmental factors include air temperature and humidity were measured at the study sites.

3.3 Earthworm sampling and identification

The sampling method involves the selection of a good stand sampling area and establishment of the permanent plot of 10 m x 10 m (100 m^2). The area was divided to 5 rows (A, B, C, D, and E) and each row further divided to 5 sample plots of 2 m x 2 m. Each sample plot was divided further to 16 quadrats of 50 cm x 50 cm for each month study. Five quadrats were chosen after the selection by randomized block design (Figure 3.2). Soil samples (50 cm x 50 cm x 30 cm) were removed from each quadrat and handsorted to collect earthworms. The earthworms were anesthetized with 10% ethanol and placed into containers of 70% ethanol for preservation pending identification at the laboratory of Center for Scientific and Technological Equiment, Suranaree University of Technology.

Preserved earthworms from each quadrat were separated into age classes on the basis of clitellum and sexual pored development as cocoon, juveniles (non-clitellates, sexual pores absent), subadults (non-clitellates, sexual pores present) and adults (clitellates). Identification of sexually mature earthworms was based upon keys of Edwards and Bohlen (1996) and Gates (1972). External characters routinely studied in earthworm taxonomy were the length; width; number of segments; the color; the shape of the body; the form of the prostomium; the position of the first dorsal pore; the numbers and arrangement of setae and the ratios of distances between them in a segment; the form and extent of the clitellum; the position and appearance of the male pores, and prostate pores if separate; the general appearance of the male genital field, including such features as seminal grooves; the appearance and distribution of accessory genital marking, and of the female and spermathecal pores. Internal characters studied were the thickening of septa; the nature of the longitudinal blood vessels, particularly the dorsal vessel; the types and segmental distribution of hearts; the form and location of any gizzards; the segmental position and structure of any calciferous glands or other esophageal diverticula; the segment of origin of the intestine; presence and location of typhlosoles and caeca; the types of nephridia,

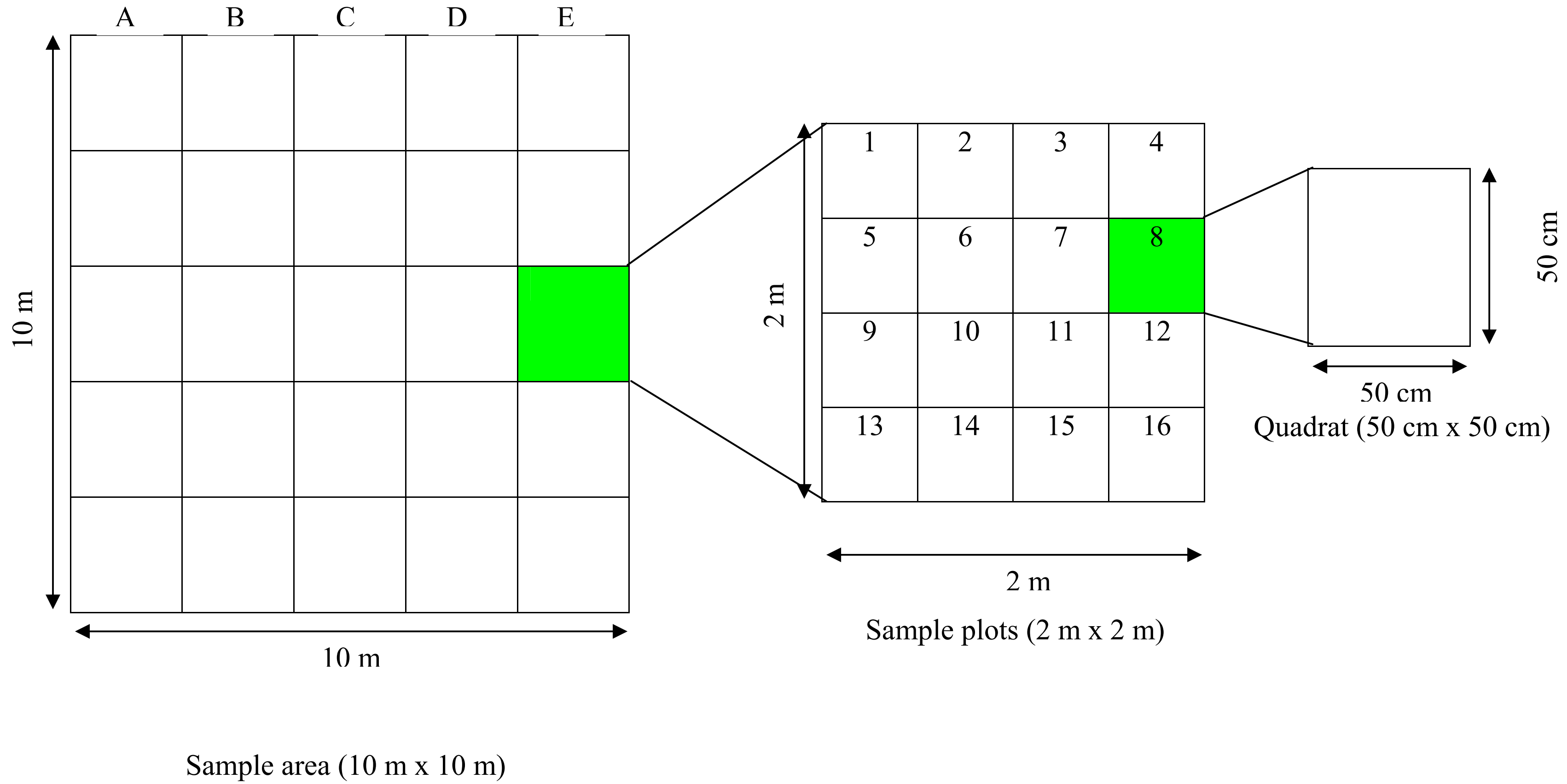

Figure 3.2 Sampling grid design used for sample the earthworm community within each quadrat.

whether holonephridia and/or meronephridia; the number and segmental location of testis sac; the form and segmental location of ovaries, ovisacs, prostate glands, penial setae (if present) and spermathecae

3.4 Litter sampling

Litter on the soil surface was collected by hand and packed into a plastic bag for subsequence analysis. Weight of litter was measured by drying litter at 95ºC in drying oven until weight was constant (18-24 hours).

3.5 Soil sampling and analysis

In each forest type, soil samples of depth 0-10 cm and weigh 300 g, were collected from five quadrats (where earthworms were sampled) and then these 5 soil samples were mixed together in a plastic bag to be one sample for subsequence analyses.

Soil moisture was measured from the weight loss of the known amount of the samples after drying for 24 hours at 105ºC in the oven. A composite soil sample was dried (40ºC, 24 hours) and either ground (<2 mm) for chemical analysis (with the exception of pH and total nitrogen) and physical analyses. Soil pH was potentiometrically measured in the supernatant suspension of a 1:5 soil:distilled water.

Soil organic matter was measured by wet combustion method of Walkley and Black (Schinner, Ohlinger, Kandeler, and Margesin, 1995). The organic carbon in the sample was oxidized with a mixture of potassium dichromate and sulphuric acid without external heating. The excess potassium dichromate was tritrated with ferrous sulphate. Organic matter is expressed as percentage of soil matter and is calculated from the calibration curve.

Total nitrogen was determined by the micro-Kjeldahl method (Schinner *et al.*, 1995). The analysis of total nitrogen required the complete breakdown or oxidation of organic matter. Hydrogen peroxide was added as an additional oxidizing agent. Selenium took place of the traditional mercury catalyst and lithium sulphate was used to raise the boiling point.

Total phosphorus was determined by method of Olsen and Sommers (Schinner *et al.*, 1995). Phosphorus was measured using the perchloric acid digestion method. The absorbance of the solution was measured at 720 nm, using the spectrophotometer.

Available potassium was determined by flame spectrophotometer (Carter, 1993). Potassium was measured by the Atomic Emission Spectrometer after diluting the extraction solution with the 0.63% cesium-solution. The wavelength for the K-measurement was 766.5 nm.

Soil texture was determined for clay (%), sand (%) and silt (%), using the pipette method after removal of soil organic matter, in accordance with Day (1965) in a constant temperature environment (25 ±1°C). Bulk density was estimated following method outlined by Okalebo, Gathua, and Woomer (1993). It was calculated from the ratio of the mass of oven-dried solids and the bulk volume of the solids plus pore space at some specified solid water content.

3.6 Data analysis

3.6.1 Earthworm population

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

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

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

Diversity index and evenness index of earthworms were calculated by using the Shannon-Wiener index as the following:

$$H = -\sum_{i=1}^{S} (Pi)\ (\text{In } Pi)$$

H = index of species diversity

S = number of species

Pi = proportion of total sample belonging to i^{th} species

Evenness:

$$E = \frac{H}{Hmax}$$

E = Equitability or evenness index

H = Shannon diversity index

Hmax = In S

3.6.2 Environmental factors

The computer statistical package Microsoft, SPSS and PC-ORD Program version 4.17 (MJM software design) were used to perform the following statistical analysis. Duncan’s new multiple range test of one-way ANOVA was used to compare the differences of means of environmental factors in terms of air temperature, relative humidity, litter and soil properties. Principal component analysis (PCA) was used to analyse the cluster of environmental factors. The stepwise multiple regressions were used to examine correlation between the number of earthworm species and various environmental factors.

CHAPTER IV

RESULTS AND DISCUSSION

The results of the study are divided into 4 parts for ease of the interpretation. The first is the environmental factors. The second is earthworm identification. The third is earthworm community and distribution. The last is the multiple regression analysis of earthworm community structure.

4.1 Environmental factors

4.1.1 Climate factors (air temperature, relative humidity and rainfall)

Climate factors composed of air temperature, relative humidity and rainfall. The results indicated that the highest mean temperature was 29.4ºC in dry evergreen forest, and the lowest was 23.9ºC in hill evergreen forest. The highest mean relative humidity was 89.0% in hill evergreen forest, and the lowest was 78.2% in grassland. The mean and standard error of these factors in five forest types are shown in Table 4.1

Generally, the temperature of all forest types varies by places and time, and the significant of variation for plants cover. From the results, the mean temperatures of MD, DE and GL were significantly higher than that of ME and HE ($p<0.05$). This might be caused by plant cover. The high density of plant and moisture content might reduce light and radiation from the sun. The shaded ground is cooler during the day than open area. Vegetation interrupts the laminar flow of air, impeding heat exchange by convection (Kimmims, 1997 and Dajoz, 2000).

Table 4.1 The mean (±SE) of climate factors, litter and soil properties of five forest types.

Forest type	MD	DE	ME	HE	GL
Temperature (°C)	28.0^{ab} (±1.5)	29.4^{a} (±1.6)	24.2^{bc} (±1.1)	23.9^{c} (±1.1)	28.6^{a} (±1.4)
RH (%)	86.7^{ab} (±2.0)	81.7^{bc} (±2.4)	88.0^{ab} (±2.3)	89.0^{a} (±1.6)	78.2^{c} (±2.4)
Litter (g)	8.39^{c} (±0.34)	18.07^{a} (±0.57)	14.57^{b} (+0.71)	14.88^{b} (±0.56)	4.21^{d} (±0.23)
Sand (%)	49.24^{c} (±2.18)	61.78^{a} (±1.46)	55.92^{b} (±1.91)	57.82^{ab} (±2.01)	60.70^{ab} (±1.73)
Silt (%)	31.33^{a} (±1.97)	17.92^{c} (±1.18)	21.81^{bc} (±0.97)	24.86^{b} (±1.47)	24.59^{b} (±2.18)
Clay (%)	19.41^{ab} (±0.68)	20.28^{ab} (±1.36)	22.26^{a} (±1.62)	17.31^{bc} (±1.05)	14.69^{c} (±1.05)
Bulk density (gm^{-3})	1.36^{a} (±0.04)	1.23^{b} (±0.02)	1.22^{b} (±0.01)	1.24^{b} (±0.02)	1.40^{a} (±0.03)
Porosity (%)	48.95^{b} (±1.56)	53.44^{a} (±0.82)	53.76^{a} (±0.70)	53.14^{a} (±0.96)	46.94^{b} (±1.26)
Soil moisture (%)	13.71^{b} (±1.47)	17.88^{ab} (±2.04)	21.00^{a} (±1.05)	13.91^{b} (±2.22)	8.89^{c} (±1.05)
pH	4.9^{c} (±0.03)	5.7^{a} (±0.03)	4.5^{d} (±0.03)	4.3^{e} (±0.01)	5.4^{b} (±0.02)
Organic matter (%)	4.55^{d} (±0.25)	8.00^{a} (±0.26)	7.02^{b} (±0.03)	7.03^{b} (±0.22)	5.93^{c} (±0.11)
Nitrogen (ppm)	484.62^{c} (±27.38)	513.85^{c} (±108.73)	792.31^{b} (±57.13)	201.54^{d} (±55.76)	1092.31^{a} (±68.37)
Phosphorus (ppm)	849.23^{b} (±61.55)	4940.00^{a} (±1248.22)	6572.31^{a} (±1175.87)	783.08^{b} (±26.99)	6674.62^{a} (±1060.80)
Potassium (ppm)	69.25^{b} (±1.65)	130.61^{a} (±10.27)	130.75^{a} (±4.73)	117.53^{a} (±15.12)	105.40^{a} (±2.76)

MD = Mix deciduous forest, DE = Dry evergreen forest, ME = Moist evergreen forest, HE = Hill evergreen forest, GL = Grassland

Remark: Significant difference is indicated by different small letter at $P<0.05$ for One-way ANOVA

As shown in Table 4.1, the mean relative humidity of MD, ME and HE were significantly higher than that of DE and GL ($p<0.05$). It might due to higher tree density of MD, ME and HE. Because of relative humidity is referring to water vapor content in the air, the water vapor gets into the air by evaporation from moist surfaces and from transpiration by plants (Kimmins, 1997).

In average, amount of rainfall per month was quite low, from November to April, and high from May to October (Figure 4.1). In 2002, the maximum amount of rainfall was 298.9 mm in September, and the minimum was 0.7 mm in January. In 2003, the maximum amount of rainfall was 179.9 mm in June, and the minimum was 0 mm in January, November and December .

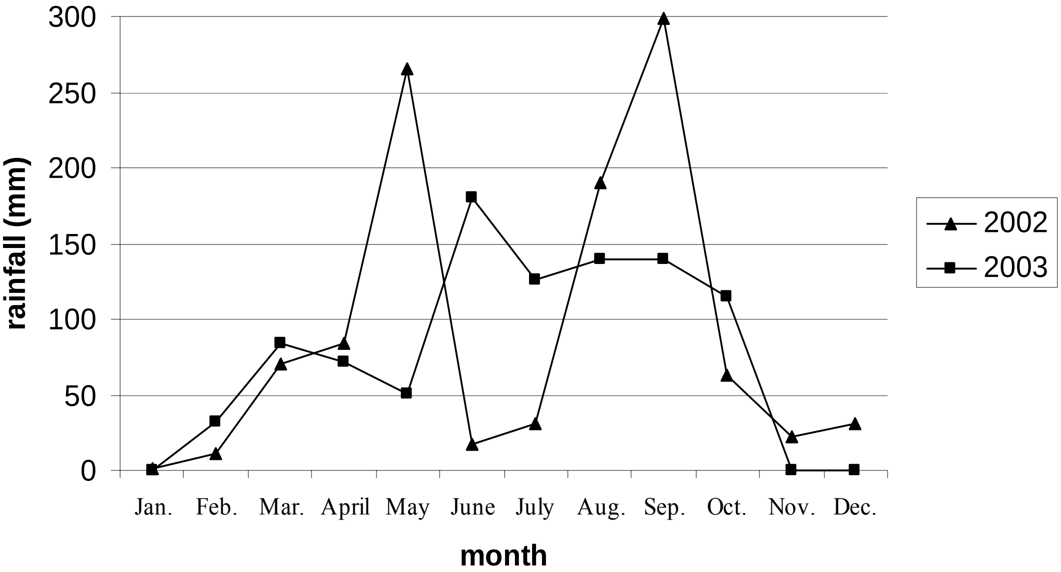

Figure 4.1 Average of rainfall (mm) from 2002 to 2003 at Pak Chong Meteorological Station, Nakhon Ratchasima Province.

4.1.2 Litter

As shown in Table 4.1, the DE showed highest litter weight (18.07 g), whereas the HE, ME and MD showed respectively inferior results, and the GL indicated the lowest (4.21 g). The results revealed significant differences ($p<0.05$) among all forest types except between ME and HE. This might due to thickness of litter on the forest floor and cover vegetation. In GL, there is a little of litter because of the annual fire. Litterfall is an important pathway for the transfer of organic matter and chemical elements from the vegetation to the soil surface in forest ecosystems (Proctor, 1983). However, litterfall rates were vary widely among tropical forests depending on kind of plant, climate, altitude and soil type (Proctor, 1984).

4.1.3 Soil properties

4.1.3.1 Soil texture

As shown in Table 4.1, soil texture of the MD and GL was identified as sandy loam, while the DE, ME and HE were identified as sandy loam to sandy loam clay. The top soil of DE, MD and HE were more high litter and high organic matter. For the GL, the top soil was black-brown sandy loam from the annual fire and the lower soil was the red-brown sandy loam. This result was similar to the results of Phoonjumpa (2002) which reported that the texture of the MD and GL in Khao Yai National Park were sandy loam, and the DE, MD and HE were sandy clay loam and sandy loam.

4.1.3.2 Bulk density

As shown in Table 4.1, the mean bulk density of all forest types was slightly different. GL was indicated the highest (1.40 g/cm^3), followed closely by MD (1.36 g/cm^3), HE (1.24 g/cm^3) and DE (1.23 g/cm^3) respectively, whereas ME represented the lowest with 1.22 g/cm^3. The highest mean bulk density of GL might be due to organic matter. Soils high in organic matter (DE) have lower bulk density than soils low in this component (Table 4.1).

4.1.3.3 Porosity

As shown in Table 4.1, the mean porosity of all forest types was slightly different range from 46.94% to 53.76%. ME was the highest, whereas GL was the lowest porosity. Soil texture were related with porosity. Sand surface soil have a range in pore volume of approximately 35 to 50%, compared to 40 to 60% or higher for medium to fine texture soils (Suriyapong, 2003). Therefore, the fine texture soil of ME (sandy clay loam) has higher porosity than MD and GL (sandy loam). Furthermore, the surface vegetation also has a considerable influence on the porosity soil. Changes in the composition of the surface vegetation, soil organic matter and the activity of soil flora and fauna influenced pore volume and soil structure (Suriyapong, 2003).

4.1.3.4 Soil moisture

Soil moisture of all forest types ranged from 8.89 to 21%. The highest was the ME and the lowest was the GL. The MD, DE and HE were high about 13.71, 17.88 and 13.91% respectively. The dense forest soils of MD, DE, ME and HE had higher water content than of GL (Table 4.1).

The higher soil moisture of the ME could be attributed to lower rate of evaporation of moisture from soil due to thick canopy of the ME in comparison with that of the MD and DE. For the HE, there is thick canopy but the major soil texture is sandy loam, it cannot preserve water, and there is the higher rate of evaporation of moisture from soil due to a wind from the hills.

4.1.3.5 Soil pH

Soil of all forest types showed slightly more acidic pH condition ranged from 4.3 in HE to 5.7 in DE, with differences between the forest type. The mean pH of MD, ME and HE were significantly ($p<0.05$) lower than DE and GL. This might cause by organic matter. In MD, ME and HE, surface soils were always covered by vegetation and leaf litter all the year, pH of soil would be affected by the organic matter supplied from the vegetation. This leaded to the soil acidification by decomposition of organic residues of microorganisms in soil (Wachrinrat, 2000).

4.1.3.6 Organic matter

Organic matter was significantly higher ($p<0.05$) in DE as compared to all sites except in ME and HE; it was not significant between MD and GL.

The results showed that soil of DE was richer in organic matter in comparison with the others. This was due to the higher amount of litter produced in DE. In natural vegetation community there was always an accumulation of plant materials at the soil surface which undergo decomposition. The results obtained in this study confirmed the above statement. Because plant residues are the principal material undergoing decomposition in soils, and are the primary source of soil organic matter (Wongseenin, 1971).

4.1.3.7 Total nitrogen

The mean total nitrogen content among GL, ME, DE, and MD and MD were significantly differences ($p<0.05$), ranged from 201.54 ppm to 1092.31 ppm. Nitrogen was significantly highest in GL and significantly lowest in HE (Table 4.1).

As seen from this result, the mean total nitrogen of GL was higher than the others. Knapp and Seastedt (1986) found that the fire removed the litter layer on the soil surface and alter the microclimate and nutrient levels in the surface soil and it allows soil temperatures to increase, resulting in enhanced nitrogen mineralization from soil organic matter (Ojima, Schimel, Parton, and Owensby, 1994).

4.1.3.8 Total phosphorus

The results shown in Table 4.1 indicated that the mean phosphorus content among GL, ME and DE, and MD and HE were significantly differences ($p<0.05$), ranged from 783.08 ppm to 6674.62 ppm. Phosphorus was significantly ($p<0.05$) highest in GL, followed by ME, DE, MD and HE respectively.

As seen from this result, the mean total phosphorus of GL was higher than the others. It might be caused by grassland burning. White and Gartner (1975) found an increase in phosphorus only in the soil of grassland if temperatures of burning did not exceed 200ºC.

4.1.3.9 Available Potassium

The mean potassium content among ME, DE and HE, and GL and MD were significantly differences ($P<0.05$), ranged from 69.25 ppm to 130.75 ppm. Potassium was significantly ($p<0.05$) highest in ME, followed by DE, HE, GL and MD respectively (Table 4.1). The mean available potassium of HE was higher than the others. Potassium content of forest was due to the quantity and quality of litter, soil moisture and the rate of decomposition of litter (Gajaseni, 1967).

4.2 Earthworm identification

A total of 13 species of terrestrial earthworms belonging to 3 families, Glossoscolecidae; Megascolecidae; and Moniligastridae, was found in this study. However, only 10 species were found in the sampling areas, while the other 3 species as *Amynthas longicauliculatus*; *Perionyx excavatus*; and *Pithemera bicincta*, were collected outside the sampling areas. The occurrence of families and species of earthworms collected are listed in Table 4.2. Some terminologies and diagnostic characters were explained in Appendix A.

Table 4.2 Occurrence of families and species of earthworms collected in Khao Yai National Park

Family	Species inside sampling areas	Species outside sampling areas
Glossoscolecidae	*Pontoscolex corethrurus***	
Megascolecidae	*Amynthas alexandri**	*Perionyx excavatus***
	*Amynthas fucosus**	*Amynthas longicauliculatus**
	Amynthas sp.1*	*Pithemera bicincta***
	Amynthas sp.2*	
	Amynthas sp.3*	
	*Metaphire peguana**	
	*Metaphire houlleti**	
	Metaphire sp.1*	
Moniligastridae	*Drawida beddardi**	

***** Native species

****** Introduced species

4.2.1 Diagnostic characters of earthworms

Family Glossoscolecidae

1900. Glossoscolecidae, Michaelsen, **Das Tierreich**. 10: p. 420.

1959. Glossoscolecidae, Gates, **Bull. Mus. Comp. Zool. Harvard College**. 112: p. 255.

1972. Glossoscolecidae, Gates, **Trans. Am. Phil. Soc**. 62(7): p. 52.

Diagnosis: Digestive system, with one esophageal gizzard in vi or its homoerotic equivalent, with paired, extramural calciferous glands in some of segments vii-xiv or their homoerotic equivalents. Vascular system, with dorsal and ventral trunks, a supra-esophageal, paired extra-esophageals median to the hearts, and a subneural adherent to the parietes. Nephridia, macroic, in intestinal region holoic, vesiculate. Setae, sigmoid, simply pointed. Dorsal pores, none. Spermathecal, adiverticulate. Ovaries, in xiii. Male pores, behind female pores. Clitellum, multilayered. Ova, not yolky. Prostates with muscular ducts, none.

Genus *Pontoscolex* Schmarda, 1861

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

1930. *Pontoscolex*, Stephenson, **Oligochaeta**. p. 489.

1972. *Pontoscolex*, Gates, **Trans. Am. Phil. Soc**. 62(7): p. 53.

Diagnosis: 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 end passing to gut dorsolaterally just in front of a septal insertion, with dorsolaterally just in front of a septal insertion, with a well-developed intestinal typhlosole but without caeca and supra-intestinal glands. Vascular system, with complete dorsal, ventral, and subneural trunks, the latter adherent to the parietes and the dorsal trunk markedly moniliform in several pre-intestinal segments, a supra-esophageal trunks (median to the hearts) united on gut at mV with connectives to supra-esophageal and subneural, hearts of vi-ix lateral, of x,xi latero-esophageal. 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 bladder elongately sausage-shaped and opening to the exterior through terminal ducts. Nephropores, obvious. Pigment, none. Septa, all present at least from v/vi. Metandric. Seminal vesicles, long, extending from xii back through several segments. Metagynous, Ovaries band-shaped. Male pores and tubercula pubertatis, in the clitellar region.

Pontoscolex corethrurus (Müller, 1856)

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

1930. *Pontoscolex corethrurus*, Gates, **Rec. Indian Mus**. 32: p. 351.

1955. *Pontoscolex corethrurus*, Gates, **Rec. Indian Mus**. 52: p. 92.

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

2002. *Pontoscolex corethrurus*, Bhattacharjee and Chaudhuri, **J. Biosci.** 27(3): p. 83.

Diagnosis: Clitellum saddle shaped, intersegmental furrows slightly, xiv/xv-xxi/xxii. Dorsal pore absent. Sexthecal, pores minute and superficial, vi/vii-viii/ix. Female pore, on left side, minute transverse slit. Male pores, lateral to B, xx/xxi. Setae, closely paired, quincunx arrangement. Calciferous glands 3 pairs in vii-ix. No intestinal caecum. Spermathecae, 3 pairs in vii, viii and ix, no diverticulum.

Description: External morphology

Total length 40-95 mm, width 3-5 mm, segment number 85-170. Prostomium lacking. Dorsal pore absent. Setae, closely paired, AB and CD gradually wider from iii, one rank after another becoming more and more irregular until the quincunx arrangement is attained, towards the posterior end enlarged and ornamented ectally by transverse rows of fine teeth (Figure 4.2 C,D). Clitellum, xiv/xv-xxi/xxii (usually seven segments), saddle-shaped, intersegmental furrows slightly indicated at maximal tumescence, setae retained, down to region of B or A. Secondary segmentation in the middle portion of body, each segment with a narrow anterior non-setal annulate and a wide posterior setal annulate. Tubercula pubertatis, translucent longitudinal bands, just lateral to B. Genital tumescences, around a,b, or a or b, xix-xxi. Sexthecal, pores minute and superficial, at C and at or close to vi/vii-viii/ix. 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). Live specimens without pigments, head portion pink to light purple, clitellum grayish pink, body light bluish pink. When head portion portion extended, three pairs of bright yellow spots (calciferous glands) on dorsal in front of clitellum.

Internal morphology

Septa, v/vi membranous, vi/vii-ix/x thickly muscular. Gizzard in vi, lage, intestinal origin, xiv or xv. No intestinal caecum. Typhlosole, beginning xxi, lamelliform, height greater than width of gut lumen. Calciferous glands 3 pairs in vii-ix, panicled-tubular type. Dorsal and lateral hearts greatly enlarges in x and xi. Metandric, passing posteriorly through one or more segments, sperm sac paired in xii,

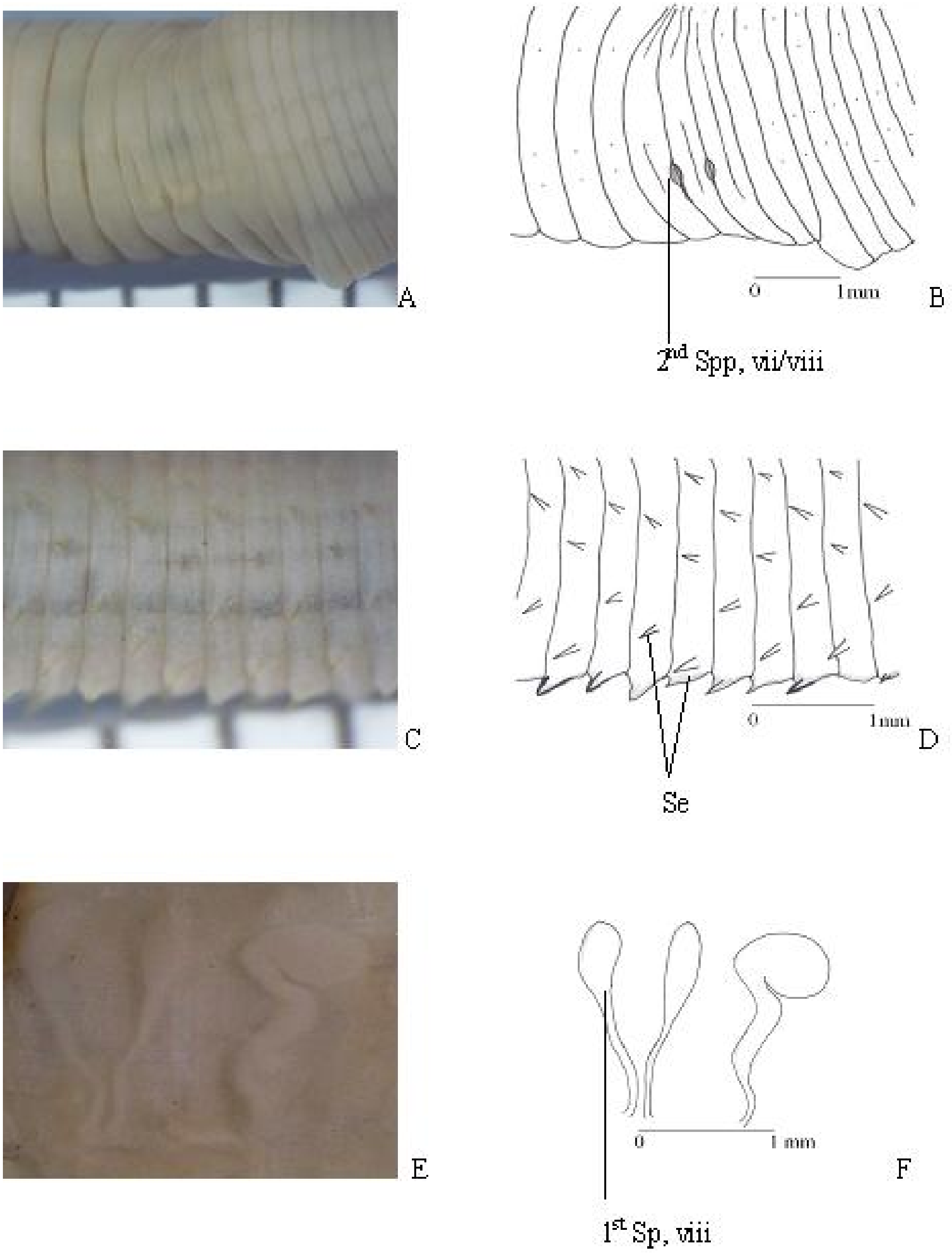

Figure 4.2 Photographs and line drawings of *Pontoscolex corethrurus*: A,B, ventral view of spermathecal pores (Spp); C,D, setae (Se) of a posterior part of the body in the quincunx arrangement; E, left spermatheca (eosin stain); F, left spermatheca (Sp).

large extending anteriorly to xi. Seminal vesicles, one pair in xiii, lateromesially flattened, mor or less deeply incised by the septa. No prostate gland. Ovaries small, under testis sacs, narrowly bandlike. Spermathecae, 3 pairs in vii, viii and ix, each small, long, ducts slender, small ampulla (Figure 4.2 E,F), no diverticulum. Spermathecal ducts connected laterally to vii – ix.

Family Megascolecidae

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

1959. Megascolecidae, Gates, **Bull. Mus. Comp. Zool. Harvard College**. 112: p. 130.

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

Diagnosis: Digestive system, with intestinal origin behind ovarian segment. Vascula system, with a supra-esophageal 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, with simply pointed tip. Dorsal pores, present. Malepores, behind female pores. Spermathecae in fromt of gonadal segments, with seminal chambers. Clitellum, multilayered, (female pore segment always included). Ovaries, in xiii, fan-shaped and with numerous egg strings. Ovisacs, not yolky. Seminal vesicles, trabeculate. Prostates, racemose and of mesoblastic origin.

Genus *Perionyx* Perrier, 1872

1900. *Perionyx*, Michaelsen, **Das Tierreich**. 10: p. 207.

1960. *Perionyx*, Gates, **Bull. Mus. Comp. Zool. Harvard College**. 123: p. 221.

1972. *Perionyx*, Gates, **Trans. Am. Phil. Soc**. 62(7): p. 130.

Diagnosis: Digestive system, without supra-intestinal and calciferous glands, intestinal caeca and typhlosoles, but with calciferous tissues in some portion of the esophagus. Vascular system, with complete, unpaired, dorsal, ventral and supra-esophageal trunks, a subneural adherent to the parieties, paired extra-esophageals median to the hearts, latero-esophageal hearts in x-xii. Nephridia, with preseptal funnels and postseptal loops that open in their own segment to the exterior through epidermal apertures. Setae, numerous, in a circle at equator of each segment from ii posteriorly. Dorsal pores, present. Biprostatic, male pores (apertures of united sperm and prostatic ducts) in xviii. Female pore, intra-clitellar and median. Clitellum, annular, setae retained. Ovaries, fan-shaped and with several egg-strings.

Perionyx excavatus Perrier, 1872

1872. *Perionyx excavatus* Perrier, **Nouv. Arch. Mus. Hist. Nat. Paris.** 8: p. 126 (Type locality, Saigon. Types, in Paris Mus.).

1895. *Perionyx excavatus*, Beddard, **A monograph of the order Oligochaeta**. p. 436.

1900. *Perionyx excavatus*, Michaelsen, **Das Tierreich.** 10: p. 208.

1924. *Perionyx excavatus*, Stephenson, **Rec. Indian Mus**. 26: p.340.

1939. *Perionyx excavatus*, Gates, **J. Thailand Res. Soc. Nat. Hist. Suppl**. 12: p. 108.

1972. *Perionyx excavatus*, Gates, **Trans. Am. Phil. Soc.** 62: p. 141.

1998. *Perionyx excavatus*, Edwards, Dominguez, and Neuhauser, **Biol. Fertil. Soils.** 27: p. 155.

Diagnosis: Clitellum, annular, xiii–xvii. First dorsal pore in iv/v. Spermathecal pores mV, at vii/viii, viii/ix. Female pore intraclitellar and median in xiv Male pore, anterolateral to tips of penial setae. Gizzard, lacking, Calciferous xiv and xi. Holandric. Spermathecae, large, duct short and stout Penial setae.

Description: External morphology

Total length 40-155 mm, width 3-4 mm, segment number 90-160. Prostomium epilobic. First dorsal pore in iv/v. Clitellum, annular, xiii–xvii. Spermathecal pores 2 pairs, pores near mV, at vii/viii, viii/ix (Figure 4.3 C,D). Female pore intraclitellar and median in xiv (Figure 4.3 A,B). Male pore, anterolateral to tips of penial setae in small transverse protuberances within a single field distinctly demarcated only at anterior and posterior margins in xviii. Color, except in first few segments restricted to dorsum, often lacking in immediate vicinity of follicle apertures.

Internal morphology

Gizzard, lacking. Esophagus, widened, bead-shaped in xiii and there with calciferous ridges that extend into xiv and xi. Intestinal origin, in xv. Last hearts, in xii. Holandric. Seminal vesicles, in xi,xii, last pair often continued in pockets of xii/xiii back to level of xiv/xv. Prostates, in xviii, ducts short and straight (Figure 4.3 E, F). Spermathecae, large, duct short and stout. Penial setae, 0.06-0.69 mm long, ornamented ectally with 6-16 circles of fairly large and elongately triangular spines, tip bluntly rounded or finely pointed or flattened and truncate.

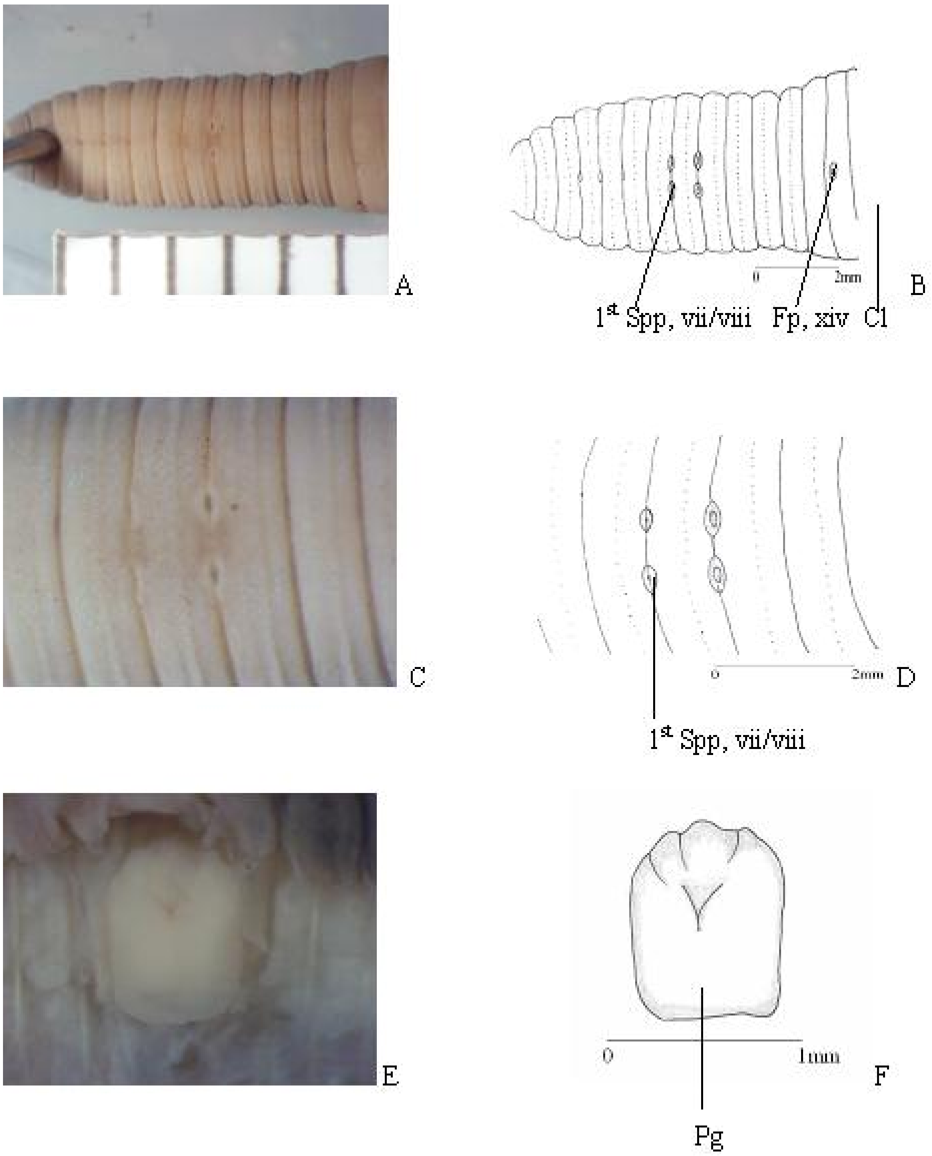

Figure 4.3 Photographs and line drawings of *Perionyx excavatus*: A,B, ventral view of anterior region (Spp, spermathecal pores; Fp, female pores; Cl, clitellum); C,D, ventral view of spermathecal pores; E,F, left prostate gland (Pg).

Genus *Amynthas* Kinberg, 1867

1867. Amynthas, Kinberg, **Ofver. K. Vetensk Acad. Förh. Stockh**. 23: p. 97.

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

1934. *Pheretima*, Michaelsen, **Quart. J. Microsc. Sci**. 77: p. 15.

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

2002. *Metaphire*, Tsai, Shen, and Tsai, **J. Nat. Hist**. 36: p. 758.

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

Diagnosis: Megascolecidae with cylindrical bodies of varying length. Setae numerous, regularly arranged around each segment. Clitellum annular, xiv-xvi, rarely beginning on xiii. Male pores paired, discharging directly onto the surface of xviii (rarely xix). Female pore single, rarely paired, xiv. Spermathecal pores small or large, usually paired (bithecal) but occasionally numerous (polythecal) or single (monothecal) between iv/v and viii/ix. Gizzard between septa vii/viii and ix/x. Oesophageal pouches 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.

Amynthas alexandri Beddard, 1901

1914. *Pheretima lignicola* Stephenson, **Rec. Indian Mus**. 8: p. 399 (Type locality, Dibrugarh. Types, in the Indian Mus.).

1925. *Pheretima lignicola*, Gates, **Ann. Mag. Nat. Hist.,** Ser. 9, 16: p. 567. Stephenson, **Rec. Indian Mus**. 27: p. 61.

1939. *Pheretima alexandri*, Gates, **J. Thailand Res. Soc. Nat. Hist. Suppl**.12: p. 80.

1955. *Pheretima alexandri*, Gates, **Rec. Indian Mus**. 52: p. 80.

1961. *Pheretima alexandri*, Gates, **Am. Midl. Nat**. 66: p.62.

1972. *Pheretima alexandri*, Gates, **Trans. Am. Phil. Soc.** 62: p. 155;

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

1995. *Amynthas alexandri*, Kaushal, Bisht, and Kalia, **Appl. Soil. Ecol**. 2(2): p. 125.

Diagnosis: Clitellum xiv-xvi, annular. Spermathecal pores 4 pairs in v/vi – viii/ix, ventro-lateral. Female pore ventral in xiv. Male pores paired in xviii. No genital marking. Spermathecal diverticulum, vi-ix. Holandric. Seminal vesicles paired large, in xi,xii. Prostate glands, large in xvi-xxii.

Description: External morphology

Total length 105-209 mm, width 4-9 mm, segment number 90-141. Prostomium prolobic, setae 9-18 in vi, 10-20 in vii, 11-22 in viii. Setae between spermathecal pores 9-11 in v, 10-12 in vi, vii,10-14 in viii, ix. Setae between male pores 12 in xviii. First dorsal pore in xii/xiii. Clitellum xiv – xvi, smooth, setae and dorsal pore absent. Spermathecal pores 4 pairs, superficial, in v/vi – viii/ix, ventro-lateral, more than 1/3C apart (Figure 4.4 A,B). Female pore single, median and ventral in xiv. Male pore paired in xviii, ventro-lateral, minute, superficial, each in a rather circular area (often slightly depressed) between arms of a U-shaped ridge that is open mesially (Figure 4.4 C,D). No genital marking. Color, in dorsal, pinkish to deeper red, yellowish on ventrum.

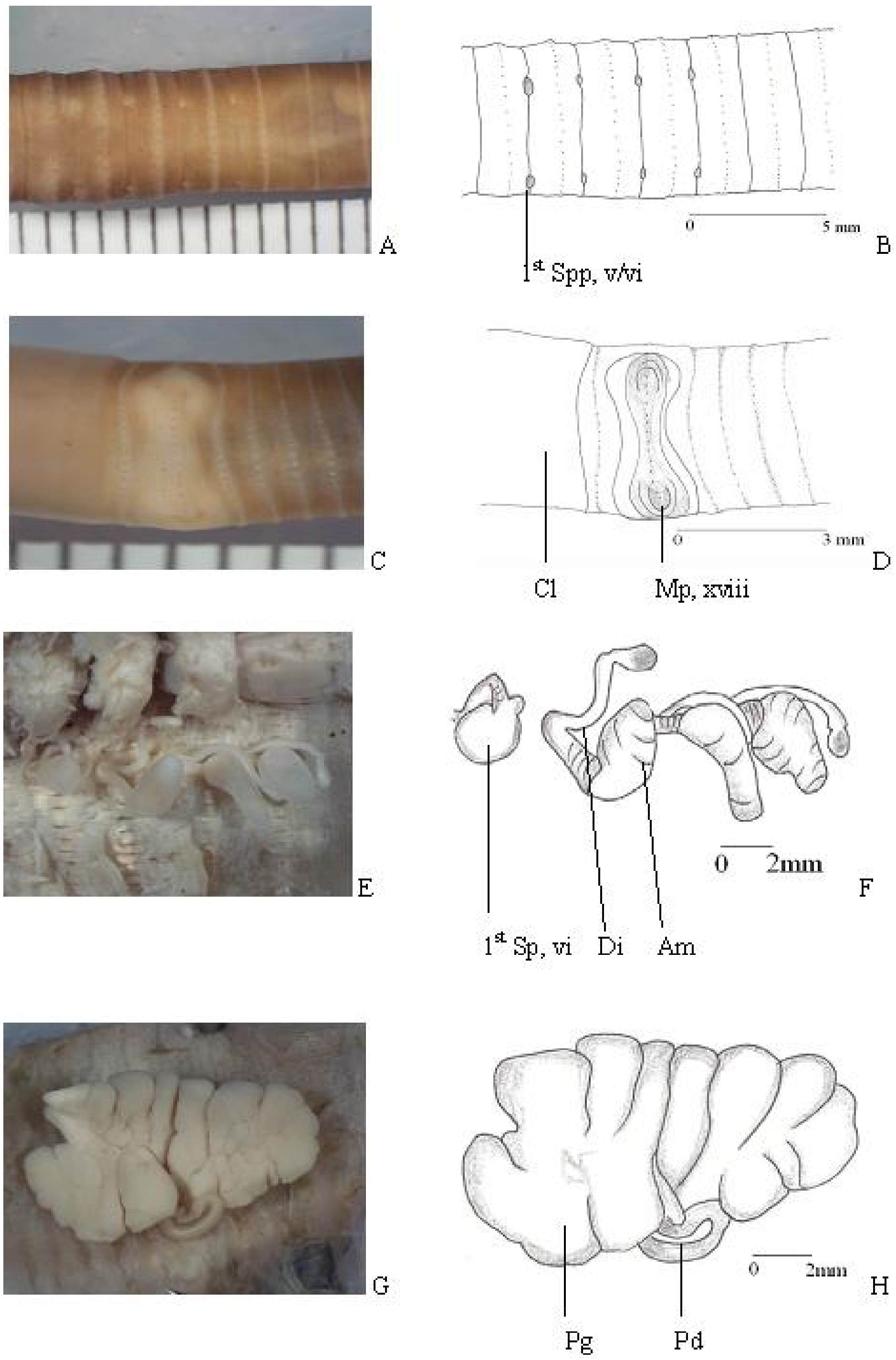

Figure 4.4 Photographs and line drawings of *Amynthas alexandri*: A,B, ventral view of spermathecal pores (Spp); C,D, ventral view of male pore region (Cl, clitellum; Mp, male pore); E,F, left spermatheca (Am, ampulla; Di, diverticulum; Sp, spermatheca); G,H, right prostate gland (Pd, prostate duct; Pg, prostate gland).

Internal morphology

Septa viii/ix-ix/x aborted, vi/vii-vii/viii much thickened. Intestinal origin in xv (sometimes in xvi). Caeca, simple in xxvii-xx. Typhlosole, lamelliform. Hearts in vii unaborted dorsal portions to gizzard, in ix lateral, in x esophageal, in xi-xiii latero-esophageal. Spermathecae in vi-ix, 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 (Figure 4.4 E,F). Testis, Holandric. Testis sacs, paired and ventral or unpaired and horseshoe-shaped. Seminal vesicles, large, especially the posterior pair, in xi,xii. Prostate glands, large in xvi-xxii, duct muscular and variously looped or coiled (Figure 4. G,H).

Amynthas fucosus (Gates, 1933)

1933. *Pheretima fucosa* Gates, **Rec. Indian Mus**. 35: p. 526 (Type locality, in region between Kyaukmedaung and Kameik of Mynmar. Types, none).

1972. *Pheretima fucosa,* Gates, **Trans. Am. Phil. Soc**. 62: p. 187;

Amynthas fucosus, Sims and Easton, **Biol. J. Linn. Soc**. 4: p. 237.

Diagnosis: Clitellum xiv-xvi, annular. Spermathecal pores 3 pairs in vi/vii – viii/ix, ventro-lateral. Female pore midventral in xiv. Male pores paired in xviii. Genital marking, 3 or 4 near male pores in xviii, xix. Spermathecal diverticulum, vii-ix. Holandric. Seminal vesicles paired large, xi, xii dorsal small. Prostate glands, large in xvi-xix.

Description: External morphology

Total length 190-240 mm, width 8-10 mm, segment number 113-133. Prostomium prolobic. Setae 64-68 in vii, 66-72 in viii. Setae between spermathecal pores 24-26 in v,vi, 30-34 in vii,viii. Setae between male pores 44. First dorsal pore in xii/xiii. Clitellum xiv – xvi, annular, smooth, setae and dorsal pore absent. Spermathecal pores 3 pairs, superficial, on vi/vii, vii/viii and viii/ix, lateral, more than 1/3C apart (Figure 4.5 A,B). Female pore single, midventral in xiv. Male pore paired in xviii, ventro-lateral, minute, superficial, porophore on xviii (Figure 4.5 C,D). Genital marking present 3 or 4 near male pores in xviii, xix, also a groove near pores. Color, in dorsal, brown to deeper brown, yellowish on ventrum.

Internal morphology

Septa viii/ix-ix/x aborted, v/vi-vii/viii much thickened. Intestinal origin in xv. Caeca, simple in xxvii-xviii. Typhlosole, begin xxvii, lamelliform, thick membrane. Hearts in viii small to gizzard, x left absent, xi-xiii latero-esophageal. Spermathecae, 3 pairs vii-ix, big ampulla. Diverticulum shorter than ampulla and slender (Figure 4.5 E,F) Testis, Holandric. Testis sacs, big, paired and unconnected. Seminal vesicles, big anterior pair in xi, xii dorsal small. Prostate glands, big, in xvi-xxi , duct slender close to gland, becomes muscular in distal half (Figure 4.5 G,H). GM gland, 3 pairs, sessile, xvii-xix.

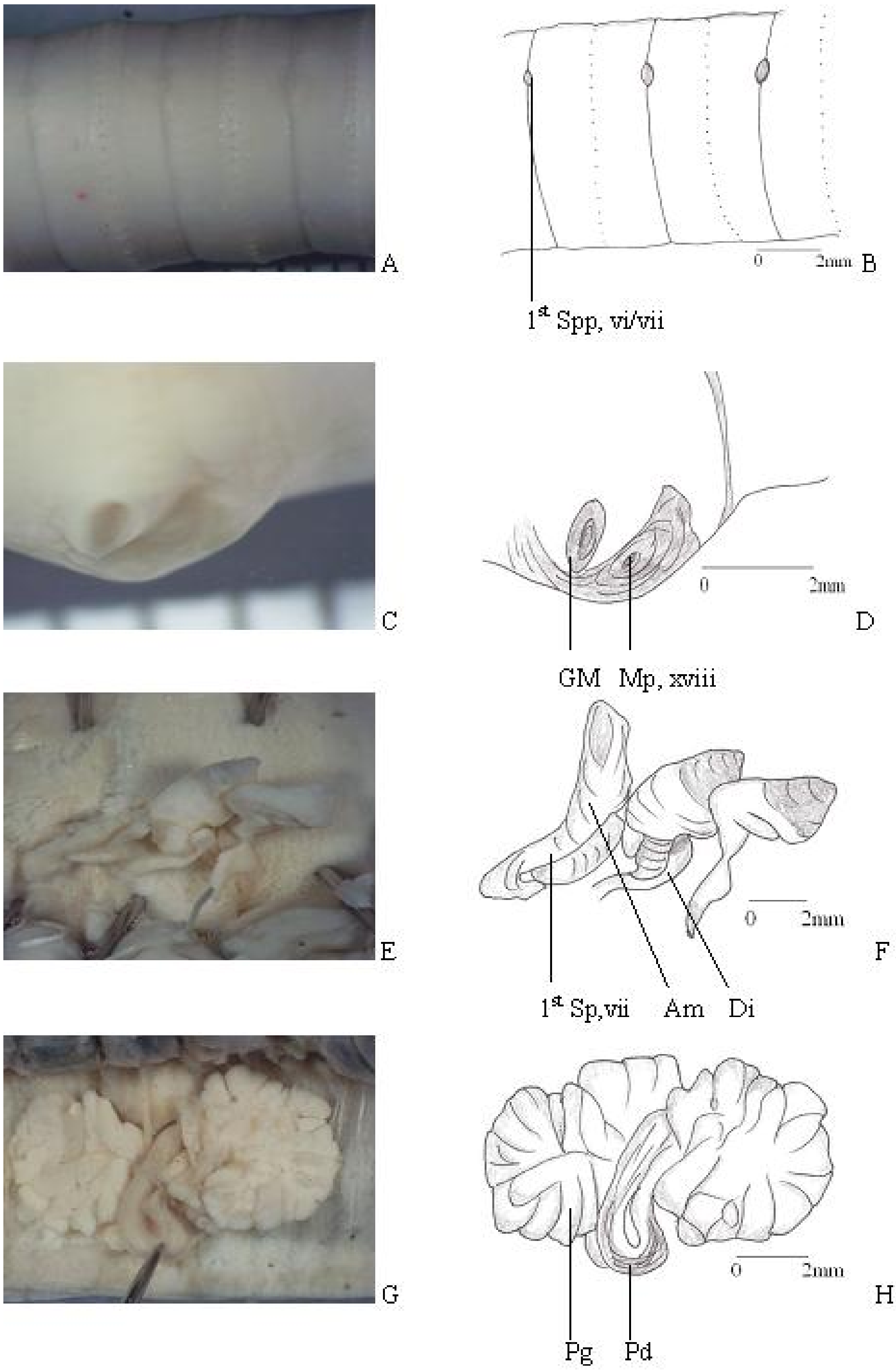

Figure 4.5 Photographs and line drawings of *Amynthas fucosus*: A,B, lateral view of spermathecal pores (Spp); C,D, ventral view of male pore region (GM, genital marking; Mp, male pore); E,F, right spermatheca (Am, ampulla; Di, diverticulum; Sp, spermatheca); G,H, left prostate gland (Pd, prostate duct; Pg, prostate gland).

Amynthas longicauliculatus Gates, 1931

1931. *Pheretima longicauliculata* Gates, **Rec. Indian Mus**. 33: p. 395 (Type locality, Tolo Senca. Types, none).

1936 *Pheretima longicauliculata*, Gates, **Rec. Indian Mus**. 38: p. 423.

1939 *Pheretima longicauliculata*, Gates, **J. Thailand Res. Soc. Nat. Hist. Suppl**. 12: p. 95.

1960. *Pheretima longicauliculata*, Gates, **Bull. Mus. Comp. Zool**. 123: p. 252.

1972. *Amynthas longicauliculatus*, Sims and Easton, **Biol. J. Linn. Soc**. 4: p. 235.

Diagnosis: Clitellum xiv-xvi, annular. Spermathecal pores 4 pairs in v/vi – viii/ix, ventro-lateral. Female pore midventral in xiv. Male pores paired in xviii. Genital marking 3 pairs on xviii/xix-xx/xxi. Spermathecal, vi-ix. Holandric. Seminal vesicles paired large, xi, xii. Prostate glands, large in xvi-xxi.

Description: External morphology

Total length 180-235 mm, width 8-10 mm, segment number 114-146. Prostomium prolobic, setae 9-18 in vi, 10-20 in vii, 11-22 in viii (Figure 4.6 A,B). Setae between spermathecal pores 9-11 in v, 10-12 in vi, vii,10-14 in viii, ix. Setae between male pores 26 in xviii. First dorsal pore in xii/xiii. Clitellum xiv – xvi, annular, smooth, setae and dorsal pore absent. Spermathecal pores 4 pairs, superficial, in v/vi – viii/ix, almost mid-lateral . Female pore single, midventral in xiv. Male pore paired in xviii, ventro-lateral, minute, superficial (Figure 4.6 C,D). Genital marking 3 pairs just median to male pores on xviii/xix-xx/xxi. Color, in dorsal, dark brown, yellowish on ventrum.

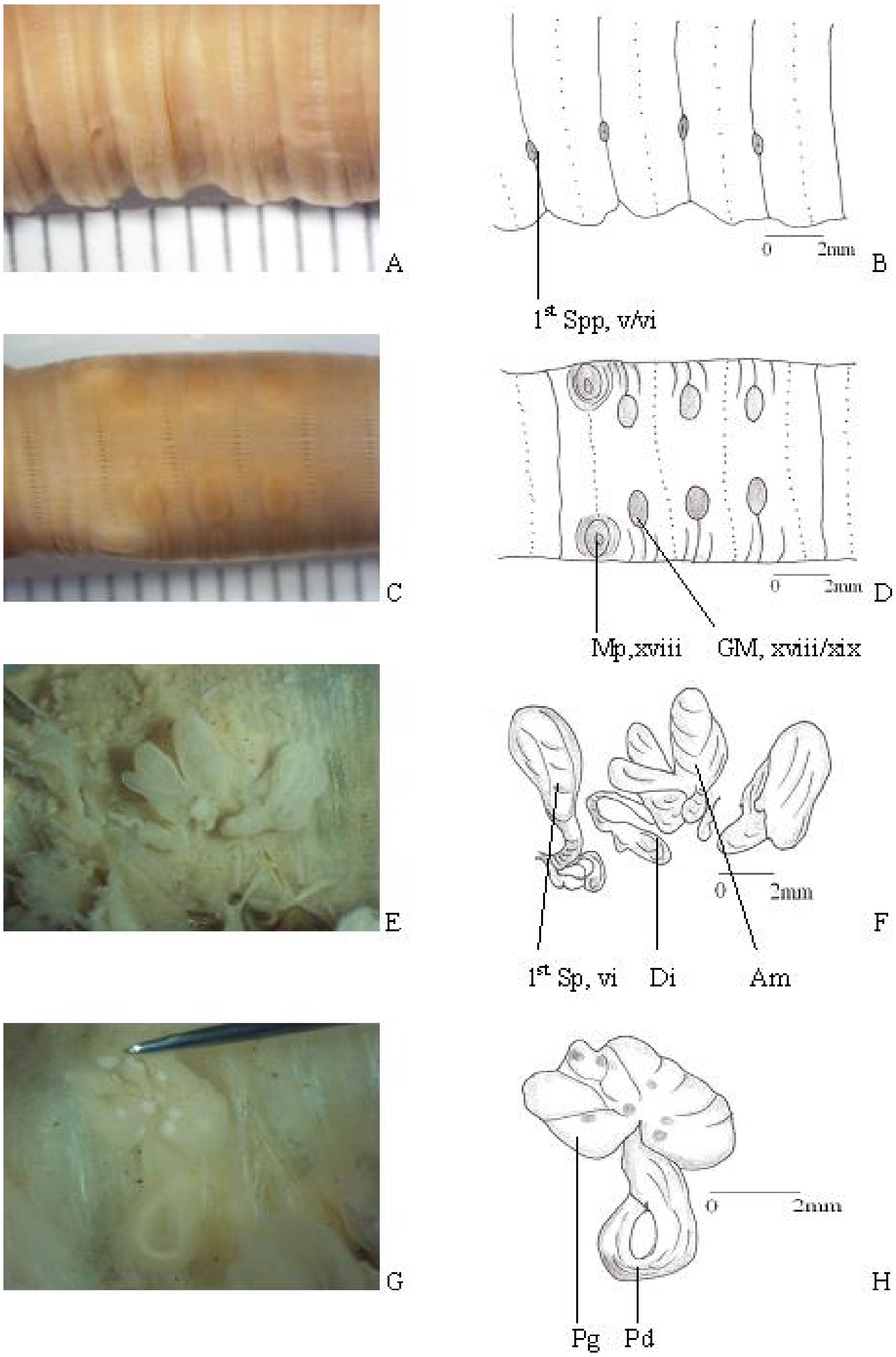

Figure 4.6 Photographs and line drawings of *Amynthas longicauliculatus*: A,B, lateral view of spermathecal pores (Spp); C,D, ventral view of male pore region (GM, genital marking; Mp, male pore); E,F, right spermatheca (Am, ampulla; Di, diverticulum; Sp, spermatheca); G,H, right prostate gland (Pd, prostate duct; Pg, prostate gland).

Internal morphology

Septa viii/ix-ix/x aborted, vi/vii-vii/viii much thickened. Intestinal origin in xv. Caeca, simple in xxvii-xvii. Typhlosole, lamelliform, thick. Hearts in vii right,ix small to gizzard, in xi-xiii latero-esophageal. Testis, holandric. Testis sacs, paired, ventral and unconnected. Seminal vesicles, large, in xi,xii. Prostate glands, large in xvi-xxi, duct muscular and variously looped or coiled (Figure 4.6 G,H). Spermathecae, 4 pairs vi-ix. Diverticulum stalk zigzag loops in beginning (Figure 4.6 E,F). GM gland, gland like, sessile, xviii/xix, xix/xx, xx/xxi.

Amynthas sp1.

Diagnosis: Clitellum xiv-xvi, annular. Spermathecal pores 3 pairs in vi/vii – viii/ix, ventro-lateral. Female pore midventral in xiv. Male pores paired in xviii, discoidal porophore. Genital marking on xviii. Spermathecal, vii-ix. Holandric. Seminal vesicles paired large, xi, xii. Prostate glands, large in xvi-xx.

Description: External morphology

Total length 110-130 mm, width 4-6 mm, segment number 123-150. Prostomium zygolobic, setae 28-35 in vii, 34-39 in viii. Setae between spermathecal pores 11-14 in vi, vii, viii, ix (Figure 4.7 A,B). Setae between male pores 8 in xviii. First dorsal pore in xii/xiii. Clitellum xiv – xvi, annular, smooth, setae and dorsal pore absent. Spermathecal pores 3 pairs, superficial, in vi/vii – viii/ix, ventro-lateral, more than 1/2C apart. Female pore single, midventral xiv. Male pore paired in xviii, ventro-lateral, minute, superficial, each in a discoidal porophore (Figure 4.7 C, D). Genital marking on xviii, within porophore. Color, only in dorsal, reddish, reddish brown, pigment in circular muscle layer.

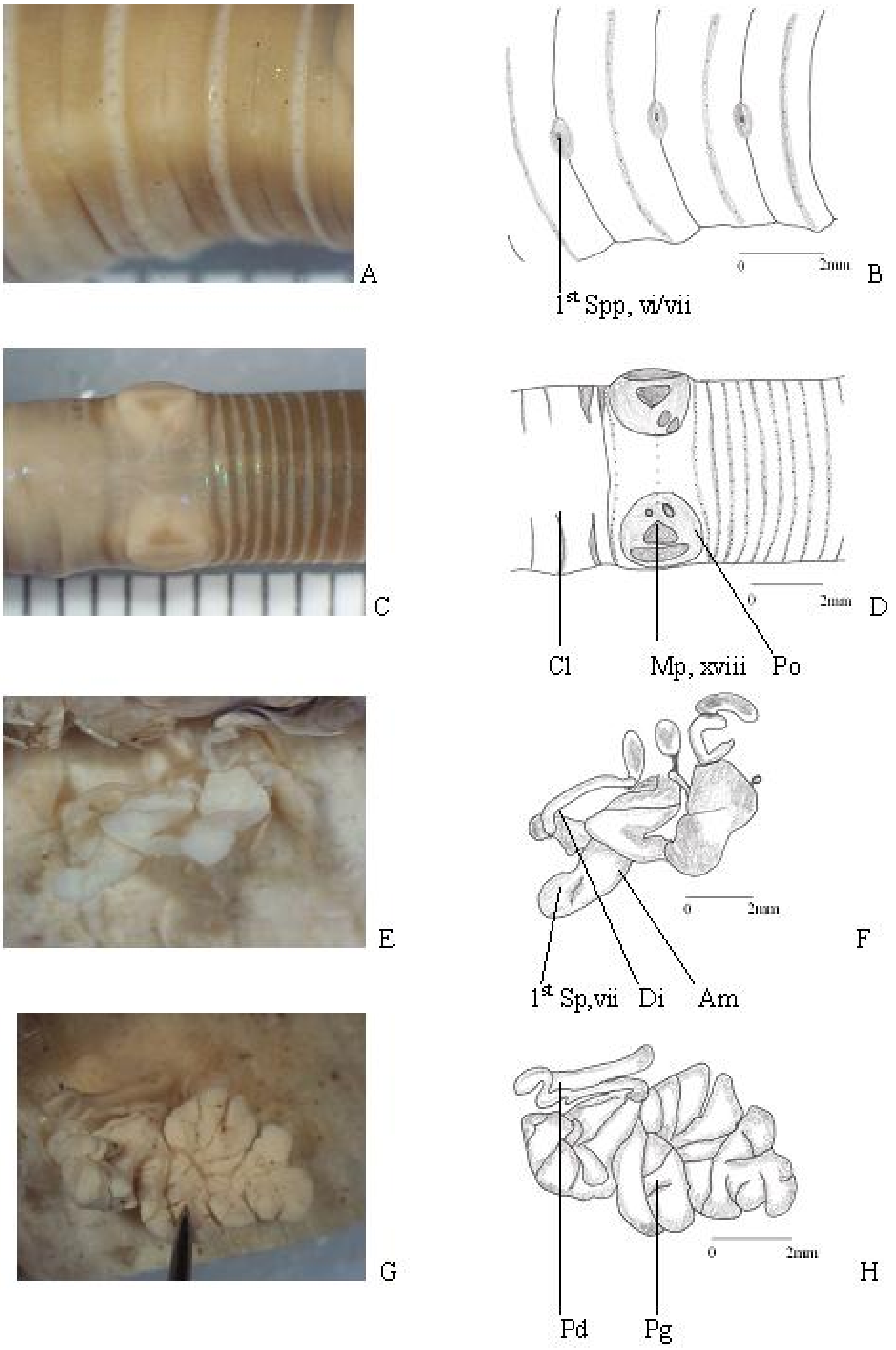

Figure 4.7 Photographs and line drawings of *Amynthas* sp.1: A,B, ventral view of spermathecal pores (Spp); C,D, ventral view of male pore region (Cl, clitellum; Mp, male pore; Po, porophore); E,F, left spermatheca (Am, ampulla; Di, diverticulum; Sp, spermatheca); G,H, left prostate gland (Pd, prostate duct; Pg, prostate gland).

Internal morphology

Septa viii/ix-ix/x aborted, vi/vii-vii/viii much thickened. Intestinal origin in xvii. Caeca, simple, long caeca in xxvii-xvii. Typhlosole, lamelliform, begin xxvii. Hearts in ix small to gizzard, in x esophageal, in xi-xiii latero-esophageal. Testes, Holandric. Testis sacs surround seminal vesicles and hearts in 11 and hearts in 10, unpaired, U-shaped. Seminal vesicles, large, xi, xii only (seminal vesicles of 10 is actually testes sac with sperm contents). Prostate glands, large in xvi-xx, duct muscular, long, hairpin or several smaller loops (Figure 4.7 G,H). Spermathecae, large, vi-ix, duct shorter than ampulla and gradually narrowed in paries, diverticulum longer than main axis, slenderly club-shaped and slightly wider entally, looping or coiling (Figure 4.7 E,F). Genital marking glands present as large sessile mass around prostatic duct.

Amynthas sp.2

Diagnosis: Clitellum xiv-xvi, annular. Spermathecal pores 2 pairs, post-seta on vii – viii, intrasegmental. Female pore midventral in xiv. Male pores paired in xviii, discoidal porophore. No genital marking. Spermathecal, vii-ix, ampulla big and flat. Holandric. Seminal vesicles paired large, x-xi, xii. Prostate glands, large in xvii-xxiii.

Description: External morphology

Total length 34-52 mm, width 3 mm, segment number 68-83. Prostomium zygolobic, setae 24-26 in vii, 20-24 in viii. Setae between spermathecal pores 11-13 in vii, 10-12 in viii. No setae between male pores. First dorsal pore in xii/xiii. Clitellum xiv – xvi, annular, smooth, setae and dorsal pore absent. Spermathecal pores 2 pairs, post-setal, superficial, on vii, viii, intrasegmental, lateral, more than 1/3C apart (Figure 4.8 A,B). Female pore single, midventral in xiv. Male pore paired in xviii, ventro-lateral, minute, superficial, on circular porophore (Figure 4.8 C,D). No genital marking. Color, in dorsal, pinkish to deeper red, yellowish on ventrum.

Internal morphology

Septa viii/ix-ix/x aborted, v/vi-vii/viii much thickened. Intestinal origin in xv. Caeca, simple in xxvii-xxii. Typhlosole, begin xxvii, lamelliform. Hearts, first hearts in vii which is in front of the gizzard, in viii to gizzard, in x-xiii latero-esophageal. Testes, Holandric. Testes sacs, paired and ventrally connected. Seminal vesicles, large,especially the anterior pair, in x-xi, xii. Prostate glands, many lobe, large in xvii-xxiii, duct muscular and variously looped or coiled (Figure 4.8 G,H). Spermathecae, ampulla big and flat, diverticulum longer or shorter than main axis (Figure 4.8 E,F).

Keys to *A. pomellus* species group, which it is not any of; all other *Amynthas* with lateral intrasegmental spermathecal pores in Taiwan, Myanmar *A. pomellus* are from China and Japan.

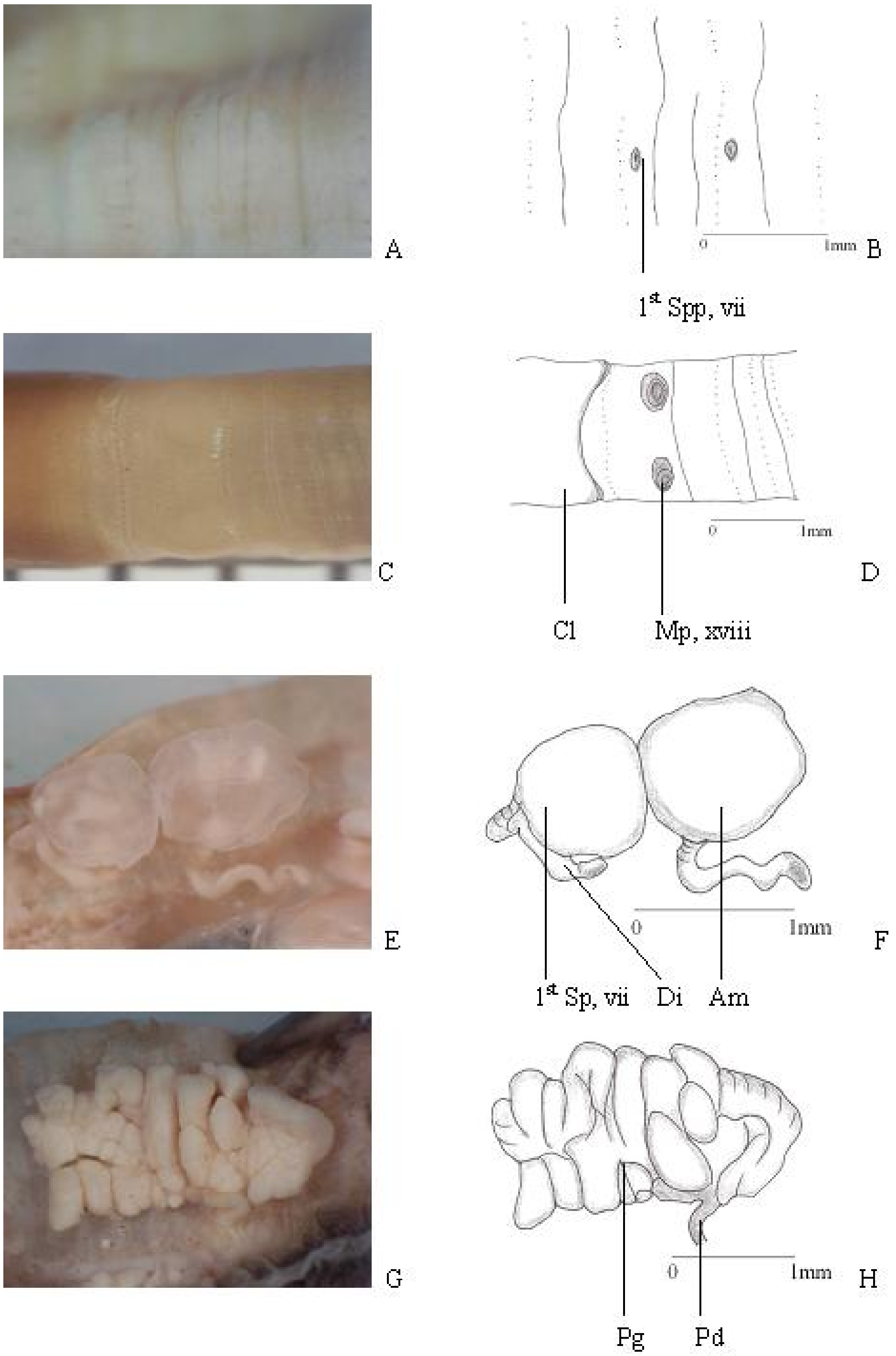

Figure 4.8 Photographs and line drawings of *Amynthas* sp.2: A,B, ventral view of post-setal intrasegment spermathecal pores (Sps); C,D, ventral view of male pore region (Cl, clitellum; Mp, male pore); E,F, right spermatheca (Am, ampulla; Di, diverticulum; Sp, spermatheca); G,H, right prostate gland (Pd, prostate duct; Pg, prostate gland).

Amynthas sp 3. (*A. sieboldi* group)

Diagnosis: Clitellum xiv-xvi, annular. Spermathecal pores 3 pairs in vi/vii – viii/ix, ventro-lateral,.. Female pore midventral in xiv. Male pores paired in xviii, porophore small 3 pairs on xviii. Genital marking on xvii-xviii. Spermathecal, vii-ix, Genital marking one paired in xviii. Holandric. Seminal vesicles paired large, x-xi, xii. Prostate glands, xvii-xix.

Description: External morphology

Total length 170-200 mm, width 5-6 mm, segment number 137-172. Prostomium prolobic. Setae 58-66 in vii, 60-64 in viii. Setae between spermathecal pores 16-18 in vi,vii,viii and ix. First dorsal pore in xii/xiii. Clitellum xiv – xvi, annular, smooth, setae and dorsal pore absent. Spermathecal pores 3 pairs, superficial, big on porophore, on vi/vii, vii/viii and viii/ix, lateral, more than 1/3C apart (Figure 4.9 A,B). Female pore single, midventral in xiv. Male pore paired in xviii, ventro-lateral, minute, superficial, porophore small 3 pairs on xviii, postsetae and presetae out size of male pore (Figure 4.9 C,D). Genital marking one pair between xvii/xviii, broad midventral pad between male pores, no setae between male pores. Color, in dorsal, brown to deeper brown, yellowish on ventrum.

Internal morphology

Septa viii/ix-ix/x aborted, v/vi-vii/viii much thickened. Intestinal origin in xvii. Caeca, simple, very long in xxvii-xvii. Typhlosole, from xxvii, lamelliform. Hearts in vii small, ix small to gizzard, x left long, xi-xiii latero-esophageal. Testes, Holandric. Testis sacs of x, xi enclose all of segment contents, big, paired and ventral connected.

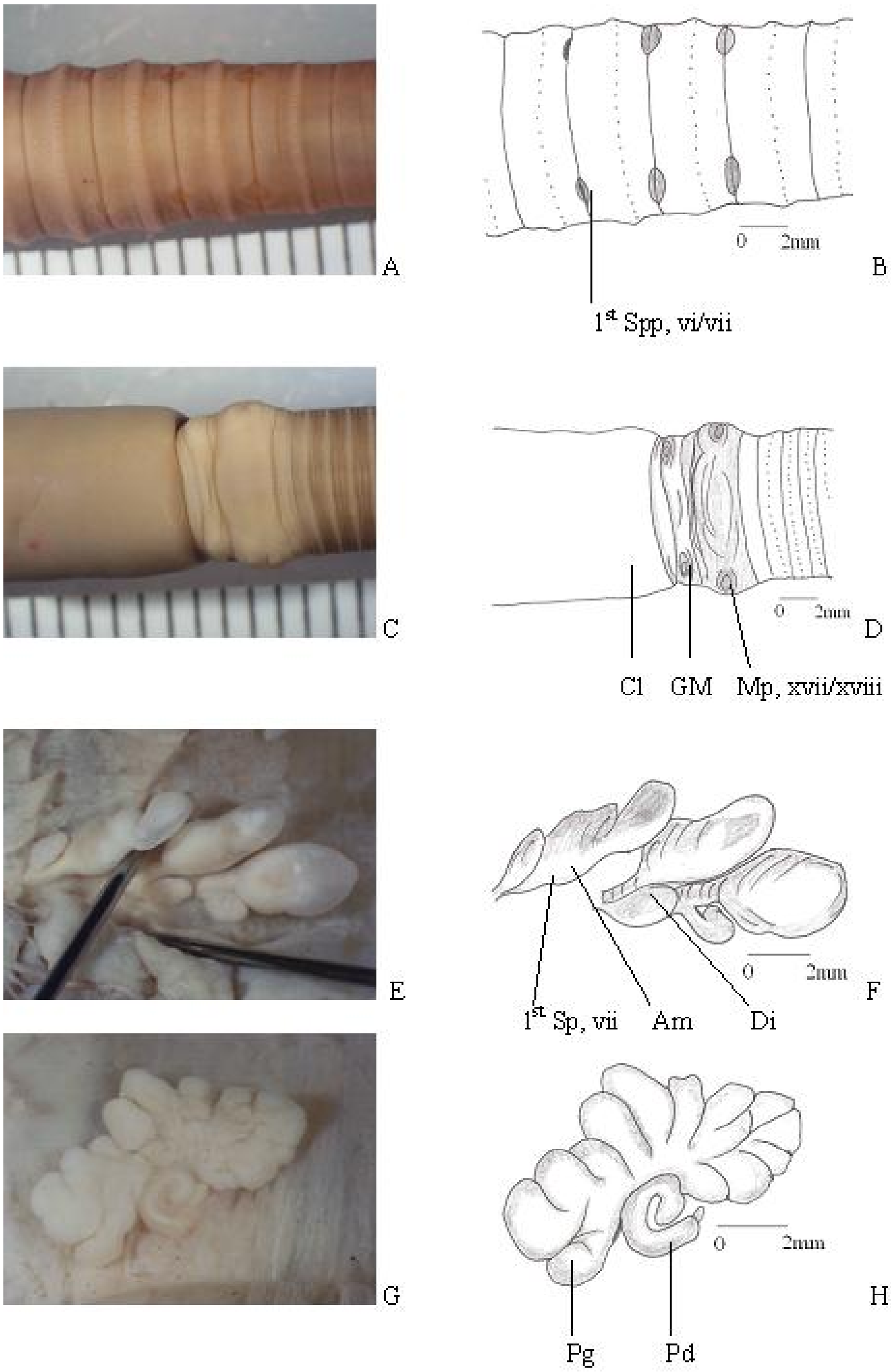

Figure 4.9 Photographs and line drawings of *Amynthas* sp.3: A,B, ventral view of spermathecal pores (Spp); C,D, ventral view of male pore region (Cl, clitellum; Mp, male pore; Po, porophore); E,F, left spermatheca (Am, ampulla; Di, diverticulum; Sp, spermatheca); G,H, left prostate gland (Pd, prostate duct; Pg, prostate gland).

Seminal vesicles, large, especially the anterior pair, in x-xi, xii. Prostate glands, in xvii-xix, duct muscular and short (Figure 4.9 G,H). Spermathecae, 3 pairs vii-ix. Diverticulum zigzag tubule enclosed in sac, sac shorter than ampulla (Figure 4.9 E,F). GM gland large diffuse area midventral on xviii.

Genus *Metaphire*

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

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

1934. *Pheretima*, Michaelsen, **Quart. J. Microsc. Sci**. 77: p. 15.

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

2000. *Metaphire*, Tsai, Shen, and Tsai, **Zool. Stud**. 39: p. 40.

2003. *Metaphire*, Tsai, Chen, Tsai, and Shen, **Endemic Species Res**. 5: p. 34.

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

Diagnosis: 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. Gizzard 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. Ovaries paired xiii. Spermathecae paired, rarely single or numerous. Meronephridial, nephridia absent from the spermathecal ducts.

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.).

1899. *Amynthas peguanus*, Michaelsen, **Mitt. Naturhist. Mus. Hamburg**. 16: p. 7.

1900. *Amynthas peguana*, Beddard, **Proc. Zool. Soc. London**. 1900: p. 628.

Pheretima peguana, Michaelsen, **Das Tierreich** 10: p. 292.

1909. *Pheretima peguana*, Michaelsen, **Mem. Indian Mus**. 1: p. 110.

1925. *Pheretima peguana*, Gates, **Ann. Mag. Nat. Hist., Ser.** 9, 16: p. 561.

1939. *Pheretima peguana*, Gates, **J. Thailand Res. Soc. Nat. Hist. Suppl**. 12: p. 102.

1955. *Pheretima peguana*, Gates, **Rec. Indian Mus**. 52: p. 89.

1961. *Pheretima peguana*, Gates, **American Midland Nat**. 66: p. 62.

1972. *Pheretima peguana*, Gates, **Trans. Am. Phil. Soc.** 62: 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: Clitellum xiv-xvi, annular. Spermathecal pores 3 pairs in vi/vii – viii/ix, ventro-lateral. Female pore midventral in xiv. Male pores paired in xviii, invagenate. Genital marking, paired, circular, central pore, on xvii and xix. Spermathecal, vii-ix. Holandric. Testes sac unpair, Seminal vesicles paired, xi, xii. Prostate glands, large in xv-xxi.

Description: External morphology

Total length 60-140 mm, width 3-8 mm, segment number 90-125. Prostomium epilobic, usually open. Setae 36-43 in vi, 38-44 in vii, 36-43 in viii. Setae between spermathecal pores 9-11 in v, 10-12 in vi, vii,10-14 in viii, ix. First dorsal pore in xii/xiii. Clitellum reaching to or nearly to xii/xiv–xvi/xvii, annular, smooth, setae and dorsal pore absent. Spermathecal pores 3 pairs, superficial, in vi/vii – viii/ix, ventro-lateral, more than 1/3C apart (Figure 4.10 A,B). Female pore single, midventral in xiv. Male pore paired in xviii, ventro-lateral, minute, invaginate, each in a small disc on median wall near roof of a slight, eversible invagination with transversely crescentic aperture (Figure 4.10 C,D). Genital markings, paired, small, circular, equatorial, slightly median to male pore levels, central pore, usually present only on xvii and xix. The apertures on the genital markings are slightly larger than the male pores. Color, light to dark gray. This characteristic constancy in number and position of the genital markings should be compared with conditions in *Methphire posthuma* which like this species also has two pairs of genital markings with somewhat similar relationships to the male apertures.

Internal morphology

Septa ix/x aborted, v/vi-vii/viii thickly muscular, viii/ix muscular and complete. Intestinal origin in xv. Caeca, simple in xxvii-xxiv. Typhlosole, lamelliform. Hearts in vii and ix lateral, viii to gizzard, in x-xi lacking, in xii-xiii latero-esophageal. Testis, Holandric. Testis sacs, unpaired, ventral in x, vertically U-shaped in xi. Seminal vesicles, of xi rather small and included in testis sac, of xii larger. Prostate glands, large in xv-xxi, duct long, 3-5 mm, each in a U-shaped loop (Figure 4.10 G,H). Spermathecae, 3 pairs vi-ix, rather small, duct shorter than ampulla. Diverticulum with short stalk from median face of duct near ampulla and longer ellipsoidal seminal chamber (Figure 4.10 E,F). GM gland, sessile on parietes, xvii-xxi.

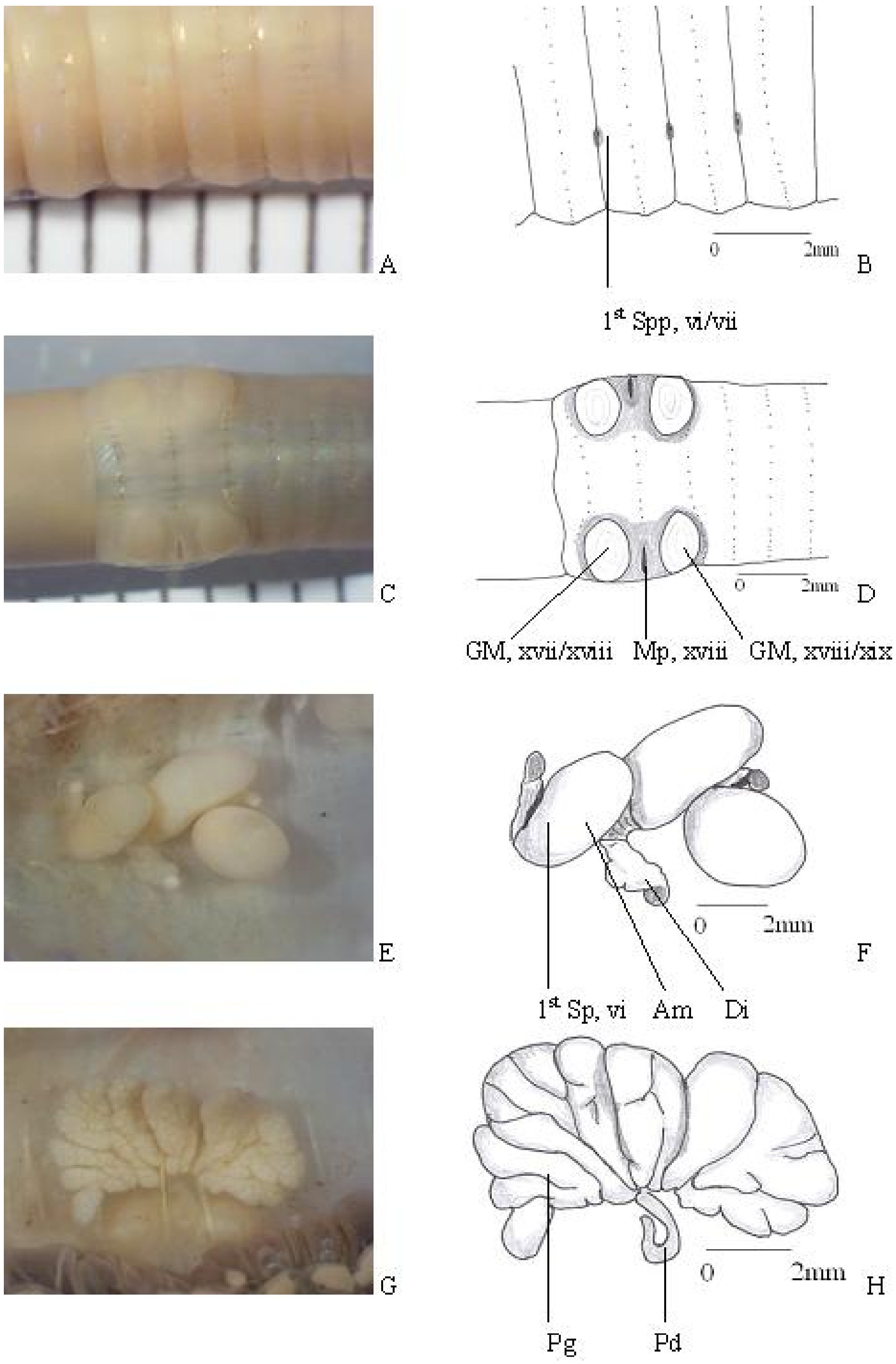

Figure 4.10 Photographs and line drawings of *Metaphire peguana*: A,B, lateral view of spermathecal pores (Spp); C,D, ventral view of male pore region (GM, genital marking; Mp, male pore); E,F, left spermatheca (Am, ampulla; Di, diverticulum; Sp, spermatheca); G,H, left prostate gland (Pd, prostate duct; Pg, prostate gland).

Metaphire houlleti (Perrier, 1872)

1872. *Perichaeta houlleti* Perrier, **Nouv. Arch. Mus. Hist. Nat. Paris** 8: p. 99 (Type locality, Calcutta. Types, in the Paris Mus.).

1900. *Amynthas houlleti*, Beddard, **Proc. Zool. Soc. London** 1900: p. 613;

Pheretima houlleti, Michaelsen, **Das Tierreich** 10: p. 273.

1909. *Pheretima houlleti*, Michaelsen, **Mem. Indian Mus**. 1: p. 110.

1929. *Pheretima houlleti*, Stephenson, **Rec. Indian Mus.** 31: p. 237.

1939. *Pheretima houlleti*, Gates, **J. Thailand Res. Soc. Nat. Hist. Suppl**.12: p.94.

1972. *Pheretima houlleti*, Gates, **Trans. Am. Phil. Soc.** 62: p. 194;

Metaphire houlleti, Sims and Easton, **Biol. J. Linn. Soc**. 4: p. 238.

2003. *Metaphire houlleti*, Blakemore. **Organ. Diver. Evol.** 3(3): p. 21.

2005. *Metaphire houlleti*, James, Shih, and Chang. **J. Nat. Hist**. 39(14): p. 1007.

Diagnosis: Clitellum xiv-xvi. Spermathecal pores 3 pairs in vi/vii – viii/ix, ventro-lateral. Female pore ventral in xiv. Male porophores paired in xviii, each in copulatory pouch with C-shaped opening. Spermathecal diverticulum enlarged and greatly coiled toward distal end. Testis sacs paired in x and xi. Seminal vesicles paired in xi and xii. Prostate glands large, paired in xvi-xx.

Description: External morphology

Total length 107-156 mm, width 3-4 mm, segment number 116-148. Prostomium zygolobic. Setae 28 in v, 32 in x, 53 in xxv. Setae between male pores, 10. First dorsal pore in xi/xii. Clitellum reaching to or nearly to xiii/xiv–xvi/xvii, annular, smooth, setae and dorsal pore absent. Spermathecal pores 3 pairs, superficial, in vi/vii – viii/ix, ventro-lateral, more than 1/3C apart (Figure 4.11 A,B). Female pore single, midventral in xiv. Male pore paired in xviii, ventro-lateral, invaginate, invagination with transversely crescentic aperture (Figure 4.11 C,D). No genital markings. Color, red to brown.

Internal morphology

Septa viii/ix-ix/x aborted, v/vi-vii/viii thickly muscular. Intestinal origin in xv meddle. Caeca, simple in xxvii-xxii. Typhlosole, lamelliform. Hearts in ix small to gizzard, in x-xiii latero-esophageal. Testis, Holandric. Testis sacs, paired, ventrally connected. Seminal vesicles, xi-xii. Prostate glands, large in xvi-xxi, duct long, muscular and coiled (Figure 4.11 G,H). Spermathecae, 3 pairs vii-ix, ampulla flat and wide (Figure 4.11 E,F). GM gland, sessile, muscular on parietes, xviii.

Metaphire sp.1 (*M. glandularis-group*)

Diagnosis: Clitellum xiv-xvi. Spermathecal pores 2 pairs in vi/vii – vii/viii, lateral. Female pore midventral in xiv. Male paired in xviii, invagination with longitudinally crescentic aperture, preseta. Spermathecal vii-viii, ampulla flat and wide.Testis sacs paired, Holandric. Seminal vesicles paired in x-xi and xii. Prostate glands large, paired in xvii-xix.

Description: External morphology

Total length 87-146 mm, width 4-6 mm, segment number 84-102. Prostomium zygolobic. Setae between male pores, 20-22. First dorsal pore in xi/xii. Clitellum, xiv–xvi, annular, smooth, setae and dorsal pore absent. Spermathecal pores 2 pairs,

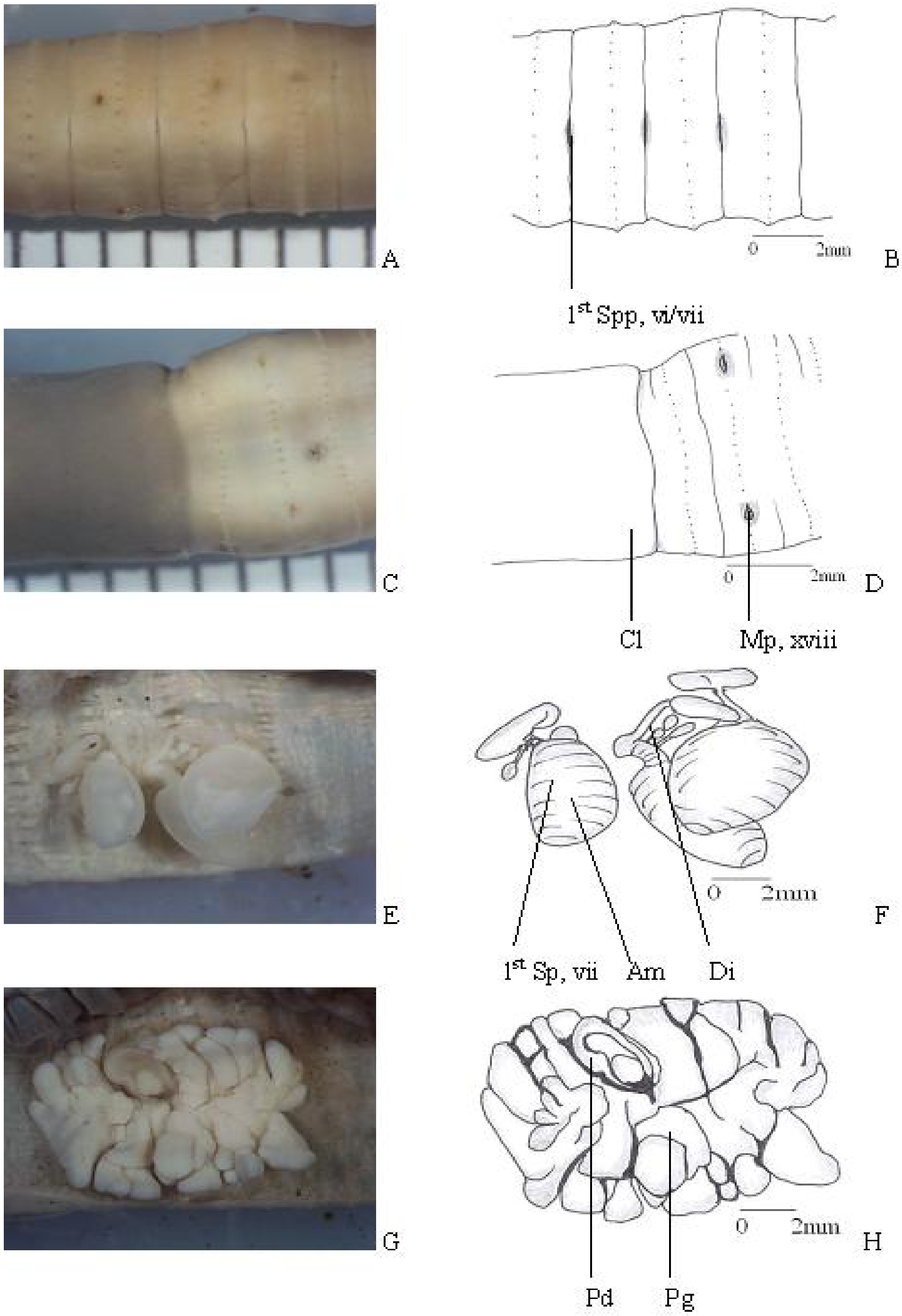

Figure 4.11 Photographs and line drawings of *Metaphire houlleti*: A,B, lateral view of spermathecal pores (Spp); C,D, ventral view of male pore region (Mp, male pore); E,F, left spermatheca (Am, ampulla; Di, diverticulum; Sp, spermatheca); G,H, left prostate gland (Pd, prostate duct; Pg, prostate gland).

superficial, in vi/vii – vii/viii, lateral, more than 1/3C apart (Figure 4.12 A,B) . Female pore single, midventral in xiv. Male pore paired in xviii, ventro-lateral, invaginate, invagination with longitudinally crescentic aperture, preseta (Figure 4.12 C,D). Copulatory pouch xviii with bump near opening on lateral side, large smooth pad deeper in pouch towards midventral side. No genital markings. Color, red to brown.

Internal morphology

Septa viii/ix-ix/x aborted, v/vi-vi/vii thickly muscular, vii/viii thin. Intestinal origin in xv. Caeca, manicate in xxvii-xxiii. Typhlosole, lamelliform. Hearts in vii short, viii absent, ix small to gizzard, in x-xiii latero-esophageal. Testis, Holandric. Testis sacs, paired, ventral connected, U-shape. Seminal vesicles, large, especially the anterior pair, in x-xi, xii. Prostate glands, xvii-xix, duct short, muscular (Figure 4.12 G,H). Spermathecae, 2 pairs vii-viii, ampulla flat and wide, last pair bigger (Figure 4.12 E,F). GM gland, sessile, muscular on parietes, xviii.

Genus *Pithemera* (Beddard, 1900)

1900. *Amynthas*, Beddard, **Proc. Zool. Soc. Lond**. 1900: p. 612.

1928. *Pheretima*, Michaelsen, **Ark. Zool**. 20 (2): p. 8.

1972. *Pithemera,* Sims and Easton, **Biol. J. Linn. Soc**. 4: p. 202.

2000. *Pithemera*, Tsai, Shen, and Tsai, **Zool. Stud.** 39(4): p. 285.

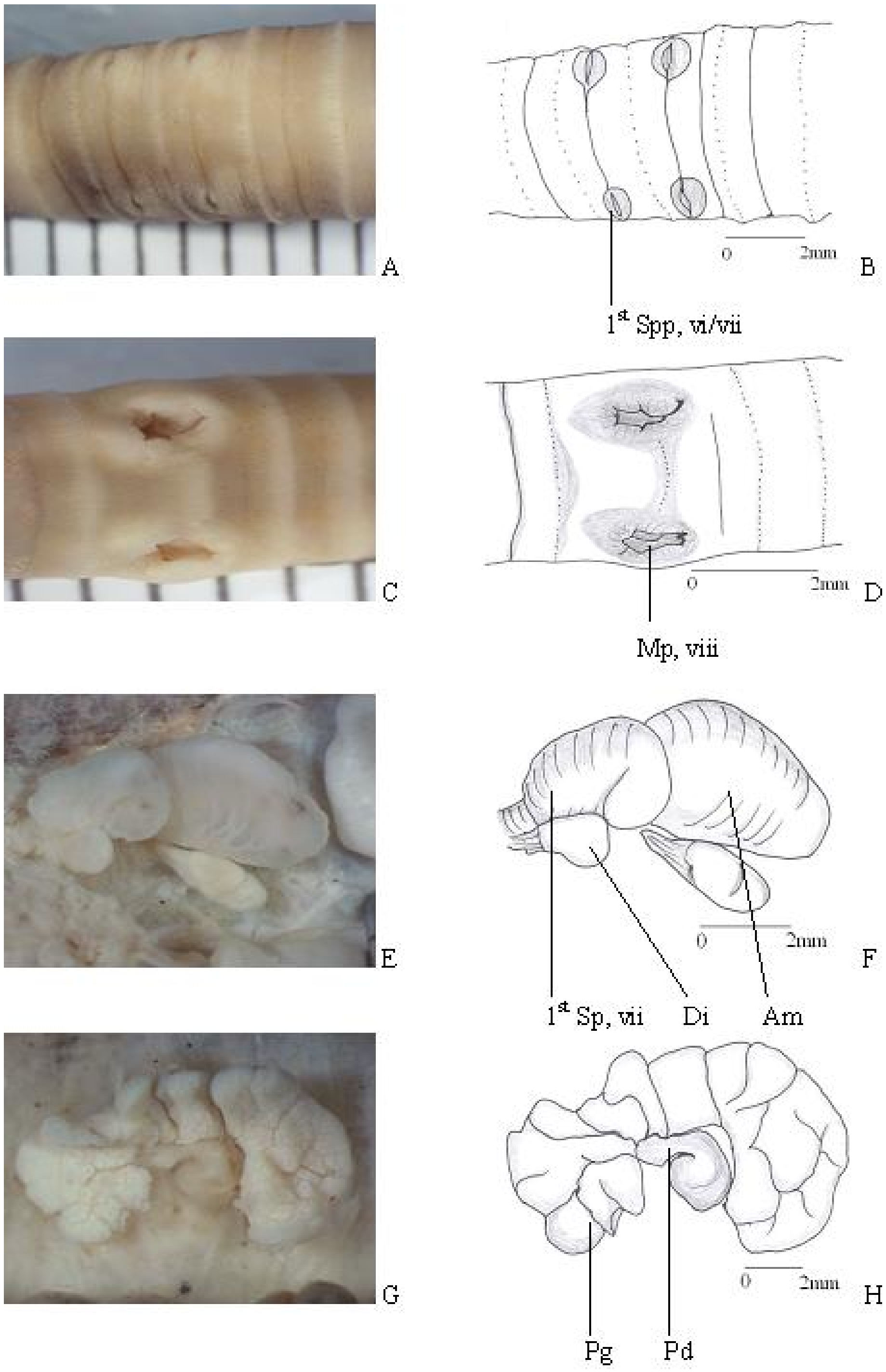

Figure 4.12 Photographs and line drawings of *Metaphire* sp.1 : A,B, ventral view of spermathecal pores (Spp); C,D, ventral view of male pore region (Mp, male pore); E,F, right spermatheca (Am, ampulla; Di, diverticulum; Sp, spermatheca); G,H, right prostate gland (Pd, prostate duct; Pg, prostate gland).

Diagnosis: Megascolecidae with cylindrical bodies usually under 130 mm in length. Setae numerous, regularly arranged around each segment. Clitellum annular, xiv-xvi. Male pores paired, discharging directly onto surface of xviii. Female pores single or closely paired on xiv. Spermathecal pores small, 3, 4 or 5 pairs between iv/v and vii/ix. Gizzard present between vii/viii and ix/x. Oesophageal pouches absent. Intestinal caeca present originating in or near, xxii, rarely xxiv, paired laterally or single midventrally. Testes holandric or metandric. Prostatic glands racemose. Copulatory pouches absent. Ovaries paired in xiii. Spermathecae 3, 4 or 5 pairs in v to ix. Meronephridial, no nephridia in spermathecal ducts.

Pithemera bicincta (Perrier, 1875)

1875. *Perichaeta bicincta* Perrier, **Compt. Rend. Acad. Sci. Paris.** 81: p. 1004 (Type ocality, supposedly in Mindonoro or in Luzon, Philippine Islands. Types, in the Paris Mus.).

1942. *Pheretima bicincta*, Gates, **Bull. Mus. Comp. Zool. Harvard College**. 89: p. 119.

1972. *Pheretima bicincta*, Gates, **Trans. Am. Phil. Soc.** 62: p. 170;

Pithemera bicincta, Sims and Easton, **Biol. J. Linn. Soc**. 4: p. 202.

1999. *Pithemera bicincta*, Shih, Chang, and Chen, **Zool. Stud**. 38(4): p. 435.

2000. *Pithemera bicincta*, Tsai, Shen, and Tsai, **Zool. Stud.** 39(4): p. 285.

Diagnosis: Clitellum xiv – ½xvi, annular, crack, setae visible in xvi. Spermathecal pores 4 pairs in v/vi – viii/ix, lateral. Female pore midventral in xiv. Male paired in xviii, superficial, Spermathecal vi-viii. Testes unpair. Holandric.

Seminal vesicles paired in xi and xii. Prostate glands large, paired in xvi-xix.

Description: External morphology

Total length 32-48 mm, width 2-3 mm, segment number 67-78. Prostomium prolobic. Setae between male pores, 18. First dorsal pore in xii/xiii. Clitellum xiv – ½xvi, annular, crack, setae visible in xvi. Spermathecal pores 4 pairs, superficial, on v/vi-viii/ix, lateral, more than 1/3C apart (Figure 4.13 A,B). Female pore single, medium and ventral in xiv. Male pore paired in xviii, ventro-lateral, minute, superficial, on porophore (Figure 4.13 C,D). No genital marking. Color, red-brown, yellowish on ventrum.

Internal morphology

Septa viii/ix-ix/x aborted, v/vi-vii/viii much thickened. Intestinal origin in xv. Caeca, simple in xxii-xviii. Typhlosole, begin xxii, lamelliform. Hearts in x-xii latero-esophageal. Testis, Holandric. Testis sacs, unpaired. Seminal vesicles, xi, xii. Prostate glands, in xvi-xix, duct muscular and U-shape (Figure 4.13 G,H). Spermathecae, 4 pairs, vi-ix, diverticulum, usually shorter than main axis, comprising a slender stalk and an ovoidal to ellipsoidal seminal chamber (Figure 4.13 E,F).

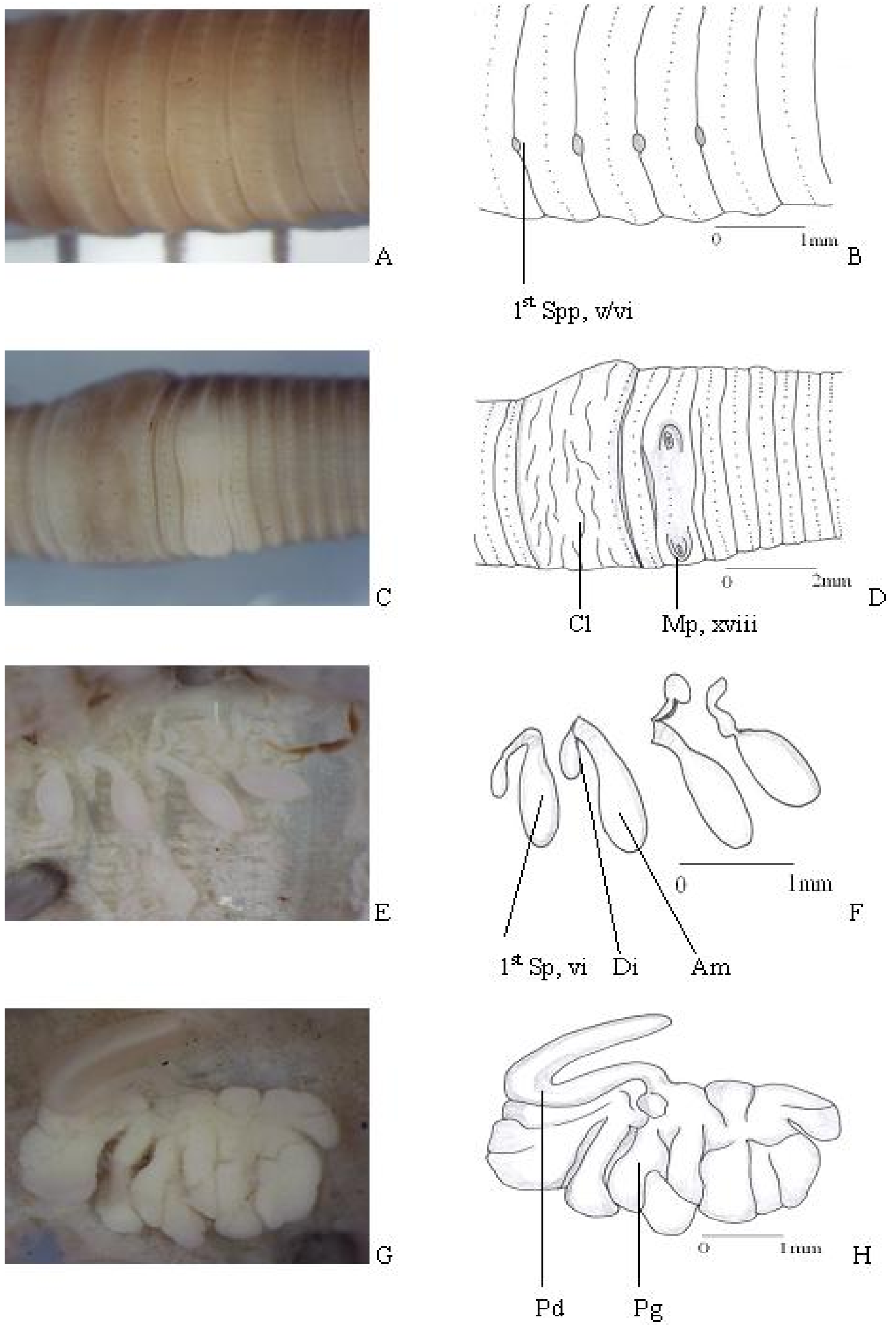

Figure 4.13 Photographs and line drawings of *Pithemera bicincta*: A,B, lateral view of spermathecal pores (Spp); C,D, ventral view of male pore region (Cl, clitellum; Mp, male pore); E,F, left spermatheca (Am, ampulla; Di, diverticulum; Sp, spermatheca); G,H, left prostate gland (Pd, prostate duct; Pg, prostate gland).

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.

Diagnosis: Digestive system, with gizzards behind ovarian segment, an intestinal origin behind xvii, with paired enterosegmental organs on the intestine dorsally, but without typhlosoles, calciferous and supra-intestinal glands. Vascular system, with dorsal, ventral and subneural 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. Spermathecae, 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.

1926. *Drawida*, Gates, **Rec. Indian Mus.** 28: p. 146

1931. *Drawida*, Gates, **Rec. Indian Mus.** 33: p. 340.

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

1962. *Drawida*, Gates, **Bull. Mus. Comp. Zool. Harvard College**. 127: p. 305.

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

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 pores, at or near x/xi. Female pores, 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.

Drawida beddardi (Rosa, 1890)

1890. *Moniligaster beddardii* Rosa, **Ann. Mus. Civ. Sto. Nat. Genova**. 29: p. 379 (Type locality, unknown. No type).

1895. *Drawida barwelli*, Beddard, **A monograph of the order Oligochaeta**. p. 200.

1900. *Drawida barwelli*, Michaelsen, **Das Tierreich**. 10: p. 116.

1926. *Drawida tecta* Gates, **Rec. Indian Mus.** 28: p. 148 (Type locality, Yaungwhe. Types, in the U.S. Natl. Natl. Mus.).

1931. *Drawida hehoensis*, Gates, **Rec. Indian Mus.** 33: p. 340.

1962. *Drawida beddardi*, Gates, **Bull. Mus. Comp. Zool. Harvard College**. 127: p. 312.

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

Diagnosis: Clitellum, annular, red, ix–xiii. Spermathecal pores 1 pairs in vii/viii. Female pores, 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 morphology

Total length 24-120 mm, width 2-4 mm, segment number 132-168. Prostomium prolobous. Clitellum, annular, red, ix–xiii. Spermathecal pores, vii/viii, rather large, at or just median to CD (Figure 4.14 A,B). Genital markings, lacking but one or both margins of male apertures may be whitened and with thickened epidermis. Female pores, at or just behind xi/xii. Male pore, transverse slits at 10/11 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 (Figure 4.14 C,D). Setae, longer in posterior segments, AA= or< BC, DD= or > ½ C.

Internal morphology

Gizzards, 4, in xii-xv. Connectives from extra-esophageals, usually on anterior face of 8/9. Sperm ducts, 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 (Figure 4.14 E,F). Ovarian chamber, closed off from parietes. Testes, in ix/x. Ovaries, in xi.

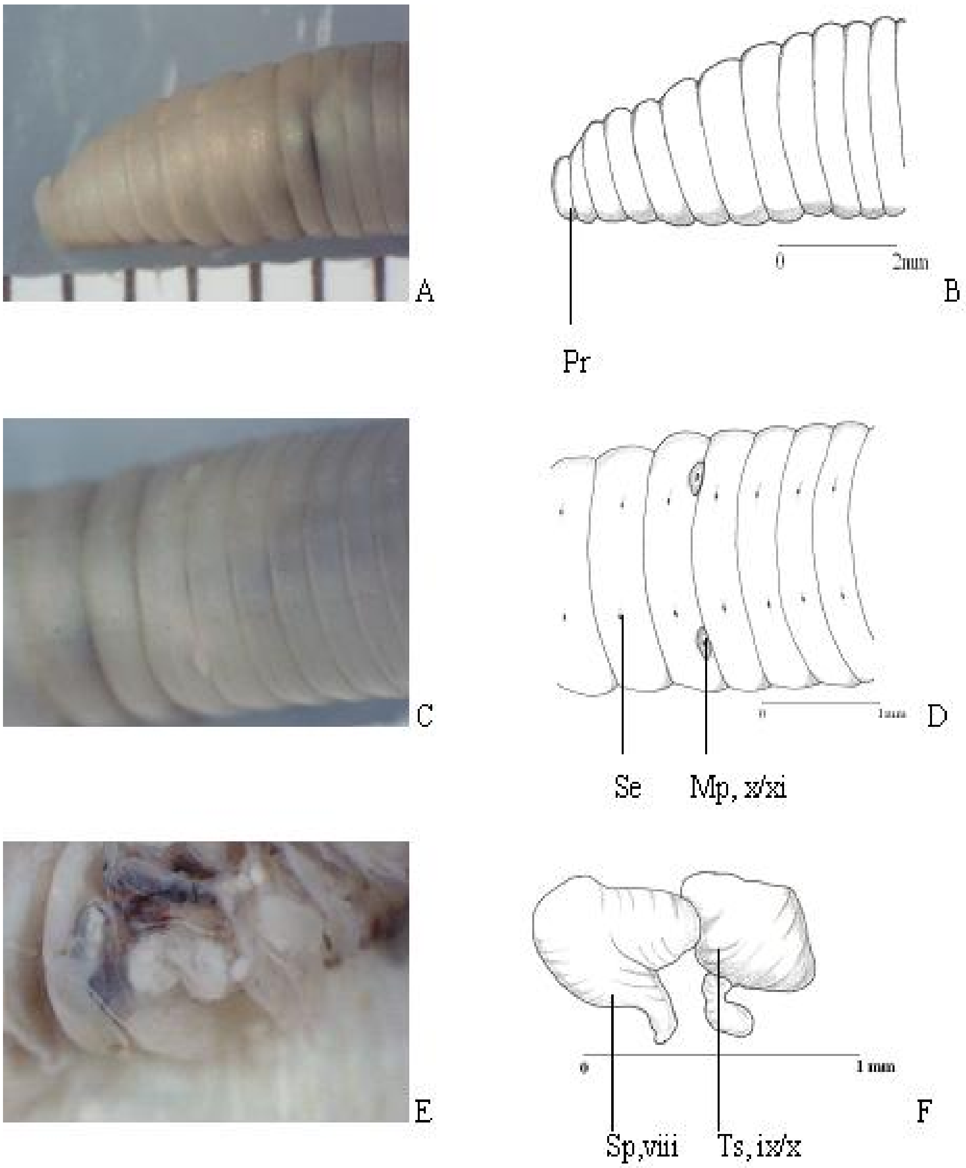

Figure 4.14 Photographs and line drawings of *Drawida beddardi*: A,B, anterior view (Pr, prostomium); C,D, ventral view of male pore region (Se, setae; Mp, male pore); E,F, left spermatheca (Sp) and testes (Ts).

Key to species of Khao Yai National Park earthworms

1. Testes and male funnels, intraseptal .... *Drawida beddardi*

   Testes and male funnels, not intraseptal ……………….. 2

2. Setae of a posterior part of the body in the

   "quincunx" arrangement ……………………………… *Pontoscolex corethrurus*

   Setae not in the quincunx arrangement ………………. 3

3. Penial setae, present ……………………………….… *Perionyx excavatus*

   Penial setae, lacking ……………………………………. 4

4. Intestinal caeca arishing in xxii ………………………… *Pithemera bicincta*

   Intestinal caeca arishing in xxvii ………………………. 5

5. Male pores, superficial …………………………………. 6

   Male pores, invaginate …………………………………. 11

6. Spermathecal pores, two pairs …………………………. *Amynthas* sp.2

   Spermathecal pores, more than two pairs ……………… 7

7. Spermathecal pores, three pairs ………………………… 8

   Spermathecal pores, more than three pairs …………….. 10

8. Genital markings, one pair at xvii/xviii ………………… *Amynthas* sp 3

   Genital markings, on male pore area …………………… 9

9. Setae between male pores 8, GM gland sessile

   and gland like …………………………………………….. *A. fucosus*

   Setae between male pores 44, GM gland sessile

   and mass ………………………………………………… *Amynthas* sp.1

10. Genital markings, on xvii, male pore area ……………. *A. alexandri*

    Genital marking, three pairs on xviii/ix – xx/xxi …….. *A. longicauliculatus*

11.Spermathecal pores, two pairs .... *Metaphire* sp.1

Spermathecal pores, three pairs 12

12. Genital markings, none .... *M. houlleti*

Genital markings, two pairs on xvii and xix .... *M. peguana*

4.3. Earthworm community and distribution

4.3.1 Earthworm species and distribution

A total of 2,880 earthworms were collected in all studied area. The 2,774 individuals were identified to species and 106 were unidentified (juveniles). The highest number of specimens (2,190) belongs to family Glossoscolecidae followed by Megascolecidae (297) and Moniligastridae (287). Of the ten species recorded here, five species were classified to genus *Amynthas*, three species were *Metaphire*, one species was *Pontoscolex* and one species was *Drawida*. The occurrence of species and number of earthworms collected in sampling areas are listed in Table 4.3.

Pontoscolex corethrurus (Müller, 1856), the only glossoscolecid species found in this study, was presented in ME, HE and GL. The highest was the ME (1,433 individuals) and the lowest was the GL (47 individuals). It was a cosmopolitan species with pantropic distribution due to transportation by man. It occured in Northeast Asia, including China (Chen, 1933), Taiwan (Kobayashi, 1938b; Tsai, Shen, and Tsai, 2000), Philippines and other parts of Southeast Asia (Gates, 1972), and was one of the most common exotic species in Thailand.

The Megascolecidae was the one in two most important families ecologically in Europe, North America, Australia and Asia. The megascolecids and their close relatives comprise more than half the known species, and this group includes

Table 4.3 Occurrence of species and numbers of earthworms collected in five forest types

Species	Number of individual in forest					
	MD	DE	ME	HE	GL	Total
Glossoscolecidae						
1. *Pontoscolex corethrurus*	-	-	1433	710	47	2190
Megascolecidae						
2. *Amynthas alexandri*	12	55	43	34	-	144
3. *Amynthas fucosus*	-	32	-	11	-	43
4. *Amynthas* sp.1	-	5	3	3	-	11
5. *Amynthas* sp.2	-	8	-	7	-	15
6. *Amynthas* sp.3	-	-	-	2	-	2
7. *Metaphire peguana*	-	15	36	28	-	79
8. *Metaphire houlleti*	-	1	-	-	-	1
9. *Metaphire* sp.1	-	2	-	-	-	2
Moniligastridae						
10. *Drawida beddardi*	96	76	-	-	115	287
Total	108	194	1515	795	162	2774

worms that were widely distributed outside the Palearctic zone, with two genera, *Pheretima* and *Dichogaster*, that together probably contain more species than any other oligochaete genera (Edwards and Bohlen, 1997). Sims and Easton (1972) reviewed the genus *Pheretima* and divided it into eight genera i.e. *Archipheretima*, *Pithemera*, *Ephemitra*, *Metapheretima*, *Planapheretima*, *Amynthas*, *Metaphire* and *Pheretima*. In the genus *Amynthas* and *Metaphire*, the shape of the male pore region and the locations and numbers of genital markings near spermathecal pores are useful characters for the discrimination of species (Hong and James, 2001).

The megascolecid *Amynthas alexandri* was the common earthworm in MD, DE, ME and HE. A total of 144 individuals were collected at studied areas. The highest was in the DE (55 individuals) and the lowest was in the MD (12 individuals). It occured in India, Myanmar, Thailand and Andaman Islands (Gates, 1972; Kaushal and Bisht, 1994).

Amynthas fucosus was found in DE and HE. A total of 43 individuals were collected at studied areas. The DE had higher number (32 individuals) than that of the GL (11individuals). It occured in Myanmar (Gates, 1933). This species was the first recorded species in Thailand.

Amynthas sp.1 was found in DE, ME and HE. A total of 11 individuals were collected at studied areas. It was highest in DE (5 individuals). This species was supposed to be a new species.

Amynthas sp.2 was found in DE (8 individuals) and HE (7 individuals). A total of 15 individuals were collected at studied areas. This species was identified to *A. pomellus* species group, which was all found in China and Japan (Sims and Easton, 1972). This species was supposed to be a new species.

Amynthas sp.3 was found only in HE. A total of 2 individuals were collected at studied areas. This species was identified to *A. sieboldi* species group, which over 50 species were described (Sims and Easton, 1972). External morphology of *Amynthas* sp.3 was similar to *Amynthas terrigena*, but there were internal structure differences.

Metaphire peguana was found in DE, ME and HE. A total of 79 individuals were collected at studied areas. The highest was in the ME (55 individuals) and the lowest was in the DE (15 individuals). It occured in India, Myanmar, Vietnam, Singapore, Malay Peninsula, Thailand (Gates, 1972) and Japan (Blakemore, 2003). In Thailand, *M. peguana* was found at Chantaburi Province, Bangkok, Chiang Mai Province, and Chiang Rai Province (Gates, 1939).

Metaphire houlleti was found only one individual in DE. It was believed to be somewhere in Southeast Asia and may include an eastern portion of Myanmar (Gates, 1972) and Taiwan (Shen, Tsai, and Tsai, 2005). The first record was appeared in Thai earthworms by Gates (1939b). The original location of this species was probably somewhere in a region comprising eastern Myanmar and Thailand.

Metaphire sp.1 was found only one individual in DE. This species was identified as *M. glandularis* species group. All were from Korea and Japan (Sims and Easton, 1972). This species was supposed to be a new species.

The other three species found outside the sampling areas were *Amynthas longicauliculatus*, *Perionyx excavatus* and *Pithemera bicincta.*

Amynthas longicauliculatus was found outside the sampling areas in the ME. The first record was appeared in Thai earthworms by Gates (1939b) at Doi Suthep (Chiang Mai Province), Khun Tam mountains (Lampang Province) and Phrae Province.

Perionyx excavatus was found outside the sampling areas in the ME. The *P. excavatus* was a tropical earthworm species commonly found in India, the Philippines, the Dominicans, Australia and parts of America (Edwards, Dominguez, and Neuhauser, 1998: Gates, 1972). The original location of this species was probably somewhere in the Himalaya (Gates, 1972).

Pithemera bicincta was found outside the sampling areas in the ME. It occured in India, Philippines, Taiwan, Caroline Island, Hawaii, Myanmar (Sims and Easton, 1972).

Drawida beddardi, the only Moniligastridae found in this study, was presented in MD, DE and GL. The highest was in the GL (115 individuals) and the lowest was in the DE (76 individuals). The first record was appeared in Burmese earthworms by Gates (1972) at Chiang Mai Province**.** The original location of this species was probably somewhere in a region comprising Indian, Myanmar and Thailand.

4.3.2 Earthworms abundance

4.3.2.1 Earthworm composition

Average of earthworm abundance in two years was 105.1 ind/m^2. Average of earthworm abundance in 2002 and 2003 was 114.8 ind/m^2 and 96.7 ind/m^2 respectively. In 2002, the abundance of earthworms was a minimum of 50.7 ind/m^2 in December and a maximum of 173.9 ind/m^2 in September. In 2003, the abundance of earthworms was a minimum of 42.4 ind/m^2 in December to a maximum of 153.6 ind/m^2 in September (Figure 4.15A).

More earthworms were collected in 2002 than 2003, which could be related to the higher rainfall from July to December 2002 than from July to December 2003 (Figure 4.1). The seasonal fluctuations in soil moisture responding to rainfall events may affect the size of earthworm populations (Bhadauria, Ramakrishnan, and Srivastava, 2000). When the soil moisture levels decrease during November to December most earthworms burrows deeper into the soil profile, and

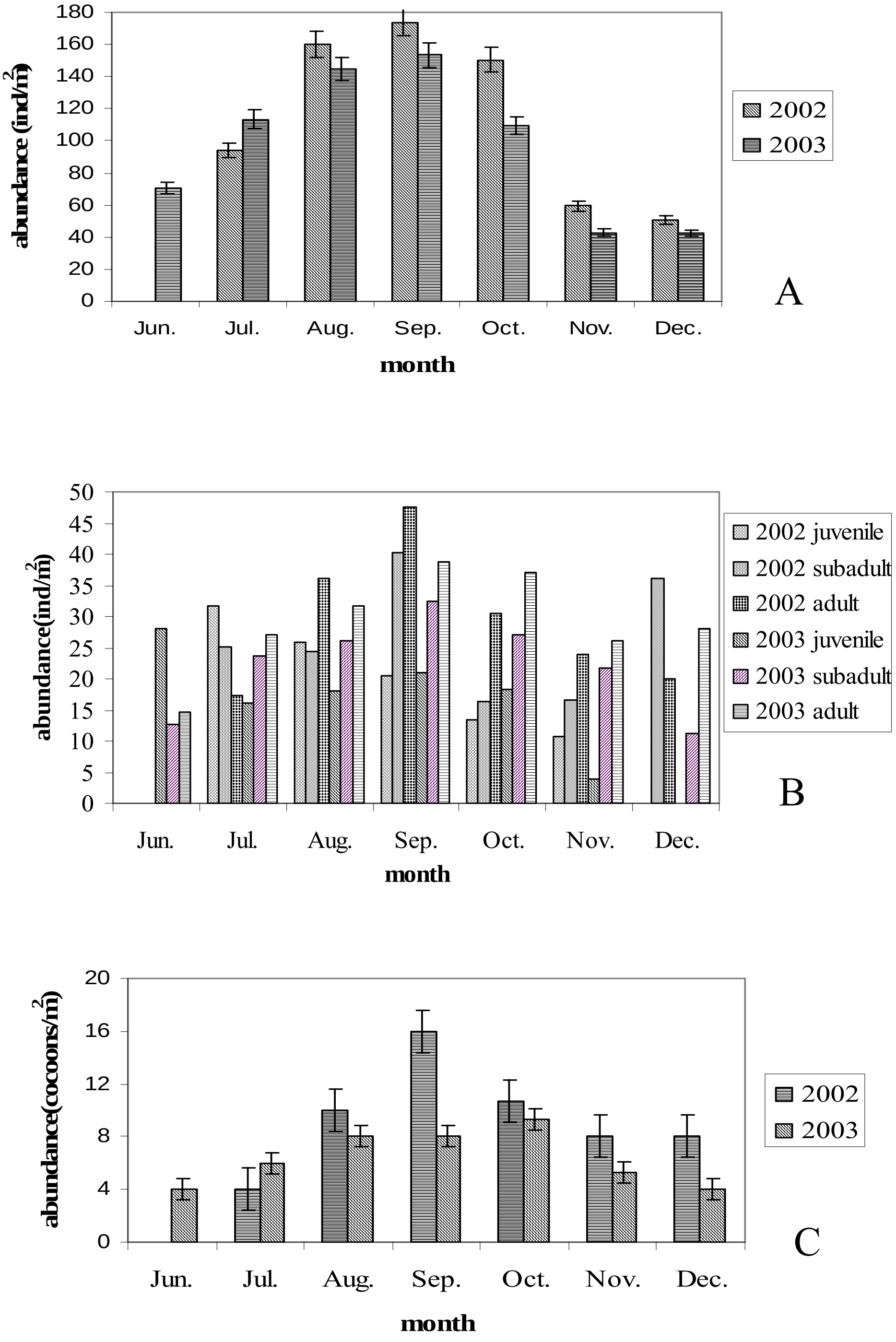

Figure 4.15 The abundance of earthworm composition (A), juvenile, subadult and adult earthworms (B), and cocoon of *P. corethrurus* (C), in July-December 2002 and June-December 2003 in sampling areas in Khao Yai National Park

enter into a state of quiescence during which they curl themselves into a tight ball to reduce water loss, and reduce their metabolic rates until environmental conditions become favorable (Edwards and Bohlen, 1997).

4.3.2.2 Age classes

A total of 2,880 earthworms were separated into 3 groups as juvenile, subadult and adult. The juvenile group showed the highest abundance during June - August and the lowest during November-December. The adult group showed the highest abundance during August-October (Figure 4.15B). This trend was similar to the study of Gates (1961), the differences of the abundance of earthworm composition during July to December were found to be higher in 2002 (114.8 ind/m^2) than in 2003 (96.7 ind/m^2).

4.3.2.3 Earthworm cocoon

All the cocoons found were belong to *P. corethrurus.* The abundance of earthworm cocoon composition tended to be high during August to October. In this study the earthworm cocoons were found only in ME (42 cocoons) and HE (17 cocoons) and the highest abundance of cocoons was present in ME. The differences of the abundance of cocoon composition between the July-December 2002 (4-16 cocoons/m^2) and June-December 2003 (4-9.3 cocoons/m^2) were shown in Figure 4.15C. The numbers of cocoons produced in a season differ greatly with both species and climate. There was a dramatic increase in cocoon production by *P. corethrurus* of Tripura, India in the summer and monsoon with a corresponding peak during April and July (Bhattacharjee and Chaudhuri, 2002).

4.3.2.4 Seasonal change in abundance of earthworm species

The abundance of glossoscolecid, *P. corethrurus*, was 61.5 ind/m^2 or 58.3 % of the total abundance. The highest abundance was present during August to September and rapidly decreased from November to December (Table 4.4). Two genera of family Megascolecidae were found in this study, *Amynthas* and *Metaphire*. The abundance of *Amynthas* five species was 18.3 ind/m^2 or 17.3% of the total abundance. For the occurrence, *A. alexandri*, 7.8 ind/m^2 was the common species in all studied areas except in grassland (Table 4.4). The *Amynthas* sp.3 was very rare species (2 individuals). The abundance of *Metaphire* three species was 8.6 ind/m^2 or 8.1% of the total abundance. The abundance of *M. peguana* was 7.7 ind/m^2 higher than of *M. houlleti* (1 individual) and *Methphire* sp.1 (2 individuals).

Drawida beddardi was only one species of family Moniligastridae that was present in sampling areas. The abundance of this species was 8.5 ind/m^2 or 8.1% of the total abundance. In 2002, the maximum abundance of *D. beddardi* was 12.7 ind/m^2 in October In 2003, the maximum abundance of *D. beddardi* was 11.4 ind/m^2 in August (Table 4.4).

The highest abundance of all species was appeared in September 2002 and 2003. The exceptions were found in *A.fucosus* and *D. beddardi*, which showed the highest abundance in August 2003. In addition, *M. peguana* had a period of highest abundance longer than *M. houlleti* and *Methphire* sp.1 from August – October of 2002 and 2003.

Bhadauria, Ramakrishnan, and Srivastava (2000) reported that earthworm activities in the tropics were limited to certain seasons; in the monsoon tropical climate of Myanmar and the humid subtropical climate of India, earthworms

Table 4.4 The abundance of earthworm species in July-December 2002 and June-December 2003 in sampling areas in Khao Yai National Park

	2002						2003							
Species	Jul.	Aug.	Sep.	Otc.	Nov.	Dec.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Average
P. corethrurus	57.2	94	95.7	97.5	29.8	38.7	40	61.3	77.7	76.4	66.9	26.5	38.4	61.5
A. alexandri	7.2	12	16	7.3	6	0	8	10	12.5	11.3	7.3	4	0	7.8
A. fucosus	4	10	5	6.7	4	4	4	12	9.3	10.7	6	2	0	6.0
Amynthas sp.1	0	0	6.7	0	0	0	0	4	4	4	0	0	0	1.4
Amynthas sp.2	0	4	4	0	0	0	0	0	10	12	0	0	0	2.3
Amynthas sp.3	0	0	6	0	0	0	0	0	0	4	0	0	0	0.8
M. peguana	4	12	13	13	5	4	4	4.8	10	10	12	4	4	7.7
M. houlleti	0	0	0	0	0	0	0	0	0	4	0	0	0	0.3
Metaphire sp.1	0	0	4	0	0	0	0	0	0	4	0	0	0	0.6
D. brddardi	9.8	10.9	12.3	12.7	10.7	4	9.1	11.3	11.4	9.8	5.6	2.4	0	8.5
Unknown	12	17.3	11.2	13.3	4	0	5.3	10	9.6	7.4	12	4	0	8.2
Total	94.2	160.2	173.9	150.5	59.5	50.7	70.4	113.4	144.5	153.6	109.8	42.9	42.4	105.1

were active mainly in the 4-6 months of the rainy season between May and October. Many field and laboratory studies have shown the seasonal effect on earthworm populations (Baker *et al*., 1993; Brown *et al*., 2003; Gates, 1961; Gerard, 1967; Mele and Carter, 1999 and Whalen and Costa, 2003).

4.3.3 Abundance of earthworms in different forest types

The highest total abundance of earthworm was 93.2 ind/m^2 in ME and declined to 64.9 ind/m^2 in HE, 15.8 ind/m^2 in DE, 14.1 ind/m^2 in GL and 11.1 ind/m^2 in MD (Figure 4.16). Abundance of earthworms of all forest types ranged from 11.1 ind/m^2 to 93.2 ind/m^2, which was higher than earthworm abundance of the tropical rainforest of Nigeria, 61.7 ind/m^2 (Cook *et al*., 1980), Sarawak, 6-26 ind/m^2 (Anderson, Proctor and Vallack, 1983), Malaysia, 64-166 ind/m^2 (Leaky and Proctor, 1987), and Peru, 68 ind/m^2 (Rambke and Verhaagh, 1992) but lower than Costa Rica, 280-401 ind/m^2 (Atkin and Proctor, 1988).

4.3.4 Density of earthworm

The density of earthworm species in each forest type was shown in Table 4.5. The results were summarized in Table 4.5 and were described as the followings:

In MD, the earthworm species occurred in this forest type was *A.alexandri* and *D.beddardi*. *D.beddardi* was the most common species approximately 5.91 ind/m^2

In DE, the eight earthworm species were *A. alexandri*, *A. fucosus*, *Amynthas* sp.1, *Amynthas* sp.2, *M. peguana*, *M. houlleti*, *Metaphire* sp.1 and *D. beddardi*. *D. beddardi* had the highest density 4.68 ind/m^2 followed by

A. alexandri 3.38 ind/m^2 and *A. fucosus* 1.97 ind/m^2 whereas *M. houlleti* had 1 individual calculated at 0.06 ind/m^2 (Table 4.5).

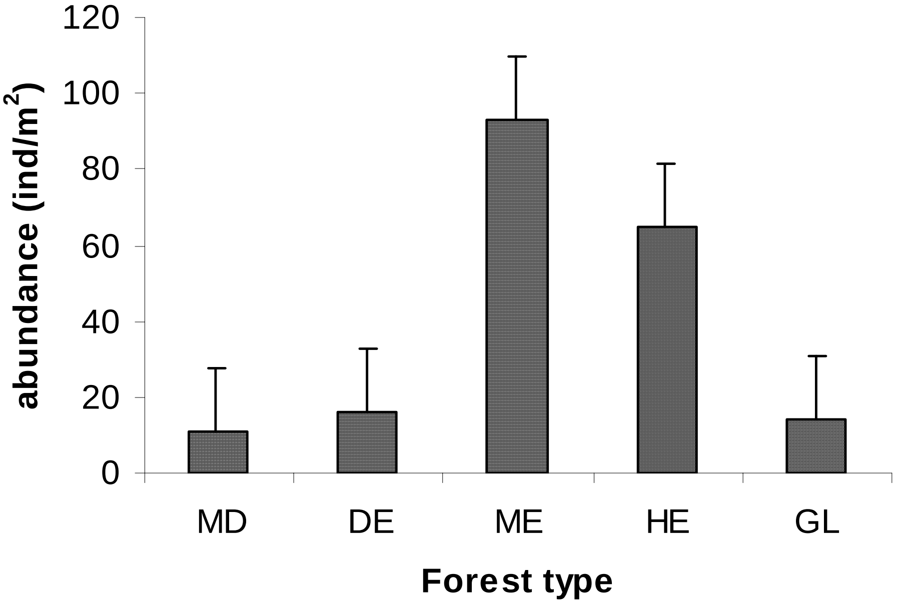

Figure 4.16 The abundance of earthworms in five forest types in Khao Yai National Park

In ME, the four earthworm species were *A. alexandri*, *Amynthas* sp.1, *M. peguana* and *P. corethrurus*. *P. corethrurus* had the highest density 88.18 ind/m^2 followed by *A. alexandri* 2.65 ind/m^2 and *M. peguana* 2.22 ind/m^2 whereas *Amynthas* sp.1 had 3 individual calculated at 0.18 ind/m^2 (Table 4.5).

In HE, the seven species of earthworms were *A. alexandri*, *Amynthas* sp.1, *Amynthas* sp.2, *Amynthas* sp.3, *A. fucosus*, *M. peguana*, and. *P. corethrurus*. *P. corethrurus* had the highest density 43.69 ind/m^2 followed by *A. alexandri* 2.09%. and other was rare species (Table 4.5).

In GL, there were two rare species of *D. beddardi* and *P. corethrurus*. *D. beddardi* had the highest density 7.08 ind/m^2 followed by *P. corethrurus* 2.89 ind/m^2 (Table 4.5).

Table 4.5 The density of earthworm species in MD, DE, ME, HE and GL.

Species	Density (ind/m^2)				
	MD	DE	ME	HE	GL
P. corethrurus	-	-	88.18	43.69	2.89
A. alexandri	0.74	3.38	2.65	2.09	-
A. fucosus	-	1.97	-	0.68	-
Amynthas sp.1	-	0.31	0.18	0.18	-
Amynthas sp.2	-	0.49	-	0.43	-
Amynthas sp.3	-	-	-	0.12	-
M. peguana	-	0.92	2.22	1.72	-
M. houlleti	-	0.06	-	-	-
Metaphire sp.1	-	0.12	-	-	-
D. beddardi	5.91	4.68	-	-	7.08
total	6.65	11.93	93.23	48.91	9.97

4.3.5 Species richness

The species richness of each forest types were shown in Table 4.6. The results showed that the highest species richness was 8 in DE and decreased to 7 and 4 in HE and ME respectively. The lowest species richness was 2 in MD and GL. Fragoso and Lavelle (1992) found that the earthworm communities of the tropical rainforests contained from 4 to 14 species, and had mean species richness 6.5 species that was not significantly different from that of temperate forests 5.7 species.

4.3.6 Shannon - Wiener index and Evenness

Species diversity was investigated by Shannon - Wiener index (H′). There was different in each habitat types (Table 4.6). The results showed that the highest index of diversity was 1.44 in DE and index was lower to 1.31, 1.07 and 0.67 in HE, ME and GL respectively. The lowest species diversity index was 0.54 in MD.

The species evenness was calculated from species diversity index and the result was shown in Table 4.6. The greatest of species evenness was 0.67 in DE and HE, and declined to 0.39 in ME and 0.19 in MD and GL.

The highest species diversity index and evenness index of DE showed that DE had more earthworm species than other forest types. The increase in number of species was due to Megascolecids as shown in Table 4.3. The earthworm diversity was affected by many factors such as soil moisture, litter, organic matter and soil pH in an area (Edwards and Bohlen, 1997).

Table 4.6 Species diversity index and evenness index of earthworms in five forest types.

Index	Forest type				
	MD	DE	ME	HE	GL
Species richness	2	8	4	7	2
Evenness	0.19	0.67	0.39	0.67	0.19
Shannon-Wiener index	0.54	1.44	1.07	1.31	0.67

4.3.7 Similarity index of earthworm community

Similarity index was calculated from species number of earthworm composition in Khao Yai National Park. Bray-Curtis equation was used to compare the similarity index of each communities, the result was shown in Table 4.7.

Table 4.7 Similarity index of earthworm community of Khao Yai National Park.

	MD	DE	ME	HE	GL
MD	-	-	-	-	-
DE	58.30	-	-	-	-
ME	1.48	7.14	-	-	-
HE	2.70	14.16	67.10	-	-
GL	71.20	42.70	5.61	9.83	-

The result revealed that GL and MD had showed the highest of similarity index (71.20%) followed by HE and ME (67.10%) and DE and MD (58.30%) respectively. The highest similarity index of MD and GL might be explained by the similarity of environmental factors between them. In contrast ME and MD was the lowest, it could be explained that environment factors of them were less similar and caused to low similarity index.

It might be concluded that environmental factors are the main factors that affect the similarity of earthworm community. Moreover, soil moisture, species and density of plants are another factors that could increase or decrease the similarity index of earthworm community (Edwards and Bohlen, 1997; Vesterdal and Rasmussen, 1998).

4.3.8 Cluster analysis of earthworm community

4.3.8.1 Dendrogram of cluster analysis

The result of cluster analysis was shown in Figure 4.16. It could be seen that the dendrogram separated five forest types into three groups of similarity. The first group consisted of MD and GL where *D. beddardi* was dominant species. The second group consisted of only one forest i.e. DE which was dominated by *Amynthas* spp. and *Metaphire* spp. The third group consisted of ME and HE where *P. corethrurus* was dominant species.

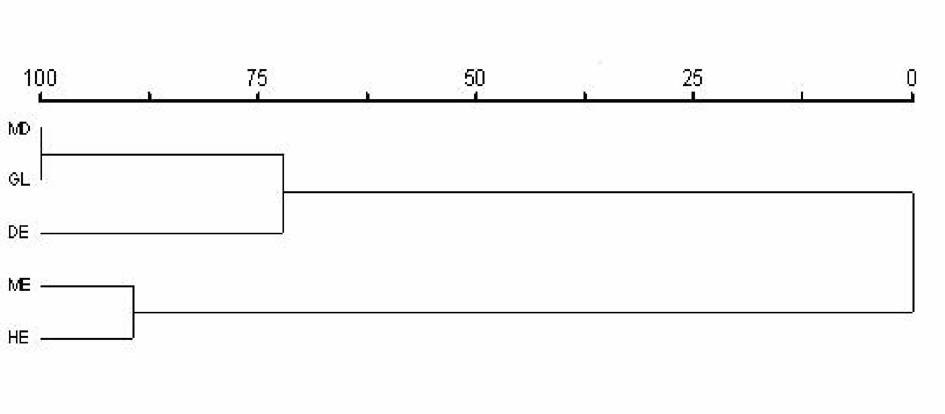

Figure 4.17 Dendrogram for hierarchical clustering of earthworms in five forest types. (MD = mix deciduous forest, DE = dry evergreen forest, ME = moist evergreen forest, HE = hill evergreen forest and GL = grassland)

4.3.8.2 Principal components analysis (PCA)

The ordination of PCA was analyzed, and the result was shown in dimension ordered. The result indicated that the forest types were three separate groups (Figure 4.18). The PCA plot was consistent with the cluster analysis results in showing how the group of DE, MD and GL, ME and HE were separated widely in space. The output from PCA analysis was also utilized to identify the relationship of

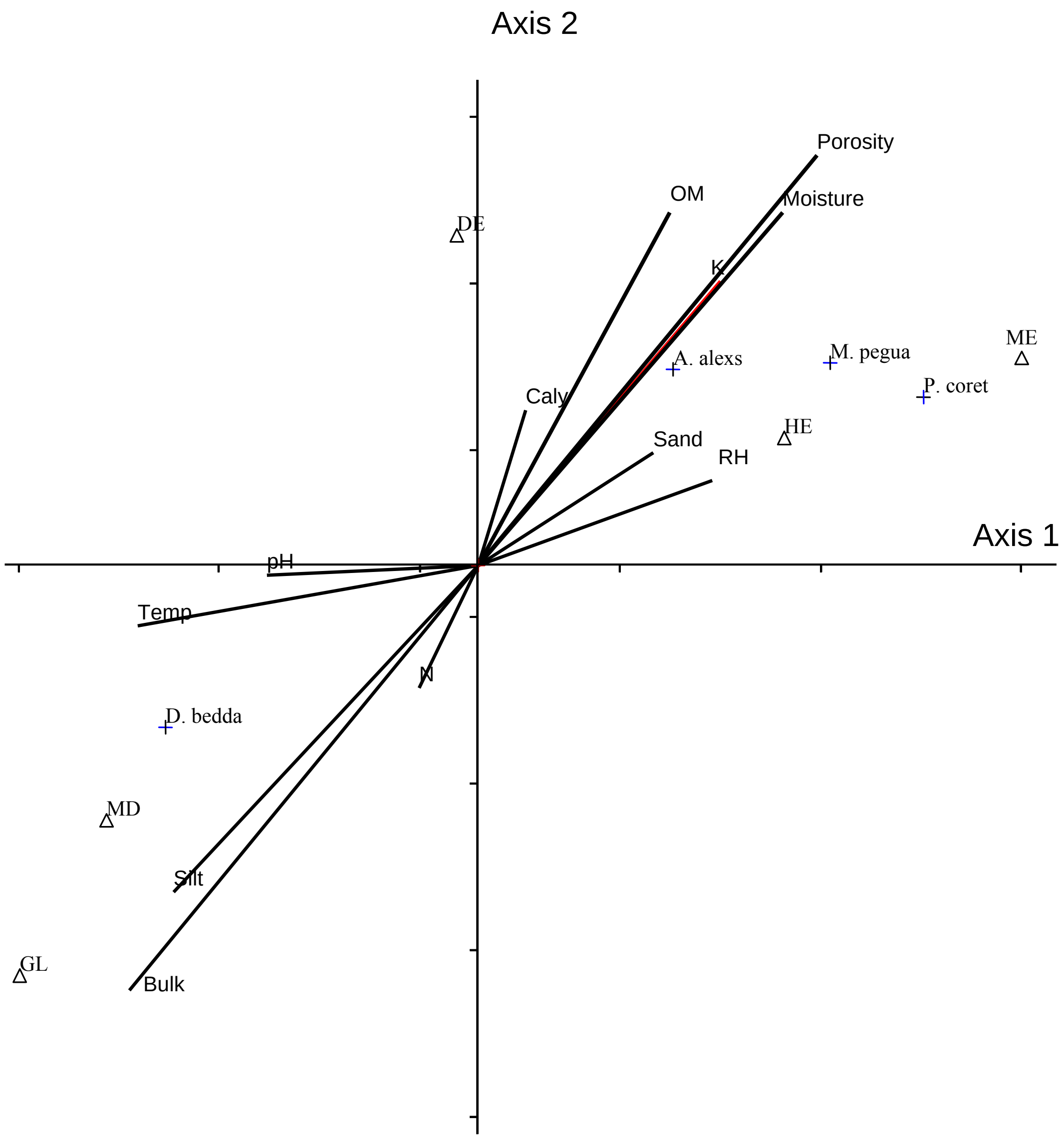

Figure 4.18 The joint plot diagram showing the relationship between a set of environmental factors and earthworm abundance. (A. alexs = *A. alexandri*, Bulk = bulk density, D. bedda = *Drawida beddardi*, DE = dry evergreen forest, GL = grassland, HE = hill evergreen forest, K = potassium, M. pegua = *Metaphire peguana*, MD = mix deciduous forest, ME = moist evergreen forest, N = nitrogen, OM = organic matter, P. coret = *Pontoscolex corethrurus*, pH = acidity, RH = relative humidity, and Temp = temperature)

earthworm community and environmental factors. The length and angle of the line indicated the direction and strength of the relationship. The Pearson and Kendall correlation with ordination axes was shown in Table 4.8.

On axis 1, bulk density, temperature, porosity, soil moisture and silt were the most significant factors determining in earthworm composition (rule 2 of significance of PCA loadings, r > 0.71 or r < -0.71, (McGarigal, Cushman, and Stafford, 2000)), followed by potassium, relative humidity, soil pH and organic matter (r > 0.63 or r < -0.63). On axis 2, bulk density, porosity, soil moisture, organic matter, silt and potassium were the most significant factors. On axis 3, phosphorus and nitrogen were the most significant factors.

The result of joint plot diagram in Figure 4.18 and Table 4.8 could be explained as follows:

The PCA axis 1, MD was positively correlated with relative humidity and negatively with bulk density, silt and pH. DE was positively correlated with porosity, soil moisture, potassium and organic matter and negatively correlated with temperature and soil pH. ME was positively correlated with porosity, soil moisture, potassium, relative humidity and organic matter and negatively correlated with temperature. HE was positively correlated with porosity, potassium, relative humidity and organic matter and negatively correlated with silt. GL was positively correlated with potassium and negatively correlated with bulk density, temperature, silt and soil pH.

The PCA axis 2, MD was negatively correlated with bulk density and silt. DE and ME were positively correlated with porosity, soil moisture, organic matter and potassium. HE was positively correlated with porosity, organic matter and potassium and negatively correlated with silt. GL was positively correlated with potassium and negatively correlated with bulk density and silt.

Table 4.8 The Pearson and Kendall correlation with ordination axis.

Factors	Axis					
	1		2		3	
	r	r-sq	r	r-sq	r	r-sq
Nitrogen	-.341	.116	-.495	.245	.772	.597
Phosphorus	.083	.007	.044	.002	.844	.713
Potassium	.695	.484	.754	.568	.226	.051
Bulk density	-.834	.696	-.921	.848	.006	.000
Porosity	.822	.676	.905	.819	.003	.000
Sand	.592	.351	.475	.225	-.013	.000
Silt	-.779	.607	-.809	.655	-.294	.086
Clay	.306	.094	.558	.311	.519	.269
Organic matter	.618	.381	.840	.705	.059	.003
Soil moisture	.779	.607	.841	.706	.374	.140
Litter	.409	.167	.271	.074	-.234	.055
Temperature	-.824	.679	-.346	.120	.282	.080
pH	-.648	.420	-.146	.021	.388	.151
Relative humidity	.684	.468	.410	.169	-.382	.146

r = correlation coefficient

The PCA axis 3, DE was positively correlated with phosphorus. HE was positively correlated with nitrogen. GL was positively correlated with phosphorus and nitrogen.

The abundances of species with a sufficient sample size (> 50 observations, specific rule A of PCA; N = 20 + 3P, P = number of variables (McGarigal, Cushman, and Stafford, 2000)) were also used as a response variable in the analyses of earthworm numbers and environmental factors. *P. corethrurus* was highly related to ME and HE, therefore *P. corethrurus* was positively correlated with porosity, soil moisture, potassium, relative humidity and organic matter and negatively correlated with temperature and silt.

A. alexandri was highly related to DE, ME and HE, therefore *A. alexandri* was positively correlated with porosity, soil moisture, potassium, relative humidity and organic matter and negatively correlated with temperature, silt and soil pH.

M. peguana was highly related to ME and HE, therefore *M. peguana* was positively correlated with porosity, soil moisture, potassium, relative humidity and organic matter and negatively correlated with temperature and silt.

D. beddardi was highly related to GL, MD and DE, therefore *D. beddardi* was positively correlated with porosity, potassium, soil moisture, organic matter, relative humidity and negatively correlated with bulk density, temperature, silt and soil pH.

4.4 Stepwise multiple regression analysis of earthworm community structure

The effects of environmental factors (independent variable) on the number of earthworm (dependent variable) were tested via the multiple regression analysis. The regression equations were presented as follows:

	r	r^2	sig.
Y *P. corethrurus* = 231.832 – 65.158 pH + .3.559 Moisture + .036 N	.816	.665	.000
Y *A. alexandri* = -.5.507 + .194 Moisture + .18 Litter	.756	.572	.000
Y *D. beddardi* = -38.974 + .378 Temperature – .4 Litter + 4.74 pH + .171 RH	.773	.597	.000

As the results of stepwise multiple regression analysis, the relation between the earthworm community and environmental factors was between 57.2% - 66.5%. Soil pH was positively correlated with *D. beddardi* whereas negatively correlated with *P. corethrurus*. Soil moisture was positively correlated with *P. corethrurus* and *A. alexandri*. Litter was positively correlated with *A. alexandri* whereas negatively correlated with *D. beddardi.* Temperature and relative humidity were positively correlated with *D. beddardi*. Nitrogen positively correlated with *P. corethrurus*.

Soil pH is a factor that limits the species, numbers and distribution of earthworms that live in any particular soil. Some species are intolerant of acid soil conditions, whereas others thrive under acid conditions, and many species can tolerate a wide range of pH. Generally, the most species of earthworms prefer soils with a neutral pH (pH = 7.0) (Edwards and Bohlen, 1997). In Khao Yai National Park, soil pH was both significant positively correlated on *D. beddardi* and negatively correlated on *P. corethrurus.* Soil pH was significantly different between the five plant communities, but it alone could not explain the observed difference in earthworm abundance and diversity because it also varied between plant communities. *P. corethrurus* was found higher tolerant of acid soil (pH = 4.32) than other species (Lavelle, *et al.*, 1987). One explanation suggested for this was that *P. corethrurus* neutralized soil as it passes through their guts by secretions of the calciferous glands. A more probable explanation is that the soil was neutralized by secretions from the intestine and by excretion of ammonia, or that it is a combination of the two (Robinson, Ineson, Piearce, and Rowland, 1992). In the semi-arid tropical grassland in India, *Octochaetona phylloti* was significant positively correlated between pH and seasonal abundance of juvenile and young adult, but the population of adult earthworms was affected more by rainfall than by pH (Reddy and Pasha, 1993).

Soil moisture can influence the numbers of earthworms at any given location in Khao Yai National Park. Most earthworms were more active in moist soil than dry soil. When the moisture was low, these earthworms go into dormancy and even die under extreme drought conditions. When the soil moisture content increased 8-10%, surviving worms became active again (Lavelle, Douhalei, and Sow, 1974). *D. beddardi* was much more resistant to dehydration than other species in Khao Yai National Park, except *P. corethrurus* a species that inhabited soil with a wide range of moisture content (Dechaine, Ruan, de Leon, and Zou, 2004). The higher densities of earthworms were always found when the moisture content was between 20% and

30%, limits which were close to the optimum levels for most earthworm species (Lee, 1985). Also, the lower densities were found during November and December. Very low densities of earthworms in the upper layers were found after the rainfall periods (Alfaro and Borges, 1996).

Litter means all of organic matter include dead parts of plant such as leaves, flowers, fruits branches, barks and stems or living parts such as seeds and fresh leaves (Klinge, 1970). However, litter cover only small amount of the plant parts and leaves which accumulate as organic matter (Suriyapong. 2003). Litter on the forest floor was important as the source of the majority of the food and nesting habitat of earthworms (Edwards and Bohlen, 1997). Earthworm populations was often food-limited, but litter quality rather than it quantity most often limited earthworm populations (Raty and Huhta, 2004). A few studies have demonstrated a positive with leaf litter in the Puerto Rican rainforest. Liu and Zou (2002) found that by reducing earthworm number in tropical soils, decomposition rates on plant litter decreased.

Temperature and relative humidity was correlated with earthworm community. The activities of many earthworms were controlled by climatic factors such as temperature and relative humidity (Edwards and Bohlen, 1997). Temperature and moisture were usually inversely related and high surface temperatures and dry soils were much more limiting to earthworms than low temperatures and water logged soils (Nordstrom and Rundgren, 1974).

Nitrogen was often considered to be the critical factor limiting earthworms in many ecosystems, both temperate and tropical (Lee, 1985). Nitrogen content can be a useful indicator of food quality when comparing widely different litters but may be less useful as a predictor of earthworm performance on more palatable residues from deciduous trees (Curry, Byrne, and Boyle, 1995).

CHAPTER V

CONCLUSION

1. Conclusion

Earthworm samplings were conducted in Khao Yai National Park during July-December 2002 and June-December 2003. The sampling areas were selected from different forest types: mix deciduous forest (MD), dry evergreen forest (DE), moist evergreen forest (ME), hill evergreen forest (HE) and grassland (GL). The objective of this research was to investigate species diversity of earthworms and relationships between earthworm species and environmental factors in the sampling areas.

A total of thirteen species of earthworms found in this study belongs to family Glossoscolecidae, Megascolecidae and Moniligastridae. Earthworm ten species were found in the sampling areas i.e. *P. corethrurus*, *Amynthas alexandri*, *A. fucosus*, *Amynthas* sp.1, *Amynthas* sp.2, *Amynthas* sp.3, *Methaphire peguana*, *M. houlleti*, *Methaphire* sp.1 and *Drawida beddardi*, and three species were found outside the sampling areas i.e. *Perionyx excavatus*, *A. longicauliculatus* and *Pithemera bicincta*. The highest abundance species was *P. corethrurus* (61.5 ind/m^2) and the lowest was *M. houlleti* (0.3 ind/m^2). Three megascolecids i.e. *Amynthas* sp.1, *Amynthas* sp.2 and *Metaphire* sp.1 were supposed to be new species. *A. fucosus* was a new recorded species in Thailand. *Amynthas* sp.3 was classified to be *A. sieboldi* species group, using key of Sims and Easton (1972), however, it needs more investigation by earthworm taxonomists to confirm the identification.

The abundance of earthworm cocoon and adult composition was high during August to October whereas the juvenile earthworm composition was high during June to August. The abundance of earthworm species was highest in September 2002 (173.9 ind/m^2) and September 2003 (153.6 ind/m^2). Total abundance of earthworms in ME (93.2 ind/m^2) was the highest followed by HE (64.9 ind/m^2), DE (15.8 ind/m^2), GL (14.1 ind/m^2) and MD (11.1 ind/m^2), respectively. The earthworm density was also highest in ME (93.23 ind/m^2) and lowest in MD (6.65 ind/m^2).

The highest species diversity and species richness of earthworms were found in DE, while the highest evenness was found in DE and HE. The community structure of earthworms in Khao Yai National Park was significantly correlated with soil pH, soil moisture, litter, temperature, relative humidity and nitrogen.

2. Recommendation

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

REFERENCES

REFERENCES

Alfaro, M. and Borges, S. (1996). Ecological aspects of earthworms from Laguna Cartagena, Puerto Rico. **Caribbean Journal of Science**. 32(4): 406-412.

Anderson, J.M., Proctor, J. and Vallack, H.W. (1983). Ecological studies in four contrasting lowland rain forests in Gunung Mulu National Park, Sarawak III. Decomposition processes and nutrient loss from leaf litter. **Journal of Ecology**. 71: 503-527.

Atkin, L. and Proctor, J. (1988). Invertebrates in the litter and soil on Volcan Barva, Costa Rica**. Journal of Tropical Ecology**. 4:307-310.

Baker, G.M. *et al*. (1993). Seasonal changes in the abundance of earthworms (Lumbricidae and Acanthodrilidae) in soils used for cereal and lucerne production in South Australia. **Transactions of the Royal Society of South Australia**. 177(1-2): 47-53.

Baltzer, R. (1956). Die regenwurmer westfalens. Eine tiergeographische, okologische und sinnesphysiologische untersuchung. **Zoologische Jahrbuecher Systematic**. 85: 355-414. Quoted in C.A. Edwards and P.J. Bohlen. 1996. **Biology and Ecology of Earthworms**. London: Chapman & Hall.

Beddard, F.E. (1895). **A monograph of the order Oligochaeta**. Oxford: Clarendon.

Beddard, F.E. (1900). A revision of the earthworms of the genus *Amynthas* (*Perichaeta*). **Proceedings of the Zoological Society of London**. 1900: 609-652.

Bhadauria, T., Ramakrishnan, P.S., and Srivastava, K.N. (2000). Diversity and distribution of endemic and exotic earthworms in natural and regenerating ecosystems in the central Himalayas, India. **Soil Biology and Biochemistry**. 32: 2045-2054.

Bhattacharjee, G. and Chaudhuri, P.S. (2002). Cocoon production, morphology, hatching pattern and fecundity in seven tropical earthworm species-a laboratory -based investigation. **Journal of Biosciences**. 27(3): 283-294.

Blakemore, R.J. (2003). Japanese earthworms (Annelida: Oligochaeta): a review and checklist of species. **Organisms Diversity and Evolution**. 11: 1-43.

Bostrom, U. and Lofs-Holmin, A. (1986). Growth of earthworms (*Allolobophora caliginosa*) fed on shoots and roots of barley, meadow fescue, and lucerne: studies in relation to particle size, protein, crude fiber and toxicity. **Pedobiologia**. 29: 1-12.

Bouche, M.B. (1971). Relations entre les structures spatiales et fonctionelles des ecosystems, illustrees par le role pedobiologique des vers de terre, in **La Vie dans les Sols, Aspects Nouveaux, Etudes Experimentales**, (ed. P. Pesson), Paris: Gauthier Villars. Quoted in C.A. Edwards and P.J. Bohlen. 1996. **Biology and Ecology of Earthworms**. London: Chapman & Hall.

Bouche, M.B. (1972). **Lombriciens de france. Ecologie et Systematique**. Instiue National de la Recherche Agronomique. Paris. Quoted in C.A. Edwards and P.J. Bohlen. 1996. **Biology and Ecology of Earthworms**. London: Chapman & Hall.

Bouche, M.B. (1977). Strategies lombriciennes, in soil organisms as components of ecosystems. **Ecological Bulletin**. 25: 122-132. Quoted in C.A. Edwards and P.J. Bohlen. 1996. **Biology and Ecology of Earthworms**. London: Chapman & Hall.

Boyd, J.M. (1957). The ecological distribution of the Lumbricidae in the Hebrides. **Proceedings of the Royal Society of Edinburgh**. 66: 311-338. Quoted in C.A. Edwards and P.J. Bohlen. 1996. **Biology and Ecology of Earthworms**. London: Chapman & Hall.

Boyd, J.M. (1958). The ecology of earthworms in cattle-grazed machair in Tiree, Argyll. **Journal of Animal Ecology**. 27: 147-157. Quoted in C.A. Edwards and P.J. Bohlen. 1996. **Biology and Ecology of Earthworms**. London: Chapman & Hall.

Briones, M.J.I., Mascato, R., and Mato, S. (1992). Relationships of earthworms with environmental factors studied by means of detrended canonical analysis. **Acta Oecologica.** 13: 617-626.

Brown, G.G., Benito, N.P., Pasini, A., Sautter, K.D., Guimaraes, M.de F. and Torres, E. (2003). No-tillage greatly increases earthworm populations in Parana state, Brazil. **Pedobiologia**. 47: 1-8.

Butt, K. (1991). The effects of temperature on the intensive production of *Lumbricus terrestris* (Oligochaeta: Lumbricidae). **Pedobiologia**. 35: 257-264.

Carter, M.R. (1993). **Soil Sampling and Methods of Analysis**. London: Lewis Publishers.

Chen, Y. (1930). On some new earthworms from Nanking. **China Science Report, National Central University, Nanking**. 1: 11-37.

Chen, Y. (1931). On the terrestrial Oligochaeta from Szechuan with description of some new forms. **Contributions from the Biological Laboratory of the Science Society of China (Zoology).** 7: 117-171.

Chen, Y. (1933). A preliminary survey of the earthworms of the Lower Yangtze valley.

Contributions from the Biological Laboratory of the Science Society of China (Zoology). 9: 178-296.

Chen, Y. (1935). On two new species of Oligochaeta from Amoy (*Pheretima Wui* sp. n. and *Howascolex sinicus* sp. n.). **Contributions from the Biological Laboratory of the Science Society of China (Zoology)**. 11: 109-122.

Chen, Y. (1936). On tertestrial Oligochaeta from Szechuan II with the notes on Gates' types. **Contributions from the Biological Laboratory of the Science Society of China (Zoology)**. 11: 269-306.

Chen, Y. (1938). Oligochaeta from Hainan, Kwangtung. **Contributions from the Biological Laboratory of the Science Society of China (Zoology)**. 12: 375-427.

Chen,Y., Hsu, C.F., Yang, T., and Fong, H.Y. (1975). On some new earthworms from China. **Acta Zootaxonomica Sinica**. 21: 89-99.

Collins, P.T. (1992). Length-biomass relationships for terrestrial Gastropoda and Oligochaeta. **American Midland Naturalist**. 128(2): 404-406.

Cook, A.G., *et al.* (1980). Effects of cultivation and DDT on earthworm activity in a forest soil in the sub-humid tropics. **Journal of Applied Ecology**. 17: 21-29.

Curry, J.P. Byrne, D., and Boyle, K.E. (1995). The earthworm population of a winter cereal field and its effects on soil and nitrogen turnover. **Biology and Fertility of Soils**. 19: 166-172.

Dajoz, R. (2000). **Insect and forests: The role and diversity of insects in the forest environment**. Translated by G.M. de Rougemont. Paris: intercept.

Daughberger, P. (1988). Temperature and moisture preference of three earthworm species (Oligochaeta: Lumbricidae). **Pedobiologia**. 32: 57-64.

Day, P.R. (1965). Particle fractionation and particle-size analysis. Quoted in C.A. Black (Ed.) (1965). **Methods of Soil Analysis**. Wisconsin: Madison**.**

de Leon, Y.S. and Zou, X. (2004). Plant influences on native and exotic earthworms during secondary succession in old tropical pastures. **Pedobiologia**. 48(3): 215-226.

Dechaine, J., Ruan, H., de Leon, Y.S., and Zou, X. (2004). Correlation between earthworms and plant litter decomposition in a tropical wet forest of Puerto Rico. **Pedobiologia**. 49: 601-607.

Easton, E.G. (1980). Japanese earthworms: a synopsis of the Megadrile species (Oligochaeta). **Bulletin of the British Museum Natural History (Zoology)**. 40: 33-65.

Edward, C.A. (1998). **Earthworm Ecology**. London: CRC Press.

Edwards, C.A., and Bohlen, P.J. (1996). **Biology and Ecology of Earthworms**. London: Chapman & Hall.

Edwards, C.A., Dooming, J., and Neuhauser, E.F. (1998). Growth and reproduction of *Perionyx excavatus* (Perr.) (Megascolecidae) as factors in organic waste management. **Biology and Fertility of Soils**. 27(2): 155-161.

El-Duweini, A.K. and Ghabbour, S.I. (1965). Population density and biomass of earthworms in different types of Egyptian soils. **Journal of Applied Ecology**. 2: 271-287. Quoted in C.A. Edwards and P.J. Bohlen. 1996. **Biology and Ecology of Earthworms**. London: Chapman & Hall.

Evans, A.C. and Guild, W.J.Mc.L. (1948). Studies on the relationship between earthworms and soil fertility. IV. On the life cycles of some British Lumbricidae. **Annual Applied Biology**. 35: 471-484. Quoted in C.A. Edwards and P.J. Bohlen.

1996. **Biology and Ecology of Earthworms**. London: Chapman & Hall.

Fragoso, C. and Lavelle, P. (1992). Earthworm communities of tropical rain forests. **Soil Biology and Biochemistry**. 24: 1397-1408.

Fragoso, C., Kanyonyo, J.K., Lavelle, P. and Moreno, A. (1992). A survey of communities and selected species of earthworms for their potential use in low-input tropical agricultural systems. **CCF Project TS2-0292-F(E)B Report**. 7-34.

Gajaseni, J. (1976). **An ecological study on population, biomass and species composition of soil fauna in dry evergreen forest, Sakaerat Nakhon ratchasima**. MS thesis, Chulalongkorn University, Thailand.

Gates, G.E. (1925). Notes on Rosa's Rangoon earthworms, *Pheretima peguana* and *Eutyphoeus foveatus*. **Annual Magazine of National History**. 16: 566-577.

Gates, G.E. (1926). Notes on earthworms from Various Places in the province of Burma, with descriptions of two new species. **Records of the Indian Museum**. 28: 141-170.

Gates, G.E. (1930). The earthworms of Burma I. **Records of the Indian Museum**. 32: 257-356.

Gates, G.E. (1931). The earthworms of Burma II. **Records of the Indian Museum**. 33: 357-442.

Gates, G.E. (1933). The earthworms of Burma. IV. **Records of the Indian Museum**. 35: 413-606.

Gates, G.E. (1935). On some Chinese earthworms. **Lingnan Science Jornual**. 14: 445-458.

Gates, G.E. (1936). The earthworms of Burma.V. **Records of the Indian Museum**.

36: 377-468.

Gates, G.E. (1937). Indian earthworm. I. The genus *Pheretima*. **Records of the Indian Museum**. 39: 175-212.

Gates, G.E. (1939a). On some species of Chinese earthworms, with special reference to specimens collected in Szechwan by Dr. D.C. Graham. **Proceeding of the United States National Museum**. 85: 405-507

Gates, G.E. (1939b). Thai earthworms. **Journal of the Thailand Research Society of National History Supply**. 12(1): 65-114.

Gates, G.E. (1942). Notes on Various Peregrine Earthworms. **Bulletin of the Museum of Comparative Zoology at Harvard College**. 89: 63-144.

Gates, G.E. (1955). The earthworms of Burma VI. **Records of the Indian Museum.** 52: 55-93.

Gates, G.E. (1959). On some earthworms from Taiwan. **American Museum Novitates**. 1941: 1-19.

Gates, G.E. (1960). On Burmese earthworms of the family Megascolecidae. **Bulletin of the Museum of Comparative Zoology at Harvard College**. 123: 203-282.

Gates, G.E. (1961). Ecology of some earthworms with special reference to seasonal activity. **American Midland Naturalist**. 66: 61-86.

Gates, G.E. (1962). On some Burmese Earthworms of the Moniligastrid genus *Drawida*. **Bulletin of the Museum of Comparative Zoology at Harvard College**. 127: 297-373.

Gates, G.E. (1970). On some New Guinea earthworms. **Australian Zoologist**. 15: 386-390.

Gates, G.E. (1972). Burmese earthworms: an introduction to the systematics and biology of megadrile oligochaetes with special reference to Southeast Asia. **Transactions of the American Philosophical Society**. 62: 1-326.

Gerard, B.M. (1967). Factors affecting earthworms in pastures. **Journal of Animal Ecology**. 36: 235-252.

Gonzalez, G., Zou, X., Sabat, A. and Fetcher, N. (1999). Earthworm abundance and distribution pattern in contrasting plant communities within a tropical wet forest. **Caribbean Journal Science**. 35: 93-100.

Graff, O. (1953) Investigation in soil zoology with special reference to the terricole Oligochaeta. **Braunschweig**. 61: 72-77. Quoted in C.A. Edwards and P.J. Bohlen. 1996. **Biology and Ecology of Earthworms**. London: Chapman & Hall.

Grant, W.C. (1955). Temperature relationships in the megascolecid earthworm, *Pheretima hupeiensis*. **Ecology**. 36(3): 412-417. Quoted in C.A. Edwards and P.J. Bohlen. 1996. **Biology and Ecology of Earthworms**. London: Chapman & Hall.

Guild, W.J.Mc.L. (1948). Effect of soil type on populations. **Annual Applied Biology**. 35(2): 181-192. Quoted in C.A. Edwards and P.J. Bohlen. 1996. **Biology and Ecology of Earthworms**. London: Chapman & Hall.

Guild, W.J.Mc.L. (1951). The distribution and population density of earthworms (Lumbricidae) in Scottish pasture fields. **Journal of Animal Ecology**. 20(1): 88-97. Quoted in C.A. Edwards and P.J. Bohlen. 1996. **Biology and Ecology of Earthworms**. London: Chapman & Hall.

Guild, W.J.Mc. L. (1952). The Lumbricidae in upland areas. II. Population variation on hill pasture. **Annual Magazine of National History**. 12(5): 286-292.

Quoted in C.A. Edwards and P.J. Bohlen. 1996. **Biology and Ecology of Earthworms**. London: Chapman & Hall.

Guild, W.J.Mc. L. (1955). Earthworms and soil structure. **Soil Zoology**. (ed. D.K.Mc.E. Kevan). London: Butterworths. Quoted in C.A. Edwards and P.J. Bohlen. 1996. **Biology and Ecology of Earthworms**. London: Chapman & Hall.

Hatai, S. (1930a). On *Drawida hattamimizu* sp. nov. **Science Reports of Tohoku University**. 5: 485-508.

Hatai, S. (1930b). Note on *Pheretima agrestis* (Goto and Hatai), together with the description of four new species of the genus *Pheretima*. **Science Reports of Tohoku University**. 5: 651-667.

Hatai, S., and Ohfuchi, S. (1936). Description of one new species of the genus *Pheretima*. **Science Reports of Tohoku University**. 10: 767-772.

Hatai, S., and Ohfuchi, S. (1937). On one new species of earthworm belonging to the genus *Pheretima* from northeastern Honshu, Japan. **Research Bulletin Saito Ho-on Kai Museum**. 12: 1-11.

Hendriksen, N.B. (1990). Leaf litter selection by detritivore and geophagous earthworms. **Biology and Fertility of Soils**. 10: 17-21.

Hendrix, P.J., Mueller, B.R., Bruce, R.R., Langdale, G.W., and Parmelee, R.W. (1992). Abundance and distribution of earthworms in relation to landscape factors on the Georgia Piedmont, U.S.A. **Soil Biology and Biochemistry**. 24: 1357-1361.

Hong, Y. and James, S.W. (2001).Five new earthworms of the genus *Amynthas* Kinberg (Megascolecidae) with four pairs of spermathecae. **Zoological**

Studies. 40(4): 269-275.

Hong, Y., Lee, W.K., and Kim, T.H. (2001). Four new species of the Genus *Amynthas* Kinberg (Oligochateta: Megascolecidae) from Korea. **Zoological Studies**. 40(4): 263-268.

Hoogerkamp, M., Rogaar, H., and Eijsackers, H.J.P. (1983). Effect of earthworms on grassland on recently reclaimed polder soils in the Netherlands, **Earthworm Ecology, from Darwin to Vermiculture**. (ed. J.E. Satchell). London: Chapman& Hall. Quoted in C.A. Edwards and P.J. Bohlen.1996. **Biology and Ecology of Earthworms**. London: Chapman & Hall.

Ishizuka, K. (1999). A review of the genus *Pheretima* s. lat. (Megascolecidae) from Japan. **Edaphologia**. 62: 55-80.

James, S.W., Shih, H.T., and Chang, H.W. (2005). Seven new species of *Amynthas* (Clitellata: Megascolecidae) and new earthworm records from Taiwan. **Journal of National History**. 39(14): 1007-1028.

Jamieson, B.G.M. (1972). A new species of *Digaster* (Megascolecidae: Oligochaeta) from Queensland. **Memoria of the Queensland Museum**. 16: 261-264.

Jamieson, B.G.M. (1974). Earthworms (Oligochaeta: Megascolecidae) from South Australia. **Transaction of the Royal Society of South Australia**. 98: 79-112.

Jamieson, B.G.M. (1988). On the phylogeny and higher classification of the Oligochaeta. **Cladistics**. 4(4): 367-401.

Jamieson, B.G.M. (1992). **Oligochaeta, in Microscopic Anatomy of Invertebrates**. New York: Alan R. Liss.

Jamieson, B.G.M. (1994). Some earthworms from the wet tropics and from Bunya mountains, Queensland (Megascolecidae: Oligochaeta). **Memoria of the**

Queensland Museum. 37(1): 157-181.

Jamieson, B.G.M. (1997). Some new and previously known earthworm species from Cape York Peninsula (Annelida: Oligochaeta: Megascolecidae). **Memoria of the Queensland Museum**. 42(1): 233-270.

Jamieson, B.G.M. and Bradbury, E.A. (1972). Investigation of the Australian earthworm genus *Didymogaster* (Megascolecidae: Oligochaeta) and discrimination of populations by analysis of setal rations. **Pedobiologia**. 12: 111-122.

Jamieson, B.G.M. and Wampler, J.E. (1979). Bioluminescent Australian earthworms II. Taxonomy and preliminary report of bioluminescence in the genera *Spenceriella*, *Fletcherodrilus* and *Pontodrilus* (Megascolecidae: Oligochaeta). **Australian Journal of Zoology**. 27: 637-669.

Knapp, A. K. and Seastedt, T. R. (1986). Detritus accumulation limits productivity of a tallgrass prairie. **Biological Science**. 36: 662-668.

Kaushal, B.R. and Bisht, S.P.S. (1994). Population dynamics of the earthworm *Amynthas alexandri* (Annelida: Megascolecidae) in a Kumaun, Himalayan Pasture soil. **Biology and Fertility of Soils**. 17(1): 9-13.

Kimmins, J.P. (1997). **Forest Ecology: A Foundation for Sustainable Management**. New Jersey: Prentice-Hall.

Kinberg, J.G.H. (1867). Annulata nova. **Ofvesigt at Kongliga Vetenskaps Akademiens Förhandlingar, Stockholm**. 23: 97-103.

Klinge, R. (1970). Fine litter production and nutrient return to the soil in three natural forest stands of Eastern Amazonia. **Revue International, d' Ecologie et de Geographie Tropicale**. 1: 159-167.

Kobayashi, S. (1934). Three new Korean earthworms belonging to the genus *Pheretima*, together with the wider range of the distribution of *Phereima hilgendorfi* (Michaelsen). **Journal of the Chosen Natural History Society.** 19: 1-11.

Kobayashi, S. (1936). Earthworms from Koryo, Korea. **Science Report of the Tohoku University**. 1: 140-184.

Kobayashi, S. (1938a). Earthworms of Korea I. **Science Report of the Tohoku University**. 13: 89-170.

Kobayashi, S. (1938b). Earthworms found in Hsinchu, Taiwan II**. Zoological Magazine (Japan)**. 51: 777-779.

Kobayashi, S. (1941). The distribution of Oligochaeta in western Japan. **Zoological Magazine (Japan)**. 53: 371-384.

Krebs, C.J. (1985). **Ecology: The Experimental Analysis of Distribution and Abundance**. New York: Harper and Row.

Krebs, C.J. (1989). **Ecological methodology**. New York: Harper & Row.

Lavelle, P., Barois, I., Cruz, I., Fragoso, C., Hernandez, A., Pineda, A., and Rangel, P. (1987). Adaptive strategies of *Pontoscolex corethrurus* (Glossoscolecidae, Oligochaeta), a peregrine geophagous earthworm of the humid tropics. **Biology and Fertility of Soils**. 5: 188 – 194.

Lavelle, P., Douhalei, N., and Sow, B. (1974). influence de I' humidité du sol sur la condommation croissance de *Millsonia anomala* (Oligochaetes-Acanthrodilidae) dans la Savanne de Lamto. **Annales de I' Universite' d' Abidjan**. 7(1): 305-314. Quoted in C.A. Edwards and P.J. Bohlen. 1996. **Biology and Ecology of Earthworms**. London: Chapman & Hall.

Lavelle, P., Melendez, G., Pashanashi, B., and Schaefer, R. (1992). Nitrogen mineralization and reorganization in casts of the geophagous tropical earthworm *Pontoscolex corethrurus* (Glossoscolecidae). **Biology and Fertility of Soils**. 14: 49-53.

Laverack, M.S. (1961). Tactile and chemical perception in earthworms II. Responses to acid pH solutions. **Comparative Biochemistry and Physiology**. 2(1): 22-34. Quoted in C.A. Edwards and P.J. Bohlen.1996. **Biology and Ecology of Earthworms**. London: Chapman & Hall.

Leaky, R.J.G. and Proctor, J. (1987). Invertebrates in the litter and soil at a range of altitudes on Gunug Silam. **Journal of Tropical Ecology**. 3: 119-129.

Lee, K.E. (1959). A key for the identification of New Zealand earthworms. **Tuatara**. 8(1): 13-60. Quoted in C.A. Edwards and P.J. Bohlen. 1996. **Biology and Ecology of Earthworms**. London: Chapman & Hall.

Lee, K.E. (1985). Earthworms: Their ecology and relationships with soils and land use. Sydney: Academic Press. Quoted in C.A. Edwards and P.J. Bohlen. 1996. **Biology and Ecology of Earthworms**. London: Chapman & Hall.

Liu, Z.G. and Zou, X.M. (2002) Exotic earthworms accelerate plant litter decomposition in a tropical pasture and a wet forest of Puerto Rico. **Ecological Applications**. 12: 1406-1417.

Ljungstrom, P.O., Orellana, J.A. de, and Priano, L.J.J. (1973). Influence of some edaphic factors on earthworm distribution in Sante Fe Province, Argentina. **Pedobiologia**. 13: 236-247.

Lowe, C.N. and Butt, K.R. (2003) influence of food particle size on inter-and intra-specific interactions of *Allolobophora chlorotica* (Savigny) and *Lumbricus* *terrestris*(L.). **Pedobiologia**. 47(6): 574-577.

Madge, D.S. (1969). Field and laboratory studies on the activities of two species of tropical earthworms. **Pedobiologia**. 9: 188-214. Quoted in C.A. Edwards and P.J. Bohlen. 1996. **Biology and Ecology of Earthworms**. London: Chapman & Hall.

McCredie, T.A., Parker, C.A., and Abbott, I. (1992). Population dynamics of the earthworm *Aporrectodea trapezoides* in a Western Australian pasture. **Biology and Fertility of Soils**. 12(4): 285-289.

McGarigal, K., Cushman, S., and Stafford, S. (2000). **Multivariate Statistics for Wildlife and Ecology Research**. New York: Springer-Verlag New York.

Mele, P.M. and Carter, M.R. (1999). Impact of crop management factors in conservation tillage farming on earthworm density, age structure and species abundance in south-eastern Australia. **Soil and Tillage Research**. 50: 1-10.

Michon, J. (1954). Influence de I'isolement a partir de la maturite sexuelle sur la biologie des Lumbricidae. **Comptes Rendus Hebdomadaire des Seancesde l' Academic des Sciences, Paris**. 2457-2458. Quoted in C.A. Edwards and P.J. Bohlen. 1996. **Biology and Ecology of Earthworms**. London: Chapman & Hall.

Michaelsen, W. (1899). Terricolen von verschiedenen Gebieten der Erde. **Jahrbuch der Hamburgischen wissenschaftlichen Anstalten**. 16: 1-122.

Michaelsen, W. (1900). Oligochaeta. **Das Tierreich**. 10: 1-575.

Michaelsen, W. (1909). The Oligochaeta of India, Nepal, Ceylon, Burma and the Andaman Islands. **Memoria of Indian Museum**. 1: 103-253.

Michaelsen, W. (1928). Oligochaeta. **Handbuchder Zoologie**. Berlin: Walter de Gruyter.

Michaelsen, W. (1934). Oligochaeta from Sarawak. **Quarterly Journal of Microscopical Science**. 77: 1-47.

Miller, S.A. and Harley, J.B. (1999). **Zoology** (4th ed). Boston: Mc Graw-Hill.

Nakamura, Y. (1968). Population density and biomass of the terrestrial earthworm in the grasslands of three different soil types near Sapporo. **Japanese Journal of Applied Entonology Zoology**. 11: 164-168.

National Park Division. (1987). **Khao Yai National Park Management Plan 1987 - 1991**. Royal Forest Department, Ministry of Agriculture and Cooperatives.

Nordstrom, S. and Rundgren, S. (1974). Environmental factors and lumbricids associations in southern Sweden. **Pedobiologia**. 14: 1-27.

Ohfuchi, S. (1935). On some new species of earthworms from northeastern Hondo, Japan. **Science Report of the Tohoku University**. 10: 409-415.

Ohfuchi, S. (1937). Descriptions of three new species of the genus *Pheretima* from northeastern Honshu, Japan. **Research Bulletin Saito Ho-on Kai Museum**. 12: 13-29.

Ohfuchi, S. (1938). New species of earthworms from northeastern Honshu, Japan. **Research Bulletin Saito Ho-on Kai Museum**.15: 33-52.

Ohfuchi, S. (1941). The cavernicolous Oligochaeta of Japan. **Science Report of the Tohoku University**. 16: 243-256.

Ojima, D. S., Schimel, D. S., Parton W. J., and Owensby, C. E. (1994). Long- and short -term effects of fire on nitrogen cycling in tallgrass prairie. **Biogeochemistry**. 24: 67-84.

Okalebo, J.R., Gathua, K.W., and Woomer, P.L. (1993). Laboratory methods of soil and plant analysis. **Soil Science Society of East Africa (SSSEA) Technical**

publication. 1: 1-88.

Olson, H.W. (1928). The earthworms of Ohio. **Bulletin of Ohio Biological Survey**. 17: 47-90. Quoted in C.A. Edwards and P.J. Bohlen. 1996. **Biology and Ecology of Earthworms**. London: Chapman & Hall.

Park, C. (2001). **The Environment: Principle and Applications** (2nd ed.). London: Routledge.

Perrier, E. (1872). Recherches pour servir å I'histoire des *Lombricins terrestres*. **Nouvelles Archives Museum d' Histoire Naturelle Paris**. 8: 5-198.

Phoonjumpa, R. (2002). **Using ants as indicators of plant communities at Khao Yai National Park**. M.S. thesis, Chiang Mai University, Thailand.

Piearce, T.G. (1972). The calcium relations of selected Lumbricidae. **Journal of Animal Ecology**. 41: 167-188.

Piearce, T.G. (1978). Gut contents of some lumbricid earthworms. **Pedobiologia**. 18: 153-157.

Proctor, J. (1983). **Tropical rainforest: Ecology and management**. Oxford: Blackwell Scientific Publications.

Proctor, J. (1984). **Tropical rainforest: The Leeds symposium**. Leeds: Leeds Philosophical Natural History Society.

Rambke, J. and Verhaagh, M. (1992). About the earthworm community in recently developed pasture, in comparison with a rain forest site in Peru. **Amazoniana**. 12(1): 29-49.

Raty, M. and Huhta, V. (2004). Earthworm communities in birch stands with different origin in central Finland. **Pedobiologia**. 48(3): 283-291.

Reddy, M.V. and Pasha, M. (1993). Influence of rainfall, temperature and some soil physiochemical variables on seasonal population structure and vertical distribution of earthworms in two semi- and tropical grassland soils. **International Journal of Biotechnology**. 37: 19-26.

Reynolds, J. W. (1994). The status of exotic earthworm systematics and biogeography in North America. In P. F. Hendrix (ed.). **Ecology and biogeography of earthworms in North America** (pp 1-27). Florida: Lewis Publishing.

Reynolds, J. W. and D. G. Cook. 1993. **Nomenclatura Oligochaetologica. Supplementum Tertium. A Catalogue of Names, Descriptions and Type Specimens of the Oligochaeta**. Canada: New Brunswick Mus. Monogr.

Rhee, J.A. van. (1969a). Inoculation of earthworms in newly-drained polder. **Pedobiologia**. 9: 128-132.

Rhee, J.A. van. (1969b). Development of earthworm populations in polder soils. **Pedobiologia**. 9: 133-140.

Richardson, H.C. (1938). The nitrogen cycle in grassland soils: with special reference to the Rothamsted Park grass experiment. **Journal of Agricultural Science of Cambridge**. 28: 73-121. Quoted in C.A. Edwards and P.J. Bohlen. 1996. **Biology and Ecology of Earthworms**. London: Chapman & Hall.

Robinson, C. H., Ineson, P., Piearce, T. G., and Rowland, A. P. (1992). Nitrogen mobilization by earthworms in limed peat soils under *Picea sitchensis*. **Journal of Applied Ecology**. 29: 226-237.

Rosa, D. (1890). Viaggio di Leonarda Fea in Birmania e Regionivicini. XXV. Moniligastridi, Geoscolecidi de Eudrilidi. **Annali di Museo Civico Di Storia Naturale de Genova**. 29: 368-400.

Rosa, D. (1891). Die exotoschen Terricolen des k.k. naturistorischen Hofmuseums.

Annalen des Naturhistorischen Hofmuseums. **Wien**. 8: 379-406.

Satchell, J.E. (1955). Some aspects of earthworm ecology. **Soil Zoology** (ed. D.K. Mc.E. Kevan). London: Butterworths. Quoted in C.A. Edwards and P.J. Bohlen. 1996. **Biology and Ecology of Earthworms**. London: Chapman & Hall.

Satchell, J.E.(1969). Studies on methodical and taxonomical questions. **Pedobiologia.** 9: 20-25.

Schinner,F. Ohlinger, R., Kandeler, E., and Margesin, R. (1995). **Methods in Soil Biology**. Germany: Springer-Verlag Berlin Heidelberg 1995.

Shen, H.P. and Tsai, C.F. (2002). Earthworm fauna of the Lanyu island (Botel Tabago). **Taiwan Endemic Species Research**. 4(2): 1-8.

Shen, H.P., Tsai, S.C., and Tsai, C.F. (2005). Occurrence of the earthworms *Pontodrilus litoralis* (Grube, 1855), *Metaphire houlleti* (Perrier, 1872), and *Eiseniella tetraedra* (Savigny, 1826) from Taiwan. **Taiwania**. 50(1): 11-21.

Shih, H.T., Chang, H.W., and Chen, J.H. (1999). A review of the earthworms (Annelida: Oligochaeta) from Taiwan. **Zoological Studies**. 38: 435-442.

Sims, R.W. and Easton, E.G. (1972). A numerical revision of the earthworm genus *Pheretima* (Megascolecidae: Oligochaeta) with the recognition of new genera and an appendix on the earthworms collected by the Royal Society North Borneo Expedition. **Biological Journal of the Liennean Society**. 4: 169-268.

Sims, R.W. and Garard, B.M. (1985). Earthworms: synopses of British fauna. **National History Museum**. 31: 1-171.

Singh, L.A.K. (1999). **Tracking tigers: A pocket book for forest guards.** New Delhi.

Spiers, G.A., Gagnon, D., Nason, G.E., Packee, E.C., and Lousier, J.D. (1986). Effects and importance of indigenous earthworms on decomposition and nutrient cycling in coastal forest ecosystems. **Canadia Journal of Forest Research**. 16: 983-989.

Srikosamatara, S. and Hansel, T. (2000). **Mammals of Khao Yai National Park** (2nd ed.). Bangkok: Green World Foundation.

Stein, A., Bekker, R.M., Blom, J.H., and Rogaar, H. (1992). Spatial variability of earthworm populations in a permanent polder grassland. **Biology and Fertility of Soils**. 14(4): 260-266.

Stephenson, J. (1914). Zoological results of the arbor expedition. **Records of the Indian Museum**. 8: 365-410.

Stephenson, J. (1924). On some Indian Oligochaeta, with a description of two new genera of Ocnerodrilinae. **Records of the Indian Museum**. 26: 317-365.

Stephenson, J. (1925). On some Oligochaeta mainly from Assam, South India and the Andaman Island. **Records of the Indian Museum**. 27: 43-73.

Stephenson, J. (1929). The Oligochaeta of the Indawgyi lake (upper Burma). **Records of the Indian Museum**. 31: 225-239

Stephenson, J. (1930). **The Oligochaeta**. London: Oxford University Press. Quoted in C.A. Edwards and P.J. Bohlen. 1996. **Biology and Ecology of earthworms**. London: Chapman & Hall.

Stockdill, S.M.J. (1982). Effect of introduced earthworms on the productivity of New Zealand pastures. **Pedobiologia**. 24: 29-35.

Suriyapong, Y. (2003). **Study of ground dwelling and populations and their relationship to some ecological factors in Sakaerat Environmental**

Research Station, Nakhon Ratchasima. Ph.D. thesis, Suranari University and Technology, Thailand.

Thai, T.B. (1982). The fauna of earthworms of the Cucfuong Forest Reserve (Vietnamm) and descriptions of new species of the genus *Pheretima*. **Zoologicheskii Zhuranl**. 61(6): 820-830.

Thai, T.B. (1984). New data on taxonomy of the genus *Pheretima* (Oligochaeta, Megascolecidae) of the fauna of Vietnam. **Zoologicheskii Zhuranl**. 63(9): 1317-1327

Tsai, C.F., Shen, H.P., and Tsai, S.C. (2000). Native and exotic species of terrestrial earthworms (Oligochaeta) in Taiwan with reference to northeast Asia. **Zoological Studies**. 39(4): 285-294.

Tsai, C.F., Shen, H.P., and Tsai, S.C. (2001). Some new earthworms of the genus *Amynthas* (Oligochaeta: Megascolecidae) from Mt. Hohuan of Taiwan. **Zoological Studies**. 40(4): 276-288.

Tsai, C.F., Shen, H.P., and Tsai, S.C. (2002). A new athecate earthworm of the genus *Amynthas* Kinberg (Megascolecidae: Oligochaeta) from Taiwan With discussion on phylogeny and biogeography of the *A. illotus* species group. **Journal of Natural History**. 36: 757-765.

Tsai, C.F., Chen, J.H., Tsai, S.C., and Shen, H.P. (2003). A new species of the earthworm belonging to the genus *Metaphire* Sims and Easton (Megascolecidae: Oligochaeta) from the northeastern Taiwan. **Endemic Species Research**. 5: 83-88.

Tsai, C.-F., Tsai, S.C., and Shen, H.P. (2004). A new gigantic earthworm of the genus *Metaphire* Sims and Easton (Megascolecidae: Oligochaeta) from

Taiwan with reference to evolutional trends in body sizes and segment numbers of the *Pheretima* genus-group. **Journal of Natural History**. 38(7): 877-887.

Vesterdal, L. and Rasmussen, K.R. (1998). Forest floor chemistry under seven tree species along a soil fertility gradient. **Canadia Journal of Forest Research**. 28(11): 1636-1647.

Viljoen, S.A., Reinecke, A.J., and Hartman L. (1992). The influence of temperature on the life-cycle of *Dendrobaena veneta* (Oligochaeta). **Soil Biology and Biochemistry**. 24: 1341-1344.

Wachrinrat, C. (2000). **Community dynamic of building phase in fire and non-fire protected secondary dry dipterocarp forest, Nakhon Ratchasima**. Ph.D. dissertation, Kasertsart University, Thailand.

Wampler and Jamieson, 1986. Cell bound bioluminescence from *Pontodrilus bermuden* and its similarities to other earthworm bioluminescence. **Comparative Biochemistry and Physiology**. 84A: 81-87.

Werff, P.A. van der., Noordhuis, R., and Dekkers, Th. B.M. (1998). Introduction of earthworms into an organic arable farming system. **Appllied Soil Ecology**. 9: 311-317.

Whalen, J.K. and Costa, C. (2003). Linking spatio-temporal dynamics of earthworm populations to nutrient cycling in temperate agricultural and forest ecosystems. **Pedobiologia**. 47(6): 801-806.

White, E.M. and. Gartner, F.R. (1975). Immediate effects of prairie fire on the soil nitrate, ammonium, available phosphorous and total N content. **Proceedings of the South Dakota Academy of Science**. 54: 188-193.

Wongseenin, P. (1971). **Studies on soil and root fungi at Sakaerat forest**. M.S. thesis, Kasetsart University, Thailand.

APPENDICES

APPENDIX A

DEFINITIONS

DEINITIONS

Aclitellate	without a clitellum. Not necessarily confined to juvenile stages.
Adiverticulate	without diverticula of spermathecae
Agiceriate	without a gizzard.
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	without testes.
Anecic earthworms	Earthworms that live in permanent vertical burrows and are characterized by medium to heavy dorsal pigmentation, large size, long generation time, and a diet of surface litter.
Aprostatic	without prostates.
Asetal	without setae, as in the peristomium and pygomere.
Athecal	without spermathecae.
Atrium (plural atria)	a diverticulum of a spermatheca in two moniligastrid genera, *Drawida* and *Moniligaster*, in older contributions of Beddard, may mean a tubular prostate as in the Acanthodrilidae, Ocnerodrilidae, and Octochaetidae or a capsular prostate as in moniligastrids, also certain genital organs in microdriles.

Atyphlosolate	without a typhlosole.
Autochthonous	native or endemic.
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. Function is supposedly production of hemoglobin and of blood corpuscles.
Brown bodies	spheroidal, ellipsoidal or discoidal bodies, free in coelomic cavities, filled with corpuscles or brown debris along with setae and foreign bodies of various sorts such a cysts of parasites, nematodes and their ova.
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 secreted material to form a cocoon. Also used to describe the stage in a worm's growth during which it has a clitellum, when it is a more specific term than adult.
Copulatory chamber	an invagination, containing the male pore, that reaches through he body wall into the coelom.
Copulatory pouches	These structures which are sometimes known as bursae copulatrices,

	when present, form the ectal portion of the posterior male system. Often each is a simple pouch-like invagination of the ventral body-wall but secretory pads, secretory diverticula which are tubular (diverticulate’muscular’ glands), stalked glands, glandular papillae, apenis or even penial setae may be associated with it.
Copulatory setae or chaetae	Those in the same segment as, also near, spermathecae. Occasionally refers to similar setae in an adjacent but athecal segment.
Crop	a widened portion of the digestive system that lacks the muscularity of a gizzard. In the *Lumbricidae*, the crop is at beginning of the intestine and in front of the gizzard.
Genital tumescences	In the *Lumbricidae* areas of modified epidermis without distinct boundaries and through which follicles of genital setae open.
Gonad	gonadal, a testes, ovary, or an organ simultaneously or consecutively production 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 (sperm ducts, oviducts).
Holandric	a classical term that now means on more than, testes restricted to x-xi,or a homoerotic equivalent. Andric and gynous characterizations of the past have been applicable only to conditions of, or those derived by reduction from, a supposedly octogonadal megadrile ancestor with testes in x-xi and ovaries in xii-xiii.

Hologynous,	a classical term that now means only, ovaries restricted to xii and xiii or a homoerotic equivalent. Hologyny, the state or condition is being hologynous.
Hyperandric	having testes additional to those of x-xi.
Hypergynous	having ovaries additional to those of xii-xiii.
Intersegmental groove	a circumferential depression of strongly contracted specimens that contains the intersegmental furrow.
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 the hatching till appearance of seminal furrows or grooves, genital tumescences, markings and/or pores.
Latero-esophageal	with reference to the vascular system, a heart or other vessel joining the ventral trunk below the gut but bifurcating above the gut, with one branch to the supra-esophageal trunk, the other to the dorsal trunk.
Lumbricin	having 4 setae per segment.
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.
Meroic	divided, with reference to the excretory system, nephridial tubules formed by longitudinal or transverse fragmentation of the original single pair of each segment. Used in place of the classical meronephridial which involved tautologies such as meronephridial nephridia.

Manicate	glove-shaped, usually referring to an intestinal caecum of certain pheretimas in which the organ comprises several anteriorly directed secondary caeca.
Metagynous	metagyny, classical terms now meaning only, ovaries restricted to xiii or a homoerotic equivalent, the state of being such.
Metandric	metandry, classical terms now meaning only, testes restricted to xi, the state of being such.
Metagynous	having ovaries only in xiii or a homoerotic equivalent.
Microic	smaller than macroic, substituting for the classical micronephridial, a term often applied to nephridia as large as, or even larger than meganephridia.
Monothecal	having only one spermatheca.
Octoprostatic	having 8 prostates.
Octothecal	having 8 spermathecae.
Peregrine	exotic or foreign.
Peristomium	anteriormost portion of the body, around the mouth and like the anus, lacking major characteristics of a segment though counted as one.
Polyandric	having testes in more segments than x-xi.
Polydiverticulate	with reference to spermathecae, having more than two diverticula.
Ployprostatic	having more than six prostates in three segments or more than eight in two segments.
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, oviduct or sperm duct.
Proandric	proandry, classical terms that now mean only, testes restricted to x or a homoerotic equivalent, the state of being such.
Prolobic	prolobous, characterizing a prostomium demarcated from and without a tongue in first segment.
Prostate	glands associated with the male ducts, usually tubular, opening beside the male pores in acanthodrilid, octochaetid and ocnerodrilid worms.
Prostomium	a lobe-like appendage attached to the dorsal aspect of the peristomium.
Quadriprostatic	with four prostate glands.
Quadrithecal	with four spermathecae.
Racemose	applied to prostates when those organs are divided into many lobes.
Seminal grooves	permanent longitudinal grooves on the ventral surface of an earthworm associated with the male and prostatic pores which form a passage for seminal and other fluids.
Seminal vesicles	septal pockets in which spermatozoa mature.
Seta, setae	stiff bristle-like structures protruding from follicles through the epidermis. Usually sigmoid in shape, except specialized setae. May be enlarged at the extreme portions of the body.
Sixprostatic	with 6 prostates in 3 consecutive segments.
Sixthecal	with 3 pairs of spermathecae.
Spermatheca	spermathecal, an organ in which sperm received from a copulatory partner are stored until extrusion during laying.
Tanylobous	the condition when the continuation of the prostomium reaches backwards to the first segmental groove.

Testis sac	closed part of the coelom is containing the testes and male funnels of a particular segment.
Thecal	having spermatheca.
Typhlosolate	having a typhlosole, usually with reference to a segment or segments of the intestine or the intestinal region of the body.
Typhlosole	any longitudinal fold of gut wall, especially if projecting into gut lumen from the roof at mid-dorsal (mD) or the floor at mid-ventral (mV). Lateral typhlosoles usually are rudimentary.
Unidiveritculate	having one diverticulum, as of spermathecae.
Uniloculate	having only one seminal chamber, as of spermathecal diverticulum.
Vermicompost	compost generated from the processing of organic waste materials by earthworms.
Vermiculture	the intensive cultivation of earthworms for used as fish bait, feed supplement, or as a by product of vermicomposting.
Zygolobous	condition when the prostomium as seen from above, is not differentiated from the peristomium by any superficial markings.

APPENDIX B

NUMBER AND SPECIES OF EARTHWORMS IN FIVE FOREST TYPES

Table 1 Number and species of earthworms in mixed deciduous forest (MD)

Month	Quadrat	*P. corethrurus*	*A. alexandri*	*A. fucosus*	*Amynthas* sp.1	*Amynthas* sp.2	*Amynthas* sp.3	*M. peguana*	*M. houlleti*	*Metaphire* sp.1	*D. beddardi*
Jul-02	1	0	0	0	0	0	0	0	0	0	4
Jul-02	2	0	0	0	0	0	0	0	0	0	0
Jul-02	3	0	0	0	0	0	0	0	0	0	2
Jul-02	4	0	0	0	0	0	0	0	0	0	2
Jul-02	5	0	0	0	0	0	0	0	0	0	1
Aug-02	1	0	0	0	0	0	0	0	0	0	1
Aug-02	2	0	1	0	0	0	0	0	0	0	4
Aug-02	3	0	0	0	0	0	0	0	0	0	3
Aug-02	4	0	1	0	0	0	0	0	0	0	2
Aug-02	5	0	0	0	0	0	0	0	0	0	0
Sep-02	1	0	0	0	0	0	0	0	0	0	4
Sep-02	2	0	2	0	0	0	0	0	0	0	3
Sep-02	3	0	0	0	0	0	0	0	0	0	4
Sep-02	4	0	0	0	0	0	0	0	0	0	2
Sep-02	5	0	0	0	0	0	0	0	0	0	2
Otc-02	1	0	2	0	0	0	0	0	0	0	4
Otc-02	2	0	0	0	0	0	0	0	0	0	3
Otc-02	3	0	0	0	0	0	0	0	0	0	4
Otc-02	4	0	0	0	0	0	0	0	0	0	2
Otc-02	5	0	2	0	0	0	0	0	0	0	3
Nov-02	1	0	0	0	0	0	0	0	0	0	2
Nov-02	2	0	0	0	0	0	0	0	0	0	1
Nov-02	3	0	0	0	0	0	0	0	0	0	0
Nov-02	4	0	0	0	0	0	0	0	0	0	3
Nov-02	5	0	0	0	0	0	0	0	0	0	0
Dec-02	1	0	0	0	0	0	0	0	0	0	0
Dec-02	2	0	0	0	0	0	0	0	0	0	0

Table 1 (continued)

Month	Quadrat	*P. corethrurus*	*A. alexandri*	*A. fucosus*	*Amynthas* sp.1	*Amynthas* sp.2	*Amynthas* sp.3	*M. peguana*	*M. houlleti*	*Metaphire* sp.1	*D. beddardi*
Dec-02	3	0	0	0	0	0	0	0	0	0	0
Dec-02	4	0	0	0	0	0	0	0	0	0	0
Dec-02	5	0	0	0	0	0	0	0	0	0	0
Jun-03	1	0	0	0	0	0	0	0	0	0	1
Jun-03	2	0	0	0	0	0	0	0	0	0	0
Jun-03	3	0	0	0	0	0	0	0	0	0	1
Jun-03	4	0	0	0	0	0	0	0	0	0	0
Jun-03	5	0	0	0	0	0	0	0	0	0	2
Jul-03	1	0	0	0	0	0	0	0	0	0	2
Jul-03	2	0	0	0	0	0	0	0	0	0	3
Jul-03	3	0	0	0	0	0	0	0	0	0	0
Jul-03	4	0	0	0	0	0	0	0	0	0	2
Jul-03	5	0	0	0	0	0	0	0	0	0	0
Aug-03	1	0	0	0	0	0	0	0	0	0	1
Aug-03	2	0	0	0	0	0	0	0	0	0	4
Aug-03	3	0	0	0	0	0	0	0	0	0	3
Aug-03	4	0	2	0	0	0	0	0	0	0	2
Aug-03	5	0	0	0	0	0	0	0	0	0	2
Sep-03	1	0	0	0	0	0	0	0	0	0	4
Sep-03	2	0	0	0	0	0	0	0	0	0	3
Sep-03	3	0	0	0	0	0	0	0	0	0	2
Sep-03	4	0	0	0	0	0	0	0	0	0	3
Sep-03	5	0	2	0	0	0	0	0	0	0	2
Otc-03	1	0	0	0	0	0	0	0	0	0	0
Otc-03	2	0	0	0	0	0	0	0	0	0	2
Otc-03	3	0	0	0	0	0	0	0	0	0	1
Otc-03	4	0	0	0	0	0	0	0	0	0	0

Table 1 (continued)

Month	Quadrat	*P. corethrurus*	*A. alexandri*	*A. fucosus*	*Amynthas* sp.1	*Amynthas* sp.2	*Amynthas* sp.3	*M. peguana*	*M. houlleti*	*Metaphire* sp.1	*D. beddardi*
Otc-03	5	0	0	0	0	0	0	0	0	0	0
Nov-03	1	0	0	0	0	0	0	0	0	0	0
Nov-03	2	0	0	0	0	0	0	0	0	0	0
Nov-03	3	0	0	0	0	0	0	0	0	0	0
Nov-03	4	0	0	0	0	0	0	0	0	0	0
Nov-03	5	0	0	0	0	0	0	0	0	0	0
Dec-03	1	0	0	0	0	0	0	0	0	0	0
Dec-03	2	0	0	0	0	0	0	0	0	0	0
Dec-03	3	0	0	0	0	0	0	0	0	0	0
Dec-03	4	0	0	0	0	0	0	0	0	0	0
Dec-03	5	0	0	0	0	0	0	0	0	0	0
total	-	0	12	0	0	0	0	0	0	0	96

Table 2 Number and species of earthworms in dry evergreen forest (DE)

Month	Quadrat	*P. corethrurus*	*A. alexandri*	*A. fucosus*	*Amynthas* sp.1	*Amyntha s* sp.2	*Amynthas* sp.3	*M. peguana*	*M. houlleti*	*Metaphire* sp.1	*D. beddardi*
Jul-02	1	0	2	0	0	0	0	0	0	0	3
Jul-02	2	0	0	0	0	0	0	0	0	0	4
Jul-02	3	0	0	0	0	0	0	0	0	0	0
Jul-02	4	0	0	1	0	0	0	0	0	0	1
Jul-02	5	0	0	0	0	0	0	0	0	0	5
Aug-02	1	0	0	0	0	0	0	0	0	0	3
Aug-02	2	0	6	0	0	0	0	0	0	0	4
Aug-02	3	0	0	3	0	0	0	0	0	0	1
Aug-02	4	0	4	0	0	1	0	0	0	0	0
Aug-02	5	0	0	0	0	0	0	0	0	0	0
Sep-02	1	0	5	0	2	0	0	0	0	0	1
Sep-02	2	0	0	0	1	2	0	1	0	0	2
Sep-02	3	0	6	0	0	0	0	0	0	1	1
Sep-02	4	0	0	1	0	1	0	0	0	0	1
Sep-02	5	0	0	1	0	0	0	0	0	0	2
Otc-02	1	0	2	1	0	0	0	0	0	0	3
Otc-02	2	0	0	0	0	0	0	0	0	0	4
Otc-02	3	0	0	2	0	0	0	3	0	0	4
Otc-02	4	0	0	2	0	0	0	0	0	0	0
Otc-02	5	0	0	0	0	0	0	0	0	0	0
Nov-02	1	0	0	0	0	0	0	1	0	0	2
Nov-02	2	0	2	0	0	0	0	1	0	0	0
Nov-02	3	0	0	0	0	0	0	0	0	0	1
Nov-02	4	0	0	0	0	0	0	0	0	0	2
Nov-02	5	0	0	2	0	0	0	0	0	0	2
Dec-02	1	0	0	0	0	0	0	0	0	0	0
Dec-02	2	0	0	0	0	0	0	0	0	0	0

Table 2 (continued)

Month	Quadrat	*P. corethrurus*	*A. alexandri*	*A. fucosus*	*Amynthas* sp.1	*Amynthas* sp.2	*Amynthas* sp.3	*M. peguana*	*M. houlleti*	*Metaphire* sp.1	*D. beddardi*
Dec-02	3	0	0	1	0	0	0	0	0	0	0
Dec-02	4	0	0	0	0	0	0	0	0	0	0
Dec-02	5	0	0	0	0	0	0	0	0	0	0
Jun-03	1	0	0	0	0	0	0	0	0	0	2
Jun-03	2	0	1	0	0	0	0	1	0	0	2
Jun-03	3	0	0	0	0	0	0	0	0	0	3
Jun-03	4	0	0	1	0	0	0	0	0	0	1
Jun-03	5	0	0	0	0	0	0	0	0	0	0
Jul-03	1	0	4	0	0	0	0	0	0	0	0
Jul-03	2	0	0	0	0	0	0	1	0	0	2
Jul-03	3	0	0	0	0	0	0	0	0	0	1
Jul-03	4	0	0	0	1	0	0	0	0	0	0
Jul-03	5	0	0	3	0	0	0	0	0	0	3
Aug-03	1	0	6	0	0	0	0	1	0	0	2
Aug-03	2	0	0	0	0	4	0	0	0	0	3
Aug-03	3	0	4	0	1	0	0	0	0	0	0
Aug-03	4	0	0	2	0	0	0	2	0	0	2
Aug-03	5	0	3	3	0	0	0	0	0	0	0
Sep-03	1	0	3	0	0	0	0	0	0	0	0
Sep-03	2	0	0	2	0	0	0	0	0	0	0
Sep-03	3	0	0	0	0	0	0	2	0	0	3
Sep-03	4	0	2	3	0	0	0	0	1	0	0
Sep-03	5	0	0	0	0	0	0	0	0	1	2
Otc-03	1	0	2	0	0	0	0	0	0	0	1
Otc-03	2	0	0	0	0	0	0	0	0	0	2
Otc-03	3	0	0	1	0	0	0	0	0	0	0
Otc-03	4	0	0	2	0	0	0	0	0	0	1

Table 2 (continued)

Month	Quadrat	*P. corethrurus*	*A. alexandri*	*A. fucosus*	*Amynthas* sp.1	*Amynthas* sp.2	*Amynthas* sp.3	*M. peguana*	*M. houlleti*	*Metaphire* sp.1	*D. beddardi*
Otc-03	5	0	3	0	0	0	0	0	0	0	0
Nov-03	1	0	0	1	0	0	0	0	0	0	0
Nov-03	2	0	0	0	0	0	0	0	0	0	0
Nov-03	3	0	0	0	0	0	0	1	0	0	0
Nov-03	4	0	0	0	0	0	0	0	0	0	0
Nov-03	5	0	0	0	0	0	0	1	0	0	0
Dec-03	1	0	0	0	0	0	0	0	0	0	0
Dec-03	2	0	0	0	0	0	0	0	0	0	0
Dec-03	3	0	0	0	0	0	0	0	0	0	0
Dec-03	4	0	0	0	0	0	0	0	0	0	0
Dec-03	5	0	0	0	0	0	0	0	0	0	0
total	-	0	55	32	5	8	0	15	1	2	76

Table 3 Number and species of earthworms in moist evergreen forest (ME)

Month	Quadrat	*P. corethrurus*	*A. alexandri*	*A. fucosus*	*Amynthas* sp.1	*Amynthas* sp.2	*Amynthas* sp.3	*M. peguana*	*M. houlleti*	*Metaphire* sp.1	*D. beddardi*
Jul-02	1	19	2	0	0	0	0	0	0	0	0
Jul-02	2	24	0	0	0	0	0	1	0	0	0
Jul-02	3	8	2	0	0	0	0	0	0	0	0
Jul-02	4	26	0	0	0	0	0	0	0	0	0
Jul-02	5	18	0	0	0	0	0	0	0	0	0
Aug-02	1	28	4	0	0	0	0	0	0	0	0
Aug-02	2	31	0	0	0	0	0	0	0	0	0
Aug-02	3	27	0	0	0	0	0	3	0	0	0
Aug-02	4	29	0	0	0	0	0	0	0	0	0
Aug-02	5	27	0	0	0	0	0	0	0	0	0
Sep-02	1	36	6	0	0	0	0	0	0	0	0
Sep-02	2	29	2	0	0	0	0	0	0	0	0
Sep-02	3	25	0	0	0	0	0	0	0	0	0
Sep-02	4	47	0	0	0	0	0	4	0	0	0
Sep-02	5	41	0	0	1	0	0	2	0	0	0
Otc-02	1	27	0	0	0	0	0	0	0	0	0
Otc-02	2	21	0	0	0	0	0	3	0	0	0
Otc-02	3	34	0	0	0	0	0	0	0	0	0
Otc-02	4	22	0	0	0	0	0	2	0	0	0
Otc-02	5	19	1	0	0	0	0	0	0	0	0
Nov-02	1	11	1	0	0	0	0	0	0	0	0
Nov-02	2	9	2	0	0	0	0	0	0	0	0
Nov-02	3	12	0	0	0	0	0	2	0	0	0
Nov-02	4	12	0	0	0	0	0	1	0	0	0
Nov-02	5	10	0	0	0	0	0	0	0	0	0
Dec-02	1	12	0	0	0	0	0	1	0	0	0
Dec-02	2	11	0	0	0	0	0	0	0	0	0

Table 3 (continued)

Month	Quadrat	*P. corethrurus*	*A. alexandri*	*A. fucosus*	*Amynthas* sp.1	*Amynthas* sp.2	*Amynthas* sp.3	*M. peguana*	*M. houlleti*	*Metaphire* sp.1	*D. beddardi*
Dec-02	3	8	0	0	0	0	0	0	0	0	0
Dec-02	4	15	0	0	0	0	0	0	0	0	0
Dec-02	5	11	0	0	0	0	0	0	0	0	0
Jun-03	2	16	0	0	0	0	0	1	0	0	0
Jun-03	3	11	2	0	0	0	0	0	0	0	0
Jun-03	4	12	0	0	0	0	0	0	0	0	0
Jun-03	5	9	0	0	0	0	0	0	0	0	0
Jul-03	1	18	2	0	0	0	0	0	0	0	0
Jul-03	2	23	0	0	0	0	0	1	0	0	0
Jul-03	3	17	0	0	0	0	0	1	0	0	0
Jul-03	4	13	0	0	0	0	0	0	0	0	0
Jul-03	5	21	0	0	0	0	0	0	0	0	0
Aug-03	1	28	0	0	0	0	0	3	0	0	0
Aug-03	2	29	3	0	0	0	0	0	0	0	0
Aug-03	3	38	3	0	0	0	0	0	0	0	0
Aug-03	4	35	0	0	1	0	0	0	0	0	0
Aug-03	5	44	0	0	0	0	0	0	0	0	0
Sep-03	1	37	4	0	0	0	0	2	0	0	0
Sep-03	2	43	2	0	0	0	0	0	0	0	0
Sep-03	3	31	0	0	1	0	0	3	0	0	0
Sep-03	4	34	0	0	0	0	0	0	0	0	0
Sep-03	5	35	0	0	0	0	0	0	0	0	0
Otc-03	1	32	1	0	0	0	0	0	0	0	0
Otc-03	2	36	2	0	0	0	0	0	0	0	0
Otc-03	3	31	0	0	0	0	0	2	0	0	0
Otc-03	4	28	0	0	0	0	0	0	0	0	0
Otc-03	5	32	0	0	0	0	0	2	0	0	0

Table 3 (continued)

Month	Quadrat	*P. corethrurus*	*A. alexandri*	*A. fucosus*	*Amynthas* sp.1	*Amynthas* sp.2	*Amynthas* sp.3	*M. peguana*	*M. houlleti*	*Metaphire* sp.1	*D. beddardi*
Nov-03	1	16	1	0	0	0	0	0	0	0	0
Nov-03	2	12	0	0	0	0	0	0	0	0	0
Nov-03	3	14	0	0	0	0	0	0	0	0	0
Nov-03	4	9	0	0	0	0	0	0	0	0	0
Nov-03	5	18	0	0	0	0	0	0	0	0	0
Dec-03	1	11	0	0	0	0	0	1	0	0	0
Dec-03	2	8	0	0	0	0	0	0	0	0	0
Dec-03	3	7	0	0	0	0	0	0	0	0	0
Dec-03	4	13	0	0	0	0	0	0	0	0	0
Dec-03	5	9	0	0	0	0	0	0	0	0	0
total	-	1433	43	0	3	0	0	36	0	0	0

Table 4 Number and species of earthworms in hill evergreen forest (HE)

Month	Quadrat	*P. corethrurus*	*A. alexandri*	*A. fucosus*	*Amynthas* sp.1	*Amynthas* sp.2	*Amynthas* sp.3	*M. peguana*	*M. houlleti*	*Metaphire* sp.1	*D. beddardi*
Jul-02	1	12	2	0	0	0	0	0	0	0	0
Jul-02	2	19	1	0	0	0	0	0	0	0	0
Jul-02	3	16	0	0	0	0	0	0	0	0	0
Jul-02	4	22	0	0	0	0	0	1	0	0	0
Jul-02	5	17	0	0	0	0	0	0	0	0	0
Aug-02	1	31	2	0	0	0	0	0	0	0	0
Aug-02	2	26	3	0	0	0	0	0	0	0	0
Aug-02	3	32	0	0	0	1	0	0	0	0	0
Aug-02	4	19	0	0	0	0	0	0	0	0	0
Aug-02	5	27	0	2	0	0	0	0	0	0	0
Sep-02	1	29	3	0	1	0	0	0	0	0	0
Sep-02	2	26	0	0	0	0	0	6	0	0	0
Sep-02	3	24	0	2	0	2	0	0	0	0	0
Sep-02	4	21	0	0	0	0	1	0	0	0	0
Sep-02	5	27	0	2	0	0	0	0	0	0	0
Otc-02	1	13	2	0	0	0	0	0	0	0	0
Otc-02	2	9	2	0	0	0	0	0	0	0	0
Otc-02	3	17	0	0	0	0	0	0	0	0	0
Otc-02	4	13	0	0	0	0	0	5	0	0	0
Otc-02	5	14	0	0	0	0	0	0	0	0	0
Nov-02	1	9	0	0	0	0	0	0	0	0	0
Nov-02	2	4	0	0	0	0	0	0	0	0	0
Nov-02	3	11	0	0	0	0	0	0	0	0	0
Nov-02	4	9	0	0	0	0	0	0	0	0	0
Nov-02	5	6	0	0	0	0	0	0	0	0	0
Dec-02	1	0	0	0	0	0	0	0	0	0	0
Dec-02	2	0	0	0	0	0	0	0	0	0	0

Table 4 (continued)

Month	Quadrat	*P. corethrurus*	*A. alexandri*	*A. fucosus*	*Amynthas* sp.1	*Amynthas* sp.2	*Amynthas* sp.3	*M. peguana*	*M. houlleti*	*Metaphire* sp.1	*D. beddardi*
Dec-02	3	0	0	0	0	0	0	0	0	0	0
Dec-02	4	0	0	0	0	0	0	0	0	0	0
Dec-02	5	0	0	0	0	0	0	0	0	0	0
Jun-03	1	13	2	0	0	0	0	0	0	0	0
Jun-03	2	9	0	0	0	0	0	0	0	0	0
Jun-03	3	11	2	0	0	0	0	0	0	0	0
Jun-03	4	15	0	0	0	0	0	0	0	0	0
Jun-03	5	16	0	0	0	0	0	0	0	0	0
Jul-03	1	18	3	0	0	0	0	0	0	0	0
Jul-03	2	15	0	0	0	0	0	2	0	0	0
Jul-03	3	21	0	0	0	0	0	0	0	0	0
Jul-03	4	16	0	0	0	0	0	1	0	0	0
Jul-03	5	18	1	0	0	0	0	0	0	0	0
Aug-03	1	12	1	0	0	0	0	0	0	0	0
Aug-03	2	9	0	0	0	0	0	0	0	0	0
Aug-03	3	11	0	0	1	0	0	0	0	0	0
Aug-03	4	13	3	0	0	0	0	4	0	0	0
Aug-03	5	10	0	2	0	1	0	0	0	0	0
Sep-03	1	6	4	0	0	0	0	0	0	0	0
Sep-03	2	4	0	0	0	3	0	3	0	0	0
Sep-03	3	7	0	3	1	0	0	0	0	0	0
Sep-03	4	4	0	0	0	0	1	0	0	0	0
Sep-03	5	6	0	0	0	0	0	0	0	0	0
Otc-03	1	2	2	0	0	0	0	0	0	0	0
Otc-03	2	15	0	0	0	0	0	5	0	0	0
Otc-03	3	4	0	0	0	0	0	0	0	0	0
Otc-03	4	0	1	0	0	0	0	0	0	0	0

Table 4 (continued)

Month	Quadrat	*P. corethrurus*	*A. alexandri*	*A. fucosus*	*Amynthas* sp.1	*Amynthas* sp.2	*Amynthas* sp.3	*M. peguana*	*M. houlleti*	*Metaphire* sp.1	*D. beddardi*
Otc-03	5	0	0	0	0	0	0	0	0	0	0
Nov-03	1	0	0	0	0	0	0	1	0	0	0
Nov-03	2	2	0	0	0	0	0	0	0	0	0
Nov-03	3	0	0	0	0	0	0	0	0	0	0
Nov-03	4	0	0	0	0	0	0	0	0	0	0
Nov-03	5	0	0	0	0	0	0	0	0	0	0
Dec-03	1	0	0	0	0	0	0	0	0	0	0
Dec-03	2	0	0	0	0	0	0	0	0	0	0
Dec-03	3	0	0	0	0	0	0	0	0	0	0
Dec-03	4	0	0	0	0	0	0	0	0	0	0
Dec-03	5	0	0	0	0	0	0	0	0	0	0
total	-	710	34	11	3	7	2	28	0	0	0

Table 5 Number and species of earthworms in grassland (GL)

Month	Quadrat	*P. corethrurus*	*A. alexandri*	*A. fucosus*	*Amynthas* sp.1	*Amynthas* sp.2	*Amynthas* sp.3	*M. peguana*	*M. houlleti*	*Metaphire* sp.1	*D. beddardi*
Jul-02	1	1	0	0	0	0	0	0	0	0	2
Jul-02	2	2	0	0	0	0	0	0	0	0	1
Jul-02	3	2	0	0	0	0	0	0	0	0	0
Jul-02	4	0	0	0	0	0	0	0	0	0	2
Jul-02	5	0	0	0	0	0	0	0	0	0	0
Aug-02	1	0	0	0	0	0	0	0	0	0	3
Aug-02	2	2	0	0	0	0	0	0	0	0	4
Aug-02	3	0	0	0	0	0	0	0	0	0	0
Aug-02	4	3	0	0	0	0	0	0	0	0	4
Aug-02	5	0	0	0	0	0	0	0	0	0	1
Sep-02	1	2	0	0	0	0	0	0	0	0	2
Sep-02	2	0	0	0	0	0	0	0	0	0	6
Sep-02	3	0	0	0	0	0	0	0	0	0	6
Sep-02	4	2	0	0	0	0	0	0	0	0	0
Sep-02	5	2	0	0	0	0	0	0	0	0	4
Otc-02	1	1	0	0	0	0	0	0	0	0	4
Otc-02	2	2	0	0	0	0	0	0	0	0	1
Otc-02	3	0	0	0	0	0	0	0	0	0	3
Otc-02	4	2	0	0	0	0	0	0	0	0	0
Otc-02	5	0	0	0	0	0	0	0	0	0	0
Nov-02	1	2	0	0	0	0	0	0	0	0	2
Nov-02	2	1	0	0	0	0	0	0	0	0	4
Nov-02	3	1	0	0	0	0	0	0	0	0	4
Nov-02	4	0	0	0	0	0	0	0	0	0	0
Nov-02	5	0	0	0	0	0	0	0	0	0	0
Dec-02	1	0	0	0	0	0	0	0	0	0	1
Dec-02	2	0	0	0	0	0	0	0	0	0	0

Table 5 (continued)

Month	Quadrat	*P. corethrurus*	*A. alexandri*	*A. fucosus*	*Amynthas* sp.1	*Amynthas* sp.2	*Amynthas* sp.3	*M. peguana*	*M. houlleti*	*Metaphire* sp.1	*D. beddardi*
Dec-02	3	1	0	0	0	0	0	0	0	0	1
Dec-02	4	0	0	0	0	0	0	0	0	0	0
Dec-02	5	0	0	0	0	0	0	0	0	0	0
Jun-03	1	1	0	0	0	0	0	0	0	0	3
Jun-03	2	0	0	0	0	0	0	0	0	0	2
Jun-03	3	1	0	0	0	0	0	0	0	0	0
Jun-03	4	2	0	0	0	0	0	0	0	0	4
Jun-03	5	0	0	0	0	0	0	0	0	0	4
Jul-03	1	3	0	0	0	0	0	0	0	0	4
Jul-03	2	1	0	0	0	0	0	0	0	0	6
Jul-03	3	0	0	0	0	0	0	0	0	0	1
Jul-03	4	0	0	0	0	0	0	0	0	0	4
Jul-03	5	0	0	0	0	0	0	0	0	0	3
Aug-03	1	2	0	0	0	0	0	0	0	0	8
Aug-03	2	0	0	0	0	0	0	0	0	0	6
Aug-03	3	0	0	0	0	0	0	0	0	0	2
Aug-03	4	2	0	0	0	0	0	0	0	0	1
Aug-03	5	0	0	0	0	0	0	0	0	0	1
Sep-03	1	0	0	0	0	0	0	0	0	0	2
Sep-03	2	0	0	0	0	0	0	0	0	0	3
Sep-03	3	0	0	0	0	0	0	0	0	0	1
Sep-03	4	0	0	0	0	0	0	0	0	0	2
Sep-03	5	3	0	0	0	0	0	0	0	0	0
Otc-03	1	2	0	0	0	0	0	0	0	0	0
Otc-03	2	1	0	0	0	0	0	0	0	0	0
Otc-03	3	0	0	0	0	0	0	0	0	0	0
Otc-03	4	0	0	0	0	0	0	0	0	0	0

Table 5 (continued)

Month	Quadrat	*P. corethrurus*	*A. alexandri*	*A. fucosus*	*Amynthas* sp.1	*Amynthas* sp.2	*Amynthas* sp.3	*M. peguana*	*M. houlleti*	*Metaphire* sp.1	*D. beddardi*
Otc-03	5	1	0	0	0	0	0	0	0	0	0
Nov-03	1	0	0	0	0	0	0	0	0	0	1
Nov-03	2	2	0	0	0	0	0	0	0	0	1
Nov-03	3	0	0	0	0	0	0	0	0	0	0
Nov-03	4	0	0	0	0	0	0	0	0	0	0
Nov-03	5	0	0	0	0	0	0	0	0	0	1
Dec-03	1	0	0	0	0	0	0	0	0	0	0
Dec-03	2	0	0	0	0	0	0	0	0	0	0
Dec-03	3	0	0	0	0	0	0	0	0	0	0
Dec-03	4	0	0	0	0	0	0	0	0	0	0
Dec-03	5	0	0	0	0	0	0	0	0	0	0
total	-	47	0	0	0	0	0	0	0	0	115

APPENDIX C

ENVIRONMENTAL FACTORS IN FIVE FOREST TYPES

Table 1 Environmental factors of mixed deciduous forest (MD)

Month	Soil pH	N (%)	P (%)	K (ppm)	OM (%)	Moisture (%)	Litter (g)	Temp (ºC)	RH (%)	Density (g/cm^3)	Porosity (%)	Sand (%)	Silt (%)	Clay (%)	texture
Jul-02	5.00	0.04	0.055	68.273	4.47	13.44	16.04	34	81.5	1.53	42.26	55.03	28.63	16.34	Sandy loam
Aug-02	4.88	0.07	0.097	67.38	4.84	18.65	19.25	33	86	1.12	57.73	45.17	33.47	21.36	Sandy loam
Sep-02	4.91	0.05	0.074	62.24	3.81	19.31	28.36	30	96	1.07	59.62	42.52	36.41	21.07	Sandy loam
Otc-02	4.95	0.06	0.071	81.813	4.24	16.44	14.33	28	91.5	1.64	41.14	44.18	37.15	18.67	Sandy loam
Nov-02	4.84	0.04	0.063	67.00	3.53	8.11	11.21	23	86	1.42	47.17	57.69	24.52	17.79	Sandy loam
Dec-02	4.87	0.04	0.094	61.963	6.85	5.71	12.54	19	72	1.37	48.29	43.42	41.31	15.27	Sandy loam
Jun-03	5.10	0.05	0.144	72.351	3.44	11.08	17.58	34	76	1.22	53.96	48.31	32.38	19.31	Sandy loam
Jul-03	4.96	0.04	0.081	69.802	4.63	14.21	25.66	31	86.5	1.34	49.34	39.31	37.06	23.63	Sandy loam
Aug-03	4.78	0.04	0.069	63.04	4.39	18.37	21.31	33	93.5	1.36	48.67	38.15	39.74	22.11	Sandy loam
Sep-03	4.97	0.05	0.103	74.161	5.71	20.45	9.61	29	95.5	1.52	42.64	58.35	21.81	19.84	Sandy loam
Otc-03	4.83	0.04	0.077	77.891	4.56	17.68	18.62	29	92	1.37	48.3	55.28	28.39	16.33	Sandy loam
Nov-03	5.04	0.06	0.085	67.654	3.94	9.57	16.41	23	86	1.44	45.65	62.47	17.85	19.68	Sandy loam
Dec-03	4.96	0.05	0.091	66.670	4.73	5.23	16.80	18	84.5	1.28	51.69	50.27	28.69	21.04	Sandy loam

Table 2 Environmental factors of dry evergreen forest (DE)

Month	Soil pH	N (%)	P (%)	K (ppm)	OM (%)	Moisture (%)	Litter (g)	Temp (ºC)	RH (%)	Density (g/cm^3)	Porosity (%)	Sand (%)	Silt (%)	Clay (%)	texture
Jul-02	5.84	0.132	0.122	111.12	7.58	18.64	5.31	26	88	1.26	52.45	67.15	13.58	19.27	Sandy loam
Aug-02	5.85	0.007	0.146	96.25	5.68	24.87	8.67	34	88	1.24	53.20	57.43	15.64	26.93	Sandy clay loam
Sep-02	5.51	0.005	0.073	144.33	7.77	28.15	18.66	31	94	1.18	55.47	63.23	14.76	22.01	Sandy clay loam
Otc-02	5.72	0.012	1.212	174.53	8.18	21.68	7.68	28	81.5	1.17	55.84	72.14	12.35	15.51	Sandy loam
Nov-02	5.69	0.12	0.152	117.20	7.45	11.31	4.60	22.5	80	1.28	51.69	58.34	16.67	24.99	Sandy clay loam
Dec-02	5.54	0.014	0.144	77.280	7.52	7.32	6.11	19	73.5	1.18	55.47	62.35	17.32	20.33	Sandy clay loam
Jun-03	5.71	0.003	1.34	194.26	9.53	15.44	8.87	35	74	1.37	48.30	51.32	20.13	28.55	Sandy clay loam
Jul-03	5.81	0.104	0.63	143.20	7.79	17.98	14.35	33	77	1.27	52.07	64.63	17.63	17.74	Sandy loam
Aug-03	5.74	0.024	0.243	166.33	8.35	24.06	18.61	36	82	1.29	51.32	56.37	21.25	22.38	Sandy clay loam
Sep-03	5.68	0.006	0.167	85.644	8.64	26.77	6.76	33	95	1.32	50.18	64.71	21.34	13.95	Sandy loam
Otc-03	5.69	0.015	1.041	124.33	7.96	20.17	9.61	36	87.5	1.06	60.00	59.36	28.69	11.95	Sandy loam
Nov-03	5.66	0.024	0.471	98.647	9.13	9.46	8.17	27	76.5	1.19	55.09	62.83	15.24	21.93	Sandy clay loam
Dec-03	5.68	0.202	0.681	164.77	8.48	6.55	6.05	21	64.5	1.22	53.72	63.35	18.44	18.21	Sandy loam

Table 3 Environmental factors of moist evergreen forest (ME)

Month	Soil pH	N (%)	P (%)	K (ppm)	OM (%)	Moisture (%)	Litter (g)	Temp (ºC)	RH (%)	Density (g/cm^3)	Porosity (%)	Sand (%)	Silt (%)	Clay (%)	texture
Jul-02	4.38	0.05	0.102	152.68	6.93	16.76	14.36	26	90	1.23	53.58	47.01	24.47	28.52	Sandy clay loam
Aug-02	4.35	0.06	0.192	108.51	7.06	21.68	18.66	27	92	1.1	58.49	41.34	27.61	31.05	Sandy clay loam
Sep-02	4.58	0.04	0.185	109.99	6.97	28.35	15.12	25	96	1.25	52.83	64.53	26.71	8.76	Sandy loam
Otc-02	4.61	0.08	0.172	109.41	7.07	24.38	16.74	23	95	1.18	55.47	52.61	21.37	26.02	Sandy clay loam
Nov-02	4.43	0.12	1.152	146.48	7.13	21.11	14.03	22	83	1.17	55.84	56.72	21.7	21.58	Sandy clay loam
Dec-02	4.54	0.08	1.022	133.28	6.97	18.97	11.51	20	73	1.32	50.18	59.46	19.88	20.66	Sandy clay loam
Jun-03	4.57	0.09	0.142	121.21	6.83	16.84	15.09	29	84	1.24	53.27	51.71	25.04	23.25	Sandy clay loam
Jul-03	4.41	0.08	0.985	136.66	6.94	16.32	11.39	31	92	1.29	51.32	59.14	16.08	24.78	Sandy clay loam
Aug-03	4.63	0.08	0.978	118.05	7.18	20.48	12.48	28	93	1.19	55.19	61.04	18.61	20.35	Sandy clay loam
Sep-03	4.57	0.10	1.024	147.33	7.04	25.46	19.69	23	97	1.28	51.69	54.27	20.49	25.24	Sandy clay loam
Otc-03	4.51	0.09	0.876	119.91	7.19	24.69	18.64	21	92	1.31	49.81	66.55	19.81	13.64	Sandy loam
Nov-03	4.57	0.08	0.904	154.79	6.89	20.07	11.67	20	86	1.16	56.22	58.94	17.73	23.33	Sandy clay loam
Dec-03	4.52	0.08	1.009	141.43	7.02	17.89	12.98	19	71	1.20	54.71	53.66	24.09	22.25	Sandy clay loam

Table 4 Environmental factors of hill evergreen forest (HE)

Month	Soil pH	N (%)	P (%)	K (ppm)	OM (%)	Moisture (%)	Litter (g)	Temp (ºC)	RH (%)	Density (g/cm^3)	Porosity (%)	Sand (%)	Silt (%)	Clay (%)	texture
Jul-02	4.28	0.074	0.066	65.31	4.98	14.64	8.34	21	92	1.24	53.2	59.79	22.36	17.85	Sandy loam
Aug-02	4.31	0.010	0.096	204.82	6.73	26.24	15.31	24	94.5	1.17	55.84	69.83	16.98	13.19	Sandy loam
Sep-02	4.45	0.010	0.074	202.14	6.92	27.06	14.09	21	97.5	1.27	52.07	69.47	20.46	10.07	Sandy loam
Otc-02	4.37	0.007	0.075	78.48	7.78	16.71	11.67	20.5	82.5	1.42	46.41	66.7	18.43	14.87	Sandy loam
Nov-02	4.29	0.005	0.07	73.07	6.18	8.66	14.17	19.5	84	1.22	53.96	49.86	25.78	24.36	Sandy clay loam
Dec-02	4.33	0.008	0.089	72.48	7.64	5.31	11.65	18	94.5	1.37	48.30	60.98	19.61	19.41	Sandy loam
Jun-03	4.31	0.007	0.071	89.85	7.67	6.03	13.28	26.5	84	1.19	55.09	50.65	26.71	22.64	Sandy clay loam
Jul-03	4.28	0.016	0.074	74.68	6.57	11.84	17.64	29	88	1.25	52.83	56.07	27.69	16.24	Sandy loam
Aug-03	4.31	0.029	0.068	97.89	6.84	22.66	14.51	28	90.5	1.23	53.58	57.6	24.75	17.65	Sandy loam
Sep-03	4.34	0.021	0.091	187.64	7.57	18.47	9.09	27.5	98	1.34	49.43	55.68	27.65	16.67	Sandy loam
Otc-03	4.35	0.008	0.076	84.22	7.33	12.85	18.67	30	84	1.14	56.98	52.33	27.31	20.36	Sandy clay loam
Nov-03	4.27	0.019	0.079	177.64	7.64	6.04	14.66	25	81.5	1.09	58.87	47.8	36.76	15.44	Sandy loam
Dec-03	4.29	0.048	0.089	119.68	7.49	4.33	17.24	20	86	1.21	54.34	54.91	28.73	16.36	Sandy loam

Table 5 Environmental factors of grassland (GL)

Month	Soil pH	N (%)	P (%)	K (ppm)	OM (%)	Moisture (%)	Litter (g)	Temp (ºC)	RH (%)	Density (g/cm^3)	Porosity (%)	Sand (%)	Silt (%)	Clay (%)	texture
Jul-02	5.22	0.11	1.189	103.86	6.05	7.62	3.04	29	76	1.36	48.67	56.44	22.61	20.95	Sandy loam
Aug-02	5.48	0.15	0.19	95.92	5.04	10.54	5.17	34	85.5	1.57	40.72	62.31	19.74	17.95	Sandy loam
Sep-02	5.46	0.1	0.167	82.49	5.45	14.71	4.99	29.5	90.5	1.28	51.69	67.49	17.43	15.08	Sandy loam
Otc-02	5.37	0.13	1.414	105.47	6.00	11.47	3.41	29	81.5	1.44	45.66	69.03	12.63	18.34	Sandy loam
Nov-02	5.37	0.08	0.852	107.23	6.46	6.33	3.65	24	71.5	1.38	47.73	57.81	32.52	9.67	Sandy loam
Dec-02	5.33	0.08	0.168	109.14	6.08	3.58	4.67	21	62	1.23	53.58	51.47	33.81	14.72	Sandy loam
Jun-03	5.32	0.08	0.524	111.91	5.89	5.81	4.58	35.5	71.5	1.32	50.18	53.09	36.77	10.14	Sandy loam
Jul-03	5.51	0.14	0.894	106.88	6.17	7.34	4.08	33	74	1.33	49.81	62.82	24.08	13.1	Sandy loam
Aug-03	5.47	0.13	0.671	118.01	5.98	11.48	5.97	34	87	1.53	42.26	66.67	17.42	15.91	Sandy loam
Sep-03	5.43	0.09	0.457	97.88	6.39	15.39	4.18	31	90.5	1.46	44.14	51.8	36.91	11.29	Sandy loam
Otc-03	5.48	0.09	0.553	113.41	6.11	10.88	3.68	28	83	1.29	51.32	58.63	21.32	20.05	Sandy loam
Nov-03	5.44	0.11	0.787	119.07	6.06	6.12	4.02	21	70.5	1.43	46.03	64.53	22.07	13.4	Sandy loam
Dec-03	5.46	0.13	0.811	98.871	5.38	4.26	3.35	23	73	1.63	38.48	67.13	22.46	10.41	Sandy loam

CURRICULUM VITAE

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