STRUGGLE FOR EXISTENCE: EARTHWORMS THROUGH DEFORESTATION IN BUNGKU (JAMBI) AND MOUNT GEDE (WEST JAVA)

ANDY DARMawan
G362110081

GRADUATE SCHOOL
BOGOR AGRICULTURAL UNIVERSITY
Bogor
2016
1. Dilengkapi melalui komunikasi secara tertulis karya lulus dalam rangka meningkatkan keterampilan komunikasi dan menyelesaikan masalah.

2. Dilengkapi melalui rapat koordinasi sebagaimana disebutkan dalam dokumen bentuk operasi populer ini.

b. Penyelenggaraan kegiatan rapat koordinasi yang wajar.

c. Penyelenggaraan kegiatan rapat koordinasi yang diselenggarakan oleh tim koordinasi, penilai, perencanaan, pelaksana, dan pelaksanaan program.

Hak Cipta Dilindungi Undang-Undang
STATEMENT LETTER

I hereby declare that dissertation entitled “Struggle for Existence of Earthworms in Bungku (Jambi) and Mount Gede (West Java)” is original result of my own research supervised by supervisory committee and has never been submitted in any form at any institution before. All information from other authors cited here are mentioned in the text and listed in the reference at the end part of the dissertation.

Bogor, January 2016

Andy Darmawan
Student ID G362110081
1. Dilengkapi muncul seluruh koran dalam daftar memperbanyak spesies
2. Dilembagakan melalui komunikasi dan kebijakan spesies.
3. Kebijakan hukum yang muncul
4. Kebijakan hukum yang muncul
5. Dilembagakan melalui komunikasi dan kebijakan spesies.

Hak Cipta Dilihndung Ungu-Lindung

Bogor Agricultural (Institut Pertanian Bogor)
SUMMARY

ANDY DARMAWAN. Struggle for Existence: Earthworms through Deforestation in Bungku (Jambi) and Mount Gede (West Java). Supervised by BAMBANG SURYOBROTO, TRI ATMOWIDI, and WASMEN MANALU.

The Gause’s principle, whereby species without niche differentiation expel each other leads to reduced diversity. This principle has been proven in laboratory and we show this principle in the nature. It is preceded by humans that alter the environment by changing the forests into plantations. In the same time, humans also introduce agricultural plantations and deliberately or not, introduce earthworms along with the plantations. The native and exotic earthworms can live together as long as they do not share the overlapping niche and equilibrium competition is not attained. However, the deforestation has made the earthworms exist in competitive equilibrium and consequently reduces the earthworm diversity.

We began the research on July 2012. The first sampling was conducted in Bungku Village, Jambi, Indonesia on November 2012. The sampled areas included secondary forests, oil palm plantations, rubber plantations, and rubber jungles. We discovered only one species of earthworm, which was *Pontoscolex corethrurus*. The second sampling was conducted in Mount Gede, West Java, Indonesia between early July and the end of October 2012 and between early September and the end of December 2013. We observed two regions in Mount Gede, viz. Bodogol and Situ Gunung. The sampled areas included forests, mixed plantations, and homogenous plantations.

We recovered 23 species of earthworms and 5 among them (*Drawida nepalensis* Michaelsen, 1907, *Notooscolex javanica* (Michaelsen, 1910), *Pheretima pura* species-group of Sims & Easton, 1972, *Polypheretima moelleri* (Michaelsen, 1921), and *Polypheretima sempolensis* Easton, 1979) were native of the Oriental region. Seven species (*Amynthas asiaticus* Michaelsen, 1900, *Amynthas hupeiensis* (Michaelsen, 1895), *Amynthas illotus* species-group sensu Sims & Easton, 1972, *Amynthas morrisi* species-group sensu Sims & Easton, 1972, *Amynthas robustus* (Perrier, 1872), *Metaphire planata* (Gates 1926), and *Ocnerodrilus occidentalis* Eisen, 1878) were reported for the first time in Indonesia. The others (*Amynthas aeruginosus* (Kinberg, 1867), *Amynthas gracilis* (Kinberg, 1867), *Amynthas minimus* (Horst, 1893), *Dichogaster affinis* (Michaelsen, 1890), *Drawida barwelli* (Beddard, 1886), *Metaphire californica* (Kinberg, 1867), *Metaphire javanica* (Kinberg, 1867), *Perionyx excavatus* Perrier, 1873, *Pheretima darnleiensis* (Fletcher, 1886), *Polypheretima bifaria* species-group of Easton, 1979, and *Pontoscolex corethrurus* (Muller, 1857)) were believed to be introduced through agricultural plantations. The most dominant species were *Ocnerodrilus occidentalis* and *Pontoscolex corethrurus*. 
Here we show that anthropogenic disturbance has altered the environmental condition. The agricultural plantations in our study act as transplant experiment for Gause’s principle. The constant alteration is reflected by increasing of soil temperature, pH, and water content, while C-organic content is decreasing. This environmental alteration does not support stenotopic earthworms and it drives them to die. Two leftover species, *Ocnerodrilus occidentalis* and *Pontoscolex corethrurus*, thrived to be eudominant competing species. It is indicated by the increasing density of one of the two causes lower density of the other. However, *Ocnerodrilus occidentalis* is able to sustain viable population and ousting *Pontoscolex corethrurus* in area with high soil temperature.

Key words: competition, exotic, Gause’s principle, plantation, soil.
RINGKASAN

ANDY DARMAWAN. Perjuangan untuk Hidup: Cacing Tanah Melalui Deforestasi di Bungku (Jambi) dan Gunung Gede (Jawa Barat). Dibimbing oleh BAMBANG SURYOBROTO, TRI ATMOWIDI, dan WASMEN MANALU.


Kata kunci: eksotik, kompetisi, perkebunan, prinsip Gause, tanah.
Hak Cipta Dilindungi Undang-Undang
1. Dilarang mengutip sebagian atau seluruh karya tulis ini tanpa mencantumkan dan menyebutkan sumber:
   a. Pengutipan hanya untuk kepentingan pendidikan, penelitian, penulisan karya ilmiah, penyusunan laporan, penulisan kritik atau tinjauan suatu masalah.
   b. Pengutipan tidak merugikan kepentingan yang wajar IPB.
2. Dilarang mengumumkan dan memperbanyak sebagian atau seluruh karya tulis ini dalam bentuk apapun tanpa izin IPB.
STRUGGLE FOR EXISTENCE: EARTHWORMS THROUGH DEFORESTATION IN BUNGKU (JAMBI) AND MOUNT GEDE (WEST JAVA)

ANDY DARMAWAN

Dissertation
submitted in partial fulfillment of the requirements for
Doctoral Degree
in
Major of Animal Bioscience

GRADUATE SCHOOL
BOGOR AGRICULTURAL UNIVERSITY
BOGOR
2016
Examiners in the open examination: Dr. Didik Widyatmoko, MSc
Dr. Dra. Rahayu Widyastuti, MScAgr

Examiners in the closed examination: Dr. Ibnuq Qayim
Dr. Ir. Noor Farhiah Hanecta
Title: Struggle for Existence: Earthworms through Deforestation in Bungku (Jambi) and Mount Gede (West Java)

Name: Andy Darmawan

Student ID: G362110081

Major: Animal Bioscience

Certified by

Supervisory Committee

Dr. drs. Bambang Suryobroto
Chair

Dr. Des Tri Atmowidi, M.Si
Member

Prof. dr. Ir. Wasmen Manalu
Member

Acknowledged by

Chair of Animal Biosciences

Dr. Ir. Drs. RR Dyah Perwitasari, M.Sc

Dean of Graduate School

Dr. Ir. Dahirul Syah, MSc Agri

Examination date: January 29, 2016
Graduation date: 29 Feb 2016
1. Dilengkapi melalui berbagai sumber data kualitas laju informasi
2. Mempertahankan dan mendukung keberlanjutan pengembangan data
3. Mendukung pengembangan dan penggunaan data
4. Menyempurnakan pengembangan dan penggunaan data
5. Mendukung pengembangan dan penggunaan data
FOREWORD

“Deo, parentibus et magistris non potest satis gratiae rependi”

(Martin Luther 1483-1546)

Lorem ipsum dolor sit amet, consectetuer adipiscing elit, sed diam nonummy nibh euismod tincidunt ut laoreet dolore magna aliquam erat volutpat. Ut wisi enim ad minim veniam, quis nostrud exerci tation ullamcorper suscipit lobortis nisl ut aliquip ex ea commodo consequat. Duis autem vel eumiriure dolor in hendrerit in vulputate velit esse molestie consequat, vel illum dolore eu feugiat nulla facilisis at vero eros et accumsan et iusto odio dignissim qui blandit praesent luptatum zzril delenit augue duis dolore te feugait nulla facilisi. Nam liber tempor cum soluta nobis eleifend option congue nihil imperdiet doming id quod maxim placerat facer possim assum. Typi non habent claritatem insitam; est usus legentis in iis qui facit eorum claritatem. Investigationes demonstraverunt lectores legere me lius quod ii legunt saepius. Claritas est etiam processus dynamicus, qui sequitur mutationem consuetudium lectorum. Mirum est notare quam littera gothica, quam nunc putamus parum claram, anteposuerit litterarum formas humanitatis per seacula quarta decima et quinta decima. Eodem modo typi, qui nunc nobis videntur parum clari, fiant sollemnes in futurum.

Bogor, January 2016

Andy Darmawan
Bogor Agricultural University (Institut Pertanian Bogor)

Hak cipta milik IPB (Institut Pertanian Bogor)

2. Dilanjutkan menguji dengan spesimen diuji selanjutnya hanya untuk cemaracampak biji yang mungkin terdapat dalam spesimen.
3. Panjang jarak waktu untuk repetisi spesimen, penelitian, pelaksanaan berbagai lingkungan penelitian, pelaksanaan kontak biologi, pelaksanaan studi musnah.

Hak Cipta Dilihat di Undang-Undang

Bogor Agricultural University (Institut Pertanian Bogor)

Hak cipta milik IPB (Institut Pertanian Bogor)
# TABLE OF CONTENT

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>TABLE OF CONTENT</td>
<td>xv</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>xvi</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>xvi</td>
</tr>
<tr>
<td>LIST OF APPENDICES</td>
<td>xvii</td>
</tr>
<tr>
<td>1 GENERAL INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>2 EARTHWORMS (OLIGOCHAETA) FROM BUNGKU VILLAGE (JAMBI) AND MOUNT GEDE</td>
<td>5</td>
</tr>
<tr>
<td>(WEST JAVA)</td>
<td></td>
</tr>
<tr>
<td>Abstract</td>
<td>5</td>
</tr>
<tr>
<td>Introduction</td>
<td>5</td>
</tr>
<tr>
<td>Material and Method</td>
<td>8</td>
</tr>
<tr>
<td>Result</td>
<td>9</td>
</tr>
<tr>
<td>Taxonomy</td>
<td>10</td>
</tr>
<tr>
<td>References</td>
<td>28</td>
</tr>
<tr>
<td>Appendix</td>
<td>34</td>
</tr>
<tr>
<td>3 Pontoscolex corethrurus (Müller, 1857) (Oligochaeta: Glossoscoleidae)</td>
<td>37</td>
</tr>
<tr>
<td>IN FOREST TRANSFORMATION SYSTEM IN BUNGKU VILLAGE, JAMBI, INDONESIA</td>
<td></td>
</tr>
<tr>
<td>Abstract</td>
<td>37</td>
</tr>
<tr>
<td>Introduction</td>
<td>37</td>
</tr>
<tr>
<td>Material and Methods</td>
<td>38</td>
</tr>
<tr>
<td>Result</td>
<td>41</td>
</tr>
<tr>
<td>Discussion</td>
<td>43</td>
</tr>
<tr>
<td>References</td>
<td>44</td>
</tr>
<tr>
<td>4 COMPETITION OF TWO SURVIVED EXOTIC EARTHWORMS</td>
<td>47</td>
</tr>
<tr>
<td>(Ocnerodrilus occidentalis Eisen, 1878 AND Pontoscolex corethrurus (Muller, 1857)) FROM DEFORESTATION IN MOUNT GEDE, INDONESIA</td>
<td></td>
</tr>
<tr>
<td>Abstract</td>
<td>47</td>
</tr>
<tr>
<td>Introduction</td>
<td>47</td>
</tr>
<tr>
<td>Material and Methods</td>
<td>49</td>
</tr>
<tr>
<td>Result</td>
<td>53</td>
</tr>
<tr>
<td>Discussion</td>
<td>56</td>
</tr>
<tr>
<td>References</td>
<td>57</td>
</tr>
<tr>
<td>Appendices</td>
<td>61</td>
</tr>
<tr>
<td>5 GENERAL DISCUSSION</td>
<td>65</td>
</tr>
<tr>
<td>6 CONCLUSION</td>
<td>67</td>
</tr>
<tr>
<td>CURRICULUM VITAE</td>
<td>68</td>
</tr>
</tbody>
</table>
LIST OF TABLES

2.1 Earthworms collected from Bungku Village and Mount Gede. Species with asterisk (*) were reported for the first time in Indonesia. See material and method for area explanation 7

3.1 Kruskal-Wallis test of *Pn. corethrurus* density in each system. The values are mean of *Pn. corethrurus* abundance/m² ± SD 41

3.2 Kruskal-Wallis test of soil parameters in each system. Mean ± SD, values with the same letter in a row are not significantly different (p-value < 0.05) 42

3.3 Soil parameters affecting *Pn. corethrurus* abundance 42

4.1 Soil parameters, presented in minimum-maximum value, in forest and plantation areas in Mount Gede were tested by multiple comparison Kruskal-Wallis’ rank sum test (α = 0.05). Values with the same superscripts in a row are not significantly different. n indicates the amount of the plot 53

4.2 Sampling areas in Mount Gede. Bodogol region (B) was sampled in three forest (B1–B3), two mixed plantations (B4, B5), and four homogenous plantation areas (B6–B9). Situ Gunung region (S) was sampled in three forests (S1–S3) and six homogenous plantation areas (S4–S9) 54

4.3 Relative dominance (RD) and prevalence (P) of earthworm species in forests and plantations in Mount Gede. All values are ranging from 0 (worst) to 100 (best). Species with asterisks are natives of the Orient 55

LIST OF FIGURES

1.1 Model of diversity in function of rate of displacement (equivalent to population growth rate), and frequency of population reduction (equivalent to disturbance) (from Huston 1979). 2

3.1 Study site in Jambi Province, Indonesia. 39
List of Appendices

2.1 Compilation of earthworm species in Indonesia.

4.1 Earthworms recovered (ind/m²) from each area in Bodogol. Species with asterisks are natives of the Orient. See Table 4.2 for explanation of the areas. n indicates the amount of the plot. Unknown species was excluded from diversity and dominance indices analysis.

4.2 Earthworms recovered (ind/m²) from each area in Situ Gunung. Species with asterisks are natives of the Orient. See Table 4.2 for explanation of the areas. n indicates the amount of the plot. Unknown species was excluded from diversity and dominance indices analysis.

4.3 Rarefaction curve in Bodogol (B) and Situ Gunung (S) region.

4.4 Soil parameter from each area in Bodogol (B1–B9) and Situ Gunung (S1–S9). For soil physical factors: data ± SD.

4.5 Relative dominance (%) of earthworm species in each area from Bodogol. Species with asterisks are natives of the Orient. See Table 4.2 for explanation of the areas.

4.6 Relative dominance (%) of earthworm species in each area from Situ Gunung. Species with asterisks are natives of the Orient. See Table 4.2 for explanation of the areas.

4.7 It was more probable to found higher O. occidentalis density than Pn. corethrurus along increasing of soil temperature (inside rectangle). Arrows pointing left indicates higher O. occidentalis density over Pn. corethrurus in certain area (see Appendix 4.4 for detailed soil parameters in each area), and vice versa. The areas without O. occidentalis and Pn. corethrurus (B1, B3, and S1) were omitted.
1. Diliurangi mengubah seluruh terang WHO sebagai
2. Diliurangi mengubah seluruh terang WHO sebagai
3. Diliurangi mengubah seluruh terang WHO sebagai
1 GENERAL INTRODUCTION

The term of struggle for existence employed by Darwin (1859) includes dependence of one being on another and success in leaving progeny. In mixed population where a species affects the others by altering environment, growth rate of each species depends on population size already accumulated, inherent growth rate, and unutilized potentialities of growth. The unutilized potentialities of growth are complex variable. Vacant spaces might also be affected by waste product (Gause 1932). These ideas lead to general theory that competing species cannot long coexist in nature. The theory has been refined by several scientists (Hardin 1960, Darlington 1972, Huston 1979) and now it is known as Gause’s principle. The original concept refers to the simple single-resource competition where a resource becomes direct and limiting factor for two populations (Darlington 1972). It is often extended into ‘competitive exclusion principle’ which stated that “1) if two noninterbreeding populations do “the same thing”, 2) if they are sympatric, 3) if population A multiplies faster than population B, then ultimately A will completely displace B, which will become extinct” (Hardin 1960).

Competitive exclusion exists in competitive equilibrium with several assumptions, such as: stable uniform environment, same limiting resource at the same time, and equilibrium is achieved. Practically, this condition rarely occurs in nature, but the immediate outcome can be observed by increasing the density of one competitor with concomitant decrease of the other (Huston 1979). Naturally, most of communities exist in non-competitive equilibrium. Environmental alteration, which affects the factors those prevent the competitive equilibrium such as population growth rate and reduction, causes attainment of competitive equilibrium (Fig. 1.1).

Competitive equilibrium can lead to reduced diversity. A model proposed by Huston (1979) shows the relationship between diversity and attainment of competitive equilibrium. Diversity is described by 3D contour lines where the highest density lies within the center of each contour line. Hence, low growth rate (transect A) with low disturbance results in high diversity as the competitive equilibrium will take a long time to be approached. Increasing frequency of reduction in this condition will reduce the diversity as population growth is not fast enough to recover from the high disturbance. Meanwhile, high growth rate (transect B) is susceptible to approaching competitive equilibrium quickly. This condition must be compensated by high frequency of reduction to maintain the high diversity. The same case reflects in transect C and D. In low frequency of reduction condition (transect C), increasing growth rate will reduce diversity as the competitive equilibrium will be reached quickly. Then, in high frequency of reduction (transect D), low growth rate cannot catch the rate of reduction and...
diversity will be decreased. This model has been proved in laboratory, and we showed that it is valid in the real world of earthworm.

Earthworms are classed as Oligochaeta. At first, Linnaeus (1758) grouped the worms into only two groups (\textit{Lumbricus terrestris} and \textit{L. marinus}), and currently, Oligochaeta consists about 9,500–10,300 species in 804 genera of 38 families (Blakemore 2010). This class is characterized by having few setae (8 up to a hundred) on each segment, not having parapodia, and absence of appendages on head (or less appendages variation if present). Several body segments are modified into clitellum which functions in reproduction (Edwards 2004).

![Figure 1.1: Model of diversity in function of rate of displacement (equivalent to population growth rate), and frequency of population reduction (equivalent to disturbance) (from Huston 1979).](image)

Earthworms can be found almost everywhere in this earth. The places where they may be found usually have constant soil temperature fluctuation and moisture such as forest, plantation, or garden. They have different tolerance to the environmental stress, therefore earthworm species may be varied within different areas (Edwards 2004). According to their ecological status, earthworms can be classified into epigeic, anecic, and endogeic. Epigeic earthworms live on the ground surface and feeding on litters. They do not have permanent burrow. Consequently, they are quite mobile. Anecic earthworms build vertical burrow where one end is opened into the surface. They come out from their burrow to feed. Meanwhile, endogeic earthworms build their burrow in the ground. They rarely come out to surface, so they feed mainly on almost decomposed organic matter and soil (Chaudhuri \textit{et al.} 2008, Blakemore 2010).

We elevate an issue concerning anthropogenic disturbance, which is changing nature equilibrium and reducing earthworm diversity. Indonesia
experienced the third largest annual forest lost in 2000–2010 (FAO 2010). We studied the earthworms in Mount Gede (West Java) and Bungku Village (Jambi) as these areas are undergoing forest transformation into plantations. The difference between acidic soil in Jambi and volcanic soil in Mount Gede probably causes the different earthworm community. Most of the recorded earthworms are introduced along agricultural plantations. The forest disturbance has caused unfavorable environmental condition for most stenotopic earthworms and killing them. The left out eurytopic earthworms which have the overlapping niche compete each other. In severely degraded condition, it is possible to leave a single species of earthworm completely dominated the area.

References


Hak Cipta Dilindungi Undang-Undang

Bogor Agricultural Institute
EARTHWORMS (OLIGOCHAETA) FROM BUNGKU VILLAGE (JAMBI) AND MOUNT GEDE (WEST JAVA)

Andy Darmawan1*, Tri Atmowidi1, Wasmen Manalu2 & Bambang Suryobroto1

1Department of Biology, Faculty of Mathematics and Natural Sciences, Bogor Agricultural University, Darmaga Campus, Bogor 16680, Indonesia
2Department of Anatomy, Physiology and Pharmacology, Faculty of Veterinary Medicine, Bogor Agricultural University, Indonesia
*Corresponding author, e-mail: and.darm@gmail.com

Abstract

We conducted the sampling in Bungku Village (Jambi) on November 2012. Meanwhile, we performed the sampling in Mount Gede (West Java) between early July and the end of October 2012 and between early September and the end of December 2013 in the wet season. Our study recovered 23 species of earthworms with 7 species were reported for the first time in Indonesia, i.e: Amynthas asiaticus Michaelsen, 1900, Amynthas hupeiensis (Michaelsen, 1895), Amynthas illotus species-group sensu Sims & Easton, 1972, Amynthas morrisi species-group sensu Sims & Easton, 1972, Amynthas robustus (Perrier, 1872), Metaphire planata (Gates, 1926), and Ocnerodrilus occidentalis Eisen, 1878. Pontoscolex coerthrurus was the only species found in Jambi. Most of the recorded species were megascolecids in Mount Gede with Ocnerodrilus occidentalis Eisen, 1878 was the most dominant species.

Key words: Bodogol, first reported, Situ Gunung.

Introduction

Earthworm systematic requires assessment of external and internal characters, especially the reproductive organs (Stephenson 1923, James 2000, Blakemore 2010). They are prominent and expensive to maintain, causing these characters become conservative, i.e. less influenced by environment (Blakemore 2010). Therefore, a diagnosis of reproductive organs, which are positioned internally, is needed to confirm the earthworm identity (Stephenson 1923, James 2000, Blakemore 2010).

Present studies of earthworm in Indonesia conducted earthworm identification based on merely external characters (Wibowo 2000, Milasari 2013), resulting dubious conclusion. Oktavia (2013) reported Pheretima andamanensis (mistyped as “andamaensis”) from Darmaga, but the description probably contain miscounted segment of male pores. Some vermicultures are also misidentified the
cultured earthworms due to lack of knowledge of earthworm characters (pers. obs.). Hence, studies of earthworm taxonomy in Indonesia are scarce. Reliable records of recent Indonesian earthworm were presented by Blakemore & Nugroho (2008), and Nugroho (2010). The compilation of their works revealed 217 species of earthworms in Indonesia (Appendix 2.1). Our study recovered 23 species of earthworms with 7 species are reported for the first time in Indonesia (Table 2.1). Earthworms with broken anterior part could not be identified, and then they were grouped into “unknown”.
Table 2.1 Earthworms collected from Bungku Village and Mount Gede. Species with asterisk (*) were reported for the first time in Indonesia. See material and method for area explanation

<table>
<thead>
<tr>
<th>Species</th>
<th>Sampling area</th>
<th>Total</th>
<th>Prevalence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amynthas aeruginosus (Kinberg, 1867)</td>
<td>3</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td><em>Amynthas asiaticus</em> Michaelsen, 1900</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Amynthas gracilis (Kinberg, 1867)</td>
<td>6</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td><em>Amynthas hupiensis</em> (Michaelsen, 1895)</td>
<td>4</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td><em>Amynthas ilotus</em> species-group sensu Sims &amp; Easton, 1972</td>
<td>6</td>
<td>1</td>
<td>33</td>
</tr>
<tr>
<td>Amynthas minimus (Horst, 1893)</td>
<td>39</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td><em>Amynthas morrisi</em> species-group sensu Sims &amp; Easton, 1972</td>
<td>4</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Amynthas robustus (Perrier, 1872)</td>
<td>17</td>
<td>68</td>
<td>47</td>
</tr>
<tr>
<td>Drawida barwelli (Beddard, 1886)</td>
<td>2</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td><em>Drawida nepalensis</em> Michaelsen, 1907</td>
<td>12</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td><em>Metaphire planata</em> (Kinberg, 1867)</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Metaphire planata (Genes 1926)</td>
<td>20</td>
<td>1</td>
<td>21</td>
</tr>
<tr>
<td>Notoscolex javanica (Michaelsen, 1910)</td>
<td>1</td>
<td>23</td>
<td>50</td>
</tr>
<tr>
<td><em>Ponatoscolex corethrurus</em> Muller, 1857</td>
<td>121</td>
<td>169</td>
<td>452</td>
</tr>
<tr>
<td>Unidentified</td>
<td>16</td>
<td>30</td>
<td>7</td>
</tr>
<tr>
<td>Number of known species</td>
<td>7</td>
<td>9</td>
<td>4</td>
</tr>
</tbody>
</table>
Material and Method

We conducted the sampling in Bungku Village (Jambi) on November 2012. Meanwhile, we performed the sampling in Mount Gede (West Java) between early July and the end of October 2012 and between early September and the end of December 2013 in the wet season. The sampling location included 19 areas:

J – Jambi: Oil palm plantations, rubber plantations, rubber jungle, and secondary forest. These areas were dominated by oil palm (*Elais guineensis*), grass (*Gramineae*), rubber (*Hevea brasiliensis*), Asian melastome (*Melastoma candidum*), billion (*Eusideroxylon zwageri*), tempinis (*Sloetia elongate*), medang (*Litsea firma*), and bamboo (*Bambusoideae*).

B1 – Bodogol forest: dominated by rasamala (*Altingia excelsa*), grasses, and bushes.

B2 – Bodogol forest: dominated by calliandra (*Calliandra* sp.), grasses, and bushes.

B3 – Bodogol forest: dominated by coffee (*Coffea* sp.), tepus (*Elateriospermum tapos*), grasses, and bushes.

B4 – Bodogol mixed plantation: dominated by coffee (*Coffea* sp.), talas (*Colocasia esculenta*), jackfruit (*Artocarpus heterophyllus*), and papaya (*Carica papaya*).

B5 – Bodogol mixed plantation: dominated by coffee (*Coffea* sp.), talas (*Co. esculenta*), manglid (*Magnolia blumei*), and java tea (*Orthosiphon aristatus*).

B6 – Bodogol avocado plantation (*Persea americana*). There were some cassava plantations (*Manihot esculenta*) and bushes surrounding the avocado plantation.

B7 – Bodogol avocado plantation (*P. americana*).

B8 – Bodogol cucumber plantation (*Cucumis sativus*).

B9 – Bodogol cassava plantation (*M. esculenta*).

S1 – Situ Gunung forest: dominated by rasamala (*Al. excelsa*), tepus (*Et. tapos*), grasses, and bushes.

S2 – Situ Gunung forest: dominated by dammar (*Agathis dammara*), grasses, and bushes.

S3 – Situ Gunung forest: dominated by rasamala (*Al. excelsa*), sago palm (*Cycas* sp.), grasses, and bushes.

S4 – Situ Gunung cabbage plantation (*Brassica oleracea capitata*).

S5 – Situ Gunung cassava plantation (*M. esculenta*).

S6 – Situ Gunung chili plantation (*Capsicum* sp.).

S7 – Situ Gunung onion plantation (*Allium cepa*).

S8 – Situ Gunung groundnut plantation (*Arachis hypogaea*).

S9 – Situ Gunung Chinese chard plantation (*Brassica rapa chinensis*).
Within forests and mixed plantations, earthworms were collected from soil under cleared grasses, bushes, and litters. Meanwhile, in homogenous plantations, earthworms were collected from soil between rows of the plantations.

Earthworm extraction was conducted using a digging and hand-sorting method. A single plot 900 cm$^2$ wide and 30 cm deep was set up, as earthworms are generally concentrated in the upper 30 cm (Fragoso & Lavelle 1992, Smith et al. 2008). Due to the different topographical conditions, the amount of plots made in each area varied from 10 to 75. Those plots in each area were placed randomly and were separated 100 cm apart from each other.

Extracted earthworms were preserved in 70% ethanol prior to identification. Earthworm identification was based on criteria established by Stephenson (1923), Sims & Easton (1972), Easton (1979), and Blakemore (2010).

**Result**

We recovered 23 species in 10 genera and 5 families. *Pontoscolex corethrurus* was the only species found in Jambi. Most of the recorded species were megascolecid in Mount Gede with *Ocnerodrilus occidentalis* Eisen, 1878 was the most dominant species.

**Phylum Annelida, Class Oligochaeta, Superorder Haplotaxida, Order Megadrili, Suborder Lumbricina**

**Family Glossoscolecidae**

**Genus Pontoscolex**
1. *Pontoscolex corethrurus* (Muller, 1857)

**Family Megascolecidae**

2. *Amynthas aeruginosus* (Kinberg, 1867)
3. *Amynthas asiaticus* Michaelsen, 1900
4. *Amynthas gracilis* (Kinberg, 1867)
5. *Amynthas hupeiensis* (Michaelsen, 1895)
6. *Amynthas illotus* species-group sensu Sims & Easton, 1972
7. *Amynthas minimus* (Horst, 1893)
8. *Amynthas morrisi* species-group sensu Sims & Easton, 1972
9. *Amynthas robustus* (Perrier, 1872)

**Genus Metaphire**

10. *Metaphire californica* (Kinberg, 1867)
11. *Metaphire javanica* (Kinberg, 1867)
12. *Metaphire planata* (Gates, 1926)

**Genus Notoscolex**

13. *Notoscolex javanica* (Michaelsen, 1910)
Genus *Perionyx*
14. *Perionyx excavatus* Perrier, 1872

Genus *Pheretima*
15. *Pheretima darnleiensis* (Fletcher, 1886)
16. *Pheretima pura* species-group of Sims & Easton, 1972

Genus *Polypheretima*
17. *Polypheretima bifaria* species-group of Easton, 1979
18. *Polypheretima moelleri* (Michaelsen, 1921)

Family Ocnerodrilidae
Genus *Ocnerodrilus*
20. *Ocnerodrilus occidentalis* Eisen, 1878

Family Octochaetidae
Genus *Dichogaster*
21. *Dichogaster affinis* (Michaelsen, 1890)

Suborder Moniligastrida
Family Moniligastridae
Genus *Drawida*
22. *Drawida barwelli* (Beddard, 1886)
23. *Drawida nepalensis* Michaelsen, 1907

**Taxonomy**

*Amyntas aeruginosus* Kinberg, 1867

*Perichaeta aeruginosa* Beddard, 1891:278.
*Pheretima aeruginosa*: Michaelsen, 1900: 253; Michaelsen, 1903: 94.

**Material examined.** 3 aclitellate specimens (dissected), Situ Gunung forest, coll. A. Darmawan, 8 and 18 Oct 2012.

occupying 16-18, ducts open to 18, copulatory pouches absent. Spermathecae 7/8, 8/9, paired, no nephridia.

**Distribution:** Cosmopolitan. Oceania domain (Michaelsen 1900, Lee 1981, Easton 1984), Indonesia (Java) (Michaelsen 1903), West New Guinea (Cognetti 1914).

**Remarks:** The name given by Kinberg (1867) was probably incorrect spelling of *Amynthas*. Blakemore (2015, pers. comm.) commented this issue “the name *Amyntas* was incorrect subsequent spelling of correct name *Amynthas* in the same Kinberg paper. This caused problems of homonymy because there is already a genus *Amyntas* (no "h"). Hence somebody put *Pheretima* as the prior genus. But that was a mistake and the correct original and prior genus should be *Amynthas*. *Pheretima* is retained but is a separate (and subordinate).

**Amynthas asiaticus** Michaelsen, 1900

*Amynthas asiaticus* Michaelsen, 1900:13. [Type locality Tien-Tsin, China on Tibet borders. Types in Moscow Museum].

*Pheretima asiatica*: Michaelsen, 1900: 527.


**Material examined.** - 2 mature (clitellate) specimens (dissected), Bodogol Forest, coll. A. Darmawan, 30 Jul 2012.


**Distribution:** China, Tibet, SE Asia (Blakemore 2010).

**Remarks:** The name given by Michaelsen (1900) was probably refered to *Amynthas*. See remarks on *A. aeruginosus*. 
**Amynthas gracilis** (Kinberg, 1867)

*Nitocris gracilis* Kinberg, 1867: 102. [Type locality Rio de Janeiro. Types in Stockholm Museum].

*Perichaeta hawayana* Rosa, 1891: 396. [Type locality Hawaii. Type in Vienna].

*Perichaeta bermudensis* Beddard, 1892: 160.


*Amyntas ijimae*: Beddard, 1900: 635.

*Pheretima hawayana*: Michaelsen, 1900: 271, 316.

*Amynthas hawayanus*: Beddard, 1900: 420.


**Material examined.** -2 mature (clitellate, 1 half-broken, dissected), and 4 not fully mature (aclitellate, dissected), Situ Gunung forest, coll. A. Darmawan, 10 Oct 2012; 1 not fully mature (aclitellate, dissected), cabbage plantation in Situ Gunung, coll. A. Darmawan, 2 Dec 2013.


**Amynthas hupeiensis** (Michaelsen, 1895)

*Perichaeta hupeiensis* Michaelsen, 1895: 35, fig. 11-12. [Type locality Shi-hui-yao by Wu-chang in the province of Hupei, China].

*Amyntas hupeiensis*: Michaelsen, 1899: 6. [From Central Japan (Nakahama)].


Material examined. -2 mature (clitellate, 1 half-broken, dissected), and 2 not fully mature (acclitellate, dissected), Bodogol forest, coll. A. Darmawan, 30 Jul 2012


Distribution: East Asia, Vietnam (Michaelsen 1899, Michaelsen 1900, Easton 1981, Blakemore 2010) and introduced into North America, New Zealand (Easton 1981), Australia.

Amynthas illotus species-group sensu Sims & Easton, 1972

Amynthas illotus species-group Sims & Easton, 1972: 236.
Amynthas illotus group; Easton, 1981: 53.
Amynthas illotus group; Tsai et al., 2002.

Material examined. -2 aclitellate (dissected), Bodogol mixed plantation, coll A. Darmawan, 10 and 14 Oct 2013; 1 aclitellate (dissected), Bodogol avocado plantation, coll A. Darmawan, 30 Sep 2013; 1 aclitellate (dissected), Situ Gunung forest, coll A. Darmawan, 12 Oct 1012; 1 aclitellate (dissected), Situ Gunung forest, coll A. Darmawan, 18 Oct 2012; 1 aclitellate (dissected), Situ Gunung chilli plantation, coll A. Darmawan, 9 Dec 2013.

Parthenogenetic morph of this species may be lacking of male reproductive organs.

**Distribution**: Most of these parthenogenetic events have no particular biogeographic nor phylogenetic merit. Reported from China, Taiwan, Korea, Japan, Myanmar (Blakemore 2010).

**Amynthas minimus** (Horst, 1893)

*Perichaeta minima* Horst, 1893: 66, fig. 27. [Type locality Tjibodas, Java. Primary type in Leiden Museum: 1836].

*Pheretima enchytraeoides* Michaelsen, 1916: 33. [Type locality in Queensland].

*Pheretima zoysiae* Chen, 1933: 288, fig. 27. [Type locality Chekiang. Types in Nanking (Ann. 570) or in Smithsonian Institution].

*Pheretima humilis* Gates, 1942: 120.

*Pheretima subtilis* Gates, 1943: 104.


**Material examined**. -1 mature (clitellate), dissected, Situ Gunung forest, coll A. Darmawan, 8 Oct 2012.


**Distribution**: USA, West and South Africa, Oriental domain, Papua New Guinea, Australia, Oceania domain (Blakemore 2010).

**Amynthas morrisi** species-group sensu Sims & Easton, 1972

*Perichaeta morrisi* Beddard, 1892: 166, Pl. IX, fig. 1. [Types in British Museum 1904:10.5.199-201].


*Amynthas barbadensis*: Michaelsen, 1900: 254.

*Pheretima hawayana lineata* Gates, 1926: 154; 1931: 384-386, fig. 24 of spermathecae.
Amynthas morrisi: Sims & Easton, 1972: 236, figs. 1A, 1H; Easton, 1981: 55; Easton, 1982: 729, fig. 4c; Sims & Gerard, 1985: 132, fig. 47a; Chang et al., 2009: 60, fig. 26.


Distribution: Originally from China or Japan. Reported in Middle and South America (Gates 1982, Brown & Fragoso 2007), Europe (England, Spain, Italy), Oriental domain (Gates 1972), New Guinea (Sillitoe 2003), Australia (Brisbane) (Easton 1982), Hawaii.

Amynthas robustus (Perrier, 1872)

Perichaeta robusta Perrier, 1872: 112, figs. 67-68. [Type locality Ile de France (= Mauritius). Types in Paris Museum].


Distribution: A probable homeland is in China (Gates 1972). Reported from Oriental domain (Thai & Samphon 1991), China, Taiwan, Korea, Japan (Easton 1981).

Dichogaster affinis (Michaelsen, 1890)

Benhamia affinis Michaelsen, 1890: 9, fig. 20. [Type locality Quelimane, Zanzibar. Type in Hamburg Museum.]

Benhamia mexicana Rosa, 1891: 394.

Benhamia crassa Beddard, 1893: 681, figs. 6,7. [Types at Kew obtained from Lagos. Type BMNH 1904:10:5:829].


**Drawida barwelli** (Beddard, 1886)

*Moniligaster barwelli* Beddard, 1886: 94, figs. 4-6; Beddard, 1887: 678; Beddard, 1893: 692; Beddard, 1895: 200. [Type locality Manila, Luzon, P.I].

*Moniligaster bahamensis* Beddard, 1893: 690, figs 1-5; Beddard, 1895: 202. [Type locality Bahamas].

*Drawida barwelli* (part?): Michaelsen, 1900: 116.


*Drawida japonicus bahamensis*: Michaelsen, 1910: 50.


**Drawida nepalensis** Michaelsen, 1907

*Drawida burchardi* Michaelsen, 1903: 7. [From Sumatra (Lomgei Lalah, Indragiri)].


*Drawida troglodytes* Stephensen, 1924: 129. [From 2.000 ft. at entrance, Siju Cave, Garo Hills, Assam. Type in Indian Museum W 1150/1].

**Material examined.** - 2 not fully mature (aclitellate, 1 half broken), dissected, Bodogol forest, coll. A. Darmawan, 7 Aug 2012; 1 mature (clitellate), dissected, Situ Gunung forest, coll. A. Darmawan, 10 Oct 2012; 1 not fully mature (aclitellate), dissected, Situ Gunung forest, coll. A. Darmawan, 8 Oct 2012.


**Distribution:** Oriental domain, China.

**Metaphire californica** (Kinberg, 1867)

Pheretima californica (part) Kinberg, 1867:102. [Type locality Sausolita Bay, California. Types from San Francisco in the Stockholm Museum: 160].

Perichaeta hesperidum Beddard, 1892:169. [Type locality Barbados. Types BM 1904:10:5:13].

Amyntas hesperidum: Beddard, 1900: 417.


Pheretima kiangensis Michaelsen, 1931: 21. [Soochow. Types in Hamburg].

Pheretima sakaguchii Ohfuchi, 1938: 53, figs. 1-2. [From Wakayama-ken and Kochi-ken, i.e., widespread].


Distribution: Probably indigenous to China or Japan. Recorded many times from the around the world: American continent, South Africa, Portugal (Madeira, Azores), Egypt, Greece, French, Lebanon, Myanmar, Vietnam, China, Taiwan, Japan, Australia, Hawaii, Easter Island.

Metaphire javanica sensu stricto Blakemore, 2010

Rhodopis javanica Kinberg, 1867: 102. [Type locality Tjibodas, Java. Types in Stockholm Museum: 1946].

Perichaeta javanica Beddard, 1891: 76.

Perichaeta operculata Rosa 1891: 98.

Pheretima capensis: Michaelsen, 1900: 259-260.


Material examined.-2 mature (clitellate, half broken), dissected, Bodogol forest, 30 Jul and 7 Aug 2012; 1 mature (clitellate), dissected, Situ Gunung forest, coll. A. Darmawan, 8 Oct 2012.

**Distribution**: South Africa, Indonesia (Java), Timor, China (Hongkong).

*Metaphire planata* (Gates, 1926)


**Distribution**: India, Bangladesh (Dacca), Myanmar, Thailand (Chiangmai, Ko Chang), Malaysia.

*Notoscolex javanica* (Michaelsen, 1910)

*Woodwardia javanica* Michaelsen, 1910: 93. [Buitenzorg, Java].


**Distribution:** Myanmar (Boyagyi, Thaton district, Mupun, Amherst district) and Java (presumably by introduction).

**Ocnerodrilus occidentalis** Eisen, 1878


*Ocnerodrilus calwoodi* Michaelsen, 1898/9.

*Ocnerodrilus tenellulus* Gates, 1945:223. [Type locality Allahabad].


**Distribution:** The original home is thought to be in Central or South America. Pantropical, especially if all the reports of various parthenogenetic morphs are included, Australia and Tasmania (Blakemore 2010), less frequently found in temperate regions.

**Perionyx excavatus** Perrier, 1872

*Perionyx excavatus* Perrier, 1872: 126, figs. 73, 74. [Type locality Saigon. Types in Paris Museum]; Michaelsen, 1900: 208; Stephenson, 1932: 50; Gates, 1972: 141, 1982: 36.


*Perionyx intermedius* Beddard, 1892: 689.
**Perionyx parvulus** Stephenson, 1916: 321, fig. 15. [Types in Calcutta].

**Perionyx fulvus** Stephenson, 1916: 322.

**Material examined.**-1 mature (clitellate), dissected, Bodogol mixed plantation, coll. A. Darmawan, 10 Oct 2013.


**Distribution:** Original home of this species is believed to be in the Himalayas, deliberate or accidental transportation has greatly extended its range. Reported in USA, Mexico, West Indies (Dominica and Cuba), Africa (Comoro, Samoa, Reunion), Madagascar, UK, Oriental domain, Japan, Korea, Australia, New Zealand, Fiji, Hawaii. Rarely reported from northern Europe.

**Pheretima darnleiensis** (Fletcher, 1886)

**Perichaeta darnleiensis** Fletcher, 1886:966. [From Darnley Island, Torres Straits, Australia].

**Perichaeta vaillanti** Beddard, 1895: 422; Michaelsen, 1900: 311.

**Perichaeta martensi** Michaelsen, 1892: 242. [From Banka Island east of Sumatra. Types Berlin: 2148]; Michaelsen 1900: 282.

**Perichaeta boschiae** Beddard, 1895: 432; Michaelsen, 1900: 256.

**Perichaeta darnleiensis:** Beddard, 1895: 406.

**Amyntas padasensis lokonensis** Michaelsen, 1899:74. [From Lokon-Gipfel, Tomohon, North Celebes. Type in Basel Museum].

**Amyntas padasensis madelinae:** Michaelsen, 1899:76.

**Amyntas padasensis padasensis:** Michaelsen, 1899: 74.

**Amyntas martensi:** Michaelsen, 1899: 87.

**Amyntas padasensis:** Beddard, 1900a: 624.

**Pheretima belli:** Michaelsen, 1900: 255.

**Pheretima boschiae:** Michaelsen, 1900: 256.

**Pheretima darnleyensis:** Michaelsen, 1900: 263.

**Pheretima floweri:** Michaelsen, 1900: 267.


**Pheretima martensi:** Michaelsen, 1900: 282.

**Pheretima padasensis typica:** Michaelsen, 1900: 290.

**Pheretima padasensis lokonensis:** Michaelsen, 1900: 290.
**Pheretima padasensis madelinae**: Michaelsen, 1900: 291.

**Pheretima vaillanti**: Michaelsen, 1900: 311.

**Pheretima decipiens** Beddard, 1912: 180. [From Luzon, Philippines].

**Pheretima benguetensis** Beddard, 1912: 183, fig. 1. [From 1,524 m in the Province of Benguet, Luzon, Philippines].

**Pheretima kuchingensis** Stephenson, 1916: 337. [Type in Calcutta: 6539].

**Pheretima indica birangi** Michaelsen, 1928: 42.

**Pheretima floweri**: Gates, 1934: 25.

**Pheretima padasensis**: Kobayashi, 1941: 397. [Type in Calcutta: 6539].


**Material examined**.—3 mature (clitellate), dissected, Bodogol avocado plantation, coll. A. Darmawan, 3 and 7 Oct 2013.


**Distribution**: the tropical Indo-Australasian Archipelago and islands, (Stephensen 1932, Gates 1935, Michaelsen 1935) Fiji and Darnley Island in the Torres Straits.

**Pheretima pura species-group of Sims & Easton, 1972**

**Pheretima pura** Michaelsen 1900: 296

**Pheretima pura**: Sims & Easton, 1972: 220

**Material examined**.—1 not fully mature (aclitellate), dissected, Bodogol combined avocado and cassava plantation, 30 Sep 2013.


**Distribution**: Lesser Sunda Islands (Nugroho 2010), Lombok (Michaelsen 1900).

**Remarks**: This species was identified following Sims & Easton (1972). They did not include the description in their paper.

**Polypheretima bifaria** species-group of Easton, 1979

*Pheretima bifaria* Michaelsen, 1924: 18.

*Pheretima (Polypheretima) bifaria*: Michaelsen, 1934: 16.

*Pheretima (Polypheretima) bifaria typical*: Michaelsen, 1938: 171.


**Polypheretima bifaria**: Easton, 1979: 41, figs. 14h, 19a.

**Material examined.** - 1 not fully mature, dissected, Situ Gunung forest, coll. A. Darmawan, 18 Oct 2012.


**Distribution**: Kepulauan Aru (Easton 1979), Papua New Guinea (Blakemore & Nugroho 2008).

**Polypheretima moelleri** (Michaelsen, 1921)

*Pheretima moelleri* Michaelsen, 1921: 12

*Metapheretima moelleri*: Sims & Easton, 1972: 233

**Polypheretima moelleri**: Easton, 1979: 38, fig. 14c.

**Material examined.** - 1 mature (clitellate), dissected, Situ Gunung forest, coll. A. Darmawan, 8 Oct 2012; 3 not fully mature (aclitellate), dissected, Situ Gunung forest, coll. A. Darmawan, 8 Oct 2012.
**Polypheretima sempolensis** Easton, 1979

*Polypheretima sempolensis* Easton, 1979: 39, figs. 14d, 18b.

**Material examined.** -2 mature (clitellate), dissected, Situ Gunung forest, coll. A. Darmawan, 8 and 12 Oct 2012; 1 not fully mature (aclitellate), dissected, Situ Gunung forest, coll. A. Darmawan, 12 Oct 2012.


**Distribution:** Indonesia (Mount Raung, Sempol (1400–1500 m), East Java) (Easton 1979, Blakemore & Nugroho 2008).


**Pontoscolex hawaiiensis** Beddard, 1895: 660. [From Hawaii]; 1900: 414.


**Distribution**: Supposedly “the most widely distributed earthworm” (Gates 1972). Pan tropical: Nearctic, Neotropical, Afrotropics, Palearctic, Oriental, and Australasia domain. Also reported in American continent, African continent, Oceania domain.

**Key to the species of earthworms in Bungku Village and Mount Gede**

1. Gizzard absent .......................................................... 2
   Gizzard present ........................................................ 3

2. Male pores on 17, setae lumbricine ................................. *Ocnerodrilus occidentalis*
   Male pores on 18 on ventral, setae perichaetine ............. *Perionyx excavatus*

3. Gizzard single .......................................................... 4
   Gizzards multiple .................................................... 21

4. Caeca absent ............................................................. 5
   Caeca present ........................................................ 9
5. Setae lumbricine ................................................................................................... 6
   Setae perichaetina ................................................................................................. 7

6. Male pores on 18 ................................................................................................... 6
   Notoscolex javanica
   Male pores not clearly defined, setae quincunx in posterior .................................. 7
   Pontoscolex corethrurus

7. Spermathecal pores and spermathecae two pairs in 5/6/7 .................................... 8
   Polypheretima sempolensis
   Spermathecal pores and spermathecae more than two pairs .................................. 8

8. Spermathecal pores and spermathecae three pairs in 5/6/7/8 ............................... 8
   Polypheretima bifaria species-group
   Spermathecal pores and spermathecae five pairs in 4/5/6/7/8/9 ............................ 8
   Polypheretima moelleri

9. Copulatory pouches present ................................................................................ 10
   Copulatory pouches absent ................................................................................ 14

10. Spermathecal duct with nephridia ...................................................................... 11
    Spermathecal duct without nephridia .................................................................... 12

11. First spermathecal pores on 5/6, four thecal segments .......................... Pheretima darnleiensis
    First spermathecal pores on 6/7, two thecal segments ........................................ 11
    Pheretima pura species-group

12. First spermathecal pore near 6/7 ....................................................................... 13
    Metaphire planata
    First spermathecal pore on 7/8 ........................................................................... 13

13. Male pores on 18, paired, ca. 0.2-0.3 ................................................................. 13
    Metaphire javanica
    Male pores on 18, paired, ca. 0.3-0.4 ................................................................. 13
    Metaphire californica

14. Spermathecal pores absent, athecate ................................................................. 15
    Amynthas illotus species-group
    Spermathecal pores present ............................................................................... 15

15. One thecal segment, first spermathecal pore on 5/6 ................................. Amynthas minimus
    More than one thecal segments ....................................................................... 16

16. First spermathecal pore on 5/6 ........................................................................... 17
    First spermathecal pore posterior to 5/6 ............................................................. 18
17. Two thecal segments ....................................... *Amynthas morrisi* species-group
   Three thecal segments .................................................. *Amynthas gracilis*

18. First spermathecal pore on 6/7................................................. 19
   First spermathecal pore on 7/8.................................................. 20

19. Genital markings absent .................................................. *Amynthas asiaticus*
   Genital markings present .................................................. *Amynthas hupeiensis*

20. Male pores on 18, paired, ca. about 0.25 .................................. *Amynthas aeruginosus*
   Male pores on 18, paired, ca. 0.3-0.5 ........................................ *Amynthas robustus*

21. Two gizzards, co-joined .................................................. *Dichogaster affinis*
   More than two gizzards, moniliform ........................................ 22

22. Three gizzards in 13-15 .................................................. *Drawida barwelli*
   Four gizzards in 14-25,26 .................................................. *Drawida nepalensis*

References


Beddard FE. 1891. Several papers. *Proceedings of Zoological Society of London.* Available at:
   http://www.archive.org/stream/proceedings03londgoog#page/n9/mode/1up.


Michaelsen W. 1891. Oligochaeta des Naturhistorischen Museums in Hamburg. IV. Jahrbuch der Hamburgischen Wissenschaftlichen Anstalten, Hamburg. 8: 3-42.


Michaelsen W. 1916. Results of Dr E. Mjoberg's Swedish Expedition to Australia 1910-1913. Kungliga Svenska Vetenskapsakademien ens Handlingar. 52: 3-74.


Appendix 2.1 Compilation of earthworm species in Indonesia.

Family Almidae
Glyphidrilus buettikoferi Michaelsen, 1922: 9
Glyphidrilus papillatus (Rosa, 1890)
Glyphidrilus quadrangulus (Horst, 1893: 44)
Glyphidrilus weberi Horst, 1889: 76

Family Glossoscolecidae
Pontoscolex corethrurus (Müller, 1857)

Family Lumbricidae
Bimastos parvus (Eisen, 1874)
Eisenia fetida (Savigny, 1826)

Family Megascolecidae
Amynthas acrophilus (Rosa, 1896: 527)
Amynthas aelianus (Rosa, 1892: 545)
Amynthas aeruginosus (Kinberg, 1867: 101)
Amynthas agilis (Michaelsen, 1923: 2)
Amynthas baliensis (Michaelsen, 1932)
Amynthas benhami (Ude, 1932: 174)
Amynthas bontainensis (Benham, 1896: 437)
Amynthas buitendijki (Michaelsen, 1922: 45)
Amynthas castaneus Michaelsen, 1899: 56
Amynthas colossus (Cognetti, 1911: 6)
Amynthas copulatrix (Michaelsen, 1923: 2)
Amynthas dalensis (Michaelsen, 1932)
Amynthas dammermani (Michaelsen, 1924: 391)
Amynthas digitatus (Benham, 1896: 432)
Amynthas doormanii (Michaelsen, 1924: 20)
Amynthas dorous (Michaelsen, 1934: 104)
Amynthas enganensis enganensis (Rosa, 1892: 546)
Amynthas enganensis tetrus (Rosa, 1892: 548)
Amynthas festivus (Michaelsen, 1922: 37)
Amynthas fissiger Michaelsen, 1899: 67
Amynthas gastrizusus (Michaelsen, 1928: 292)
Amynthas glandulosus (Rosa, 1896: 524)
Amynthas gracilis (Kinberg, 1867: 102)
Amynthas halmaheranae baijanensis (Michaelsen, 1896: 269)
Amynthas halmaheranae caecilus (Michaelsen, 1896)
Amynthas halmaheranae galileensis (Michaelsen, 1896)
Amynthas halmaheranae gamsungi (Michaelsen, 1896)
Amynthas halmaheranae halmaheranae (Michaelsen, 1896)
Amynthas halmaheranae imparicystis (Michaelsen, 1896)
Amynthas halmaheranae kauensis (Michaelsen, 1896: 220)
Amynthas heurni (Michaelsen, 1924: 23)
Amynthas hexathecus (Benham, 1897: 440)
Amynthas jacobsoni (Michaelsen, 1922)
Amynthas jampeanus fumigatus Michaelsen, 1899: 64
Amynthas jampeanus jampeanus (Benham, 1896: 430)
Amynthas juleshii (Benham, 1896: 431)
Amynthas juloides Michaelsen, 1899: 53
Amynthas keianus (Michaelsen, 1924/5: 394)
Amynthas lalangi (Michaelsen, 1923: 5)
Amynthas lompobatangensis Michaelsen, 1899: 33
Amynthas maximus (Cognetti, 1915: 493)
Amynthas minahassae (Michaelsen, 1896: 235)
Amynthas minimus (Horst, 1893)
Amynthas misellos (Cognetti, 1913: 291)
Amynthas miserus (Cognetti, 1913: 292)
Amynthas moerbergi (Michaelsen, 1923: 10)
Amynthas modiglianii (Rosa, 1889: 134)
Amynthas nanus (Rosa, 1896: 519)
Amynthas noebianus (Michaelsen, 1934: 114)
Amynthas ocellatus Michaelsen, 1899: 89
Amynthas orenkensis (Cognetti, 1911: 3)
Amynthas pataniensis labuensis (Michaelsen, 1896: 224)
Amynthas pataniensis pataniensis (Michaelsen, 1896: 212, 222)
Amynthas petahanus (Michaelsen, 1934: 102)
Amynthas principalis (Michaelsen, 1932)
Amynthas proporus (Rosa, 1896)
Amynthas purpureus (Benham, 1897: 445)
Amynthas rodericensis (Grube, 1879)
Amynthas sarasinorum (Michaelsen, 1899)
Amynthas semifasciatus (Michaelsen, 1899)
Amynthas silvestris (Michaelsen, 1923: 16)
Amynthas sinabunganus (Michaelsen, 1923: 12)
Amynthas supuensis (Michaelsen, 1896: 225)
Amynthas thienemanni (Michaelsen, 1932: 602)
Amynthas tobaensis Michaelsen, 1899: 91
Amynthas udei (Rosa, 1896)
Amynthas versteegi (Michaelsen, 1938: 172)
Amynthas vialis (Michaelsen, 1924: 25)
Amynthas vordermani (Horst, 1890)
Amynthas wetzeli (Ude, 1932)
Amynthas winkleri (Michaelsen, 1928: 29)
Amynthas zebras (Bennh, 1896: 442)
Amynthas ? forbesi (Beddard, 1890: 65)
Archipheretima picta (Michaelsen, 1892: 246)
Archipheretima zonata (Michaelsen, 1922: 42)
Lampito mauritii Kinberg, 1866/7
Megascolex filiciseta Stephenson, 1915: 94
Metapheretima carolinensis (Michaelsen, 1910)
Metapheretima joccana (Cognetti, 1911: 5)
Metapheretima sembalunensis (Ude, 1932: 139)
Metaphire baliensis (Gates, 1948: 144)
Metaphire berhalana (Stephenson, 1930: 1)
Metaphire bindjeyensis (Michaelsen, 1899: 94)
Metaphire bryoni (Michaelsen in Michaelsen and Boldt, 1932: 618)
Metaphire burchardi burchardi (Michaelsen, 1899: 88)
Metaphire caducichaeta (Benham, 1895: 47)
Metaphire cai (Michaelsen, 1916: 14)
Metaphire california (Kinberg, 1867: 102)
Metaphire densipapillata (Michaelsen, 1896: 227)
Metaphire ditheca (Michaelsen, 1928)
Metaphire falcata (Horst, 1893: 316)
Metaphire fasciata (Rosa, 1892: 543)
Metaphire ferrinandi (Michaelsen, 1891: 38)
Metaphire ferion (Cognetti, 1913: 298)
Metaphire feuerborni (Michaelsen in Michaelsen and Boldt, 1932: 605)
Metaphire floresiana (Michaelsen, 1934: 108)
Metaphire gylleleri (Cognetti, 1914: 358)
Metaphire houlleti (Perrier, 1872)
Metaphire impudens (Michaelsen, 1899: 84)
Metaphire insignis (Michaelsen, 1921: 14)
Metaphire javanica (Kimberg, 1866/7)
Metaphire kockensis (Michaelsen, 1930: 2)
Metaphire longa (Michaelsen, 1892: 239)
Metaphire musiana (Michaelsen, 1932: 614)
Metaphire musica (Horst, 1883: 193)
Metaphire notizusa (Michaelsen, 1928)
Metaphire pajana (Michaelsen, 1928: 33)
Metaphire peguana (Rosa, 1890: 113)
Metaphire posthuma (Vaillant, 1868/9: 228)
Metaphire quadrstaria (Perrier, 1872: 122)
Metaphire quadrupapillata (Michaelsen, 1899: 93)
Metaphire saonekana (Cognetti, 1913: 39)
Metaphire singalangi (Michaelsen, 1930: 3)
Metaphire sintangi (Michaelsen, 1922: 28)
Metaphire tjanulana (Michaelsen, 1932: 5)
Metaphire variabilis (Horst, 1893)
Metaphire weberi (Cognetti, 1913: 37)
Metaphire willeyi (Benham, 1895)
Natoscolex javanica (Michaelsen, 1910: 93)
Perionyx excavatus Perrier, 1872
Perionyx violaceus Horst, 1893
Pheretima (Parapheretima) aberrans Cognetti, 1911: 2
Pheretima (Parapheretima) algmaarica Cognetti, 1913: 298
Pheretima (Parapheretima) barbara barbara Cognetti, 1913: 302
Pheretima (Parapheretima) barbica Blakemore, 2004: 129
Pheretima (Parapheretima) beaufortii apotrema Cognetti, 1913: 297
Pheretima (Parapheretima) beaufortii beaufortii Cognetti, 1911: 3
Pheretima (Parapheretima) bernhardi (Gates, 1948: 149)
Pheretima (Parapheretima) hellwigiana Cognetti, 1913: 300
Pheretima (Parapheretima) pluviosa Cognetti, 1913: 300
Pheretima (Parapheretima) rufa Gates, 1948: 160
Pheretima (Parapheretima) utakwana Cognetti, 1915: 494
Pheretima (Pheretima) ambonensis Cognetti, 1913: 40
Pheretima (Pheretima) ceramensis Cognetti, 1922: 1
Pheretima (Pheretima) darbleisen (Fletcher, 1886: 966)
Pheretima (Pheretima) dubia (Horst, 1893: 68)
Pheretima (Pheretima) habbemana Gates, 1948: 151
Pheretima (Pheretima) korinchiana Cognetti, 1922: 2
Pheretima (Pheretima) leopoldi Michaelsen, 1930: 4
Pheretima (Pheretima) montana Kinberg, 1867: 102
Pheretima (Pheretima) philippina (Rosa, 1891: 397)
Pheretima (Pheretima) poisana Michaelsen, 1913: 88
Pheretima (Pheretima) pura (Rosa, 1898: 285)
Pheretima (Pheretima) racemosa (Rosa, 1891: 399)
Pheretima (Pheretima) sangirensis chica (Michaelsen, 1896: 207)
Pheretima (Pheretima) sangirensis crassicyctis (Michaelsen, 1896: 204)
Pheretima (Pheretima) sangirensis (Michaelsen, 1891: 36)
Pheretima (Pheretima) sluiteri (Horst, 1890)
Pheretima (Pheretima) tosariana Cognetti, 1913: 38
Pheretima (Pheretima) urceolata (Horst, 1893: 322)
Pheretima? atheca (Rosa, 1896: 520)
Pheretima? flabellifera Cognetti, 1911: 2
Pithemera bicincta (Perrier, 1875: 1004)
Pithemera? liangi (Michaelsen, 1922: 36)
Planapheretima celebensis (Michaelsen, 1899: 32)
Planapheretima hasselti (Horst, 1883: 190)
Planapheretima nieuwenhuisi (Michaelsen, 1922: 47)
Planapheretima rufomaculata (Gates, 1948: 162)
Planapheretima subulata (Michaelsen, 1899: 29)
Pleionogaster horsti (Beddard, 1886: 300)
Polypheretima annulata (Horst, 1883: 195)
Polypheretima badia (Ude, 1932: 171)
Polypheretima bifaria (Michaelsen, 1924: 18)
Polypheretima brevis (Rosa, 1898: 283 or 288)
Polypheretima elberti (Ude, 1932: 175)
Polypheretima elongata (Perrier, 1872: 124)
Polypheretima everetti (Beddard and Fedarb, 1895: 69)
Polypheretima fakfakensis (Cognetti, 1908: 1)
Polypheretima gatesi Easton, 1979: 44
Polypheretima grata (Cognetti, 1914: 362)
Polypheretima kellneri (Ude, 1932: 177)
Polypheretima lesonae Easton, 1979: 51
Polypheretima mertonii (Michaelsen, 1910: 256)
Polypheretima panarana (Michaelsen, 1938: 167)
Polypheretima phacellotheca (Michaelsen, 1899: 47)
Polypheretima renshi (Ude, 1932: 141)
Polypheretima sempolensis Easton, 1979: 39
Polypheretima sibogae (Michaelsen, 1922: 23)
Polypheretima stelleri (Michaelsen, 1891: 39)
Polypheretima swelaensis (Ude, 1932: 178)
Polypheretima? moelleri (Michaelsen, 1921: 12)
Pontodrilus litoralis (Grube, 1855)

Family Moniligastridae
Desmogaster buettikoferii (Horst, 1884: 105)
Desmogaster giardi Horst, 1899: 293
Desmogaster horsti Beddard, 1895: 205
Desmogaster schildi Rosa, 1897: 339
Drawida barwelli (Beddard, 1886)
Drawida heterochaeta Michaelsen, 1922: 3
Drawida longatria longatria Gates, 1925: 50
Drawida nepalensis Michaelsen, 1907: 146
Drawida parva (Bourne, 1894)
Drawida ramnadana Michaelsen, 1907: 145
Eupolygaster coerulea (Horst, 1895: 137)
Eupolygaster modiglianii (Rosa, 1896: 503)
Hastirogaster houtenii houtenii (Horst, 1887: 97)
Hastirogaster houtenii rookmaakeri (Michaelsen, 1931: 78)
Moniligaster stralenii Michaelsen, 1930: 1

Family Ocnerodrilidae
Eukerria kuekenthali (Michaelsen, 1908)

Family Octochaetidae
Dichogaster affinis (Michaelsen, 1890)
Dichogaster annae (Horst, 1893)
Dichogaster boluai (Michaelsen, 1891)
Dichogaster modiglianii (Rosa, 1896)
Dichogaster sadiens (Beddard, 1893)
Dichogaster tamiana Cognetti, 1911: 6
Lennogaster pusilla (Stephenson, 1920: 252)
Lennogaster pusillus (Stephenson, 1920)
Ramiella bishambhari (Stephenson, 1914)
Pontoscolex corethrurus (Müller, 1857) (Oligochaeta: Glossoscolecidae) is a widely distributed exotic earthworm. We showed that Pn. corethrurus completely dominated the secondary forest and agricultural plantations in Bungku Village, Jambi Province, Sumatra, Indonesia. Bungku Village in Jambi consists of the forest undergoing transformation into oil palm plantation, rubber plantations, and rubber jungle. Purposive random sampling with hand-sorting method was conducted to extract Pn. corethrurus. We found that all of 940 recovered earthworms were Pn. corethrurus. Their density was not significantly different in the four systems. Our result showed that Pn. corethrurus abundance was significantly influenced by soil physical factor, mineral content, and texture. We propose that anthropogenic practice in Bungku Village caused the condition which does not support the native earthworms. Pn. corethrurus which have better tolerance than the native earthworms are favored by anthropogenic practice.

Key words: earthworm; exotic; oil palm; rubber; soil.

Introduction

Pontoscolex corethrurus (Müller, 1857) (Oligochaeta: Glossoscolecidae) is a widely distributed exotic earthworm (Brown et al. 2006, Gonzalez et al. 2006, Hendrix et al. 2006). This endogeic earthworm is originally native in South America and is the commonest earthworm in Brazil (Hendrix & Bohlen 2002). Nowadays, it is quite dispersed up to South Africa and Asia Pacific regions as alien species (Plisko 2001, Blakemore 2010). Its dispersal is probably related to the introduction of rubber plant, Hevea brasiliensis, from Brazil (Murdiyarso et al. 2002, Nath & Chaudhuri 2010) or pine seedling (Pinus sp.) (Plisko, 2001). Frequently, it becomes invasive competing with the native earthworms or...
colonizing the disturbed habitat where the native earthworms are reduced (Gonzalez et al. 2006).

Anthropogenic transformation of forest results in unfavorable and reduced resources for native earthworms (Hendrix et al. 2006, Marichal et al. 2010). *Pn. corethrurus* density increases with the increase in the age of disturbed habitat while the density of native earthworms decreases (Nath & Chaudhuri 2010). The native earthworms tend to disappear and *Pn. corethrurus* fills the niche (Gonzalez et al. 2006, Marichal et al. 2010). Although direct competition with native earthworms is common, the extirpation of natives is not easily demonstrated (Hendrix et al. 2006). On the other hand, Hendrix et al. (2006) stated that exotic earthworms invade ecosystem even in the absence of obvious human disturbance. Therefore, it requires more study to conclude that the anthropogenic influence is necessary for *Pn. corethrurus* to successfully invade the area.

Indonesia experienced almost half million hectare net loss of forest area in 2000-2010 (FAO 2010). Central Sumatra had annual deforestation rate of 3.2–5.9% (Achard et al. 2002) and Jambi is undergoing a rapid primary forest transformation into agricultural system (Murdiyarso & Wasrin 1995). Bungku Village in Jambi consists of the forest undergoing transformation into oil palm plantation, rubber plantation, and rubber jungle. Here, we showed that *Pn. corethrurus* completely dominated the secondary forest and agricultural plantations in Bungku Village, Jambi Province, Sumatra, Indonesia. Moreover, we also analyzed the soil parameters affecting their abundance.

### Material and Methods

#### Study Sites

Sampling was conducted on November 2012 in wet season in Bungku Village, Batanghari Regency, Jambi (1°15’-2°20’ south latitude - 120°30’-104°30’ east longitude) (Fig. 3.1). This area had average annual temperature of 25.5 °C and cumulative precipitation of 2700 mm (BPPD 2010). Sampling area comprised of 15 year-old oil palm plantation (S 01° 54’ 33.8”, E 103° 15’ 56.3”), 11 year-old rubber plantation (S 01° 54’ 39.6”, E 103° 15’ 59.3”), 19 year-old rubber jungle (S 01° 55’ 39.9”, E 103° 15’ 32.0”), and secondary forest (S 01° 54’ 52.1”, E 103° 15’ 57.3”). The coordinates were taken in the outer side of each system.

Dominant plants in oil palm plantation were oil palm, *Elais guineensis*, and grass (Gramineae). Rubber plantation consisted of only rubber, *H. brasiliensis*. Rubber jungle was dominated by rubber, Asian melastome, *Melastoma candidum*, grass, and billian, *Eusideroxylon zwageri*. Meanwhile, secondary forest was dominated by tempinis, *Sloetia elongata*, medang, *Litsea firma*, and bamboo (Bambusoideae). Vegetation analysis using profile method revealed that the structure of old jungle rubber and secondary forest are similar (Gouyon et al. 1993).
Figure 3.1 Study site in Jambi Province, Indonesia.

**Pontoscolex corethrurus Extraction**

Purposive random sampling was conducted to extract *Pn. corethrurus*. Three sets of sampling sites, about 20 m apart from each other, were placed in each system. Each set consisted of 25 of 30 x 30 cm and 30 cm depth plots placed randomly 1 m apart from each other, making total of 75 plots in each system. Hand-sorting method was carried out. *Pn. corethrurus* were cleansed with paper towel prior to recording the biomass and fixation in 70% ethanol. Due to insensitivity of the weight scale, we only measured the adult *Pn. corethrurus* biomass. Identification and description of *Pn. corethrurus* were conducted by following Blakemore method (2010). *Pn. corethrurus* with and without clitellum were classified into adult and juvenile, respectively. Meanwhile, *Pn. corethrurus* without anterior part was classified into unknown stage.

Soil Parameter

Human disturbance may cause changes in soil physical and chemical properties (Guariguata & Ostertag 2001) viz. temperature, pH, water, mineral content, and texture, which are directly related to the *Pn. corethrurus* abundance (Edwards 2004). Soil parameters observed were soil physical factors (temperature, pH, water content), mineral content (C-organic, P, Ca, Mg, K, Na), and texture (sand, silt, clay).

Soil physical factors were assessed in each plot. Soil temperature was measured using soil thermometer. Meanwhile, soil pH and water contents were measured using soil pH and humidity tester.

Soil mineral content and texture were assessed following compositing method. Soils from each set of sampling site were sampled, making total of 12 soil samples for 4 systems (3 samples for each system). Five hundred grams of soil was air dried prior to analyzing its C-organic, P, Ca, Mg, K, Na contents, and texture. The soils were analyzed for organic content and texture following Walkley-Black and Pipette method, respectively. Meanwhile, soil Ca, Mg, K, and Na contents were analyzed using neutral 1 M ammonium acetate (NH₄OAc) method. Afterward, soil phosphorus was analyzed using solution of HCl 25% (Sarkar & Haldar 2005). Soil analysis was conducted in Laboratory of Department of Soil Science and Land Resource, Faculty of Agriculture, Bogor Agricultural University.

Statistical Analysis

Data analysis was conducted using R 2.11.0 software (Ihaka & Gentleman 1996, R Development Core Team 2010). Kruskal-Wallis test in ‘agricolae’ package (Mendiburu 2010) was used to assess *Pn. corethrurus* density, adult biomass, and soil parameters in all systems. Soil factors influencing *Pn. corethrurus* abundance was analyzed by constructing generalized linear model as the abundance followed Poisson distribution (Zuur et al. 2009). *Pn. corethrurus* abundance as response, soil factors as predictors. Soil factors were transformed logarithmic naturally to meet the normality assumption. Outliers were removed from analysis. Collinearity among soil factors was assessed using Variance Inflation Factors, and the value of 3.00 was set as threshold. The model was simplified using drop1. The final model used was: *Pn. corethrurus* abundance ~ pH + water content + C-organic + Na + salt. Homogeneity of variance was assessed on model residual vs. fitted value and independence of soil factors was assessed on model residual vs. soil factors plot. No clear pattern on those plots indicated that the model met homogeneity of variance and independence assumption.
Result

Domination, Density, and Adult Biomass of *Pn. corethrurus* in Four Land Systems

A common effect of anthropogenic disturbance into agricultural system is domination of exotic earthworm like in Tripura, India, where *Pn. corethrurus* successfully dominated rubber plantation with >70% frequency (Chaudhuri et al. 2008, Chaudhuri & Nath 2011). We also found *Pn. corethrurus* in Bungku Village. All of 940 recovered earthworms there were *Pn. corethrurus*. Previous study by Bignell et al. (2000) found only two earthworm species in neighboring 15 years old monoculture rubber plantation and one species in secondary forest in Pasir Mayang, Jambi. However, they found five species in jungle rubber of Pancuran Gading, Jambi, which contained rubber trees and secondary forest regrowth with liana. Unfortunately, they did not mention the earthworm species. They concluded that earthworms had low diversity in Jambi except in Sengon (*Paraserianthes*) plantation and jungle rubber. In comparison, the other study conducted by Darmawan et al. (2015) (presented in this dissertation chapter 4) in undisturbed forest in West Java recovered more than six earthworm species including *Pn. corethrurus*.

*Pontoscolex corethrurus* density was not significantly different in the four systems (Table 3.1). All of our results were lower than previous study in Tripura, India, which found a *Pn. corethrurus* density of 78-88 ind/m² (Chaudhuri et al. 2008, Chaudhuri & Nath 2011).

The adult biomass ± SD of *Pn. corethrurus* in oil palm plantation, rubber plantation, rubber jungle, and secondary forest were 7.56 ± 6.25a, 4.74 ± 3.49b, 7.56 ± 6.23a, and 5.45 ± 4.15b g/m² respectively (p-value < 0.01). The values with the same letter are not different.

<table>
<thead>
<tr>
<th>System</th>
<th>Stage</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Juvenile</td>
<td>Adult</td>
</tr>
<tr>
<td>Oil palm plantation</td>
<td>7.85 ± 10.30</td>
<td>22.22 ± 19.55</td>
</tr>
<tr>
<td>Rubber plantation</td>
<td>5.78 ± 8.04</td>
<td>20.44 ± 17.90</td>
</tr>
<tr>
<td>Rubber jungle</td>
<td>8.74 ± 10.38</td>
<td>23.56 ± 18.08</td>
</tr>
<tr>
<td>Secondary forest</td>
<td>6.67 ± 9.13</td>
<td>20.00 ± 13.30</td>
</tr>
</tbody>
</table>

Table 3.1 Kruskal-Wallis test of *Pn. corethrurus* density in each system. The values are mean of *Pn. corethrurus* abundance/m² ± SD
Soil Parameters in Four Land Systems and Their Influence on *Pn. corethrurus* Abundance

Oil palm and rubber plantation had high value of soil phosphorus and potassium as the consequences of being fertilized with NPK (nitrogen, phosphate, potassium) by the landowner (Table 3.2). Conceptually, tree plantations may affect earthworm community structure through alteration of soil physical and chemical properties (Gonzalez et al. 1996, Sarlo 2006, Nadeem et al. 2007). However, rubber plantation and mixed forest which had similar soil properties consisted of different earthworm community structures in Tripura, India (Chaudhuri & Nath 2011). As earthworm abundance is affected by soil parameters, our result showed that *Pn. corethrurus* abundance was significantly influenced by soil physical factor, mineral content, and texture (Table 3.3).

### Table 3.2 Kruskal-Wallis test of soil parameters in each system. Mean ± SD, values with the same letter in a row are not significantly different (p-value < 0.05)

<table>
<thead>
<tr>
<th>System</th>
<th>Oil palm plantation</th>
<th>Rubber plantation</th>
<th>Rubber jungle</th>
<th>Secondary forest</th>
<th>All systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (ºC)</td>
<td>29.76 ± 1.46</td>
<td>27.81 ± 1.06</td>
<td>26.54 ± 1.14</td>
<td>27.47 ± 0.90</td>
<td>27.90 ± 1.65</td>
</tr>
<tr>
<td>pH</td>
<td>6.67 ± 0.15</td>
<td>6.51 ± 0.18</td>
<td>6.44 ± 0.16</td>
<td>6.47 ± 0.23</td>
<td>6.52 ± 0.20</td>
</tr>
<tr>
<td>Water content (%)</td>
<td>61.47 ± 20.53</td>
<td>46.80 ± 12.88</td>
<td>38.11 ± 8.05</td>
<td>51.88 ± 12.65</td>
<td>49.56 ± 16.51</td>
</tr>
<tr>
<td>C-organic (%)</td>
<td>1.91 ± 0.13</td>
<td>1.86 ± 0.17</td>
<td>1.72 ± 0.33</td>
<td>2.79 ± 0.07</td>
<td>2.07 ± 0.47</td>
</tr>
<tr>
<td>P (ppm)</td>
<td>97.93 ± 1.44</td>
<td>95.10 ± 3.56</td>
<td>81.9 ± 4.31</td>
<td>93.57 ± 4.00</td>
<td>92.12 ± 7.05</td>
</tr>
<tr>
<td>Ca (me/100g)</td>
<td>2.02 ± 0.11</td>
<td>4.80 ± 4.35</td>
<td>0.66 ± 0.16</td>
<td>1.62 ± 0.47</td>
<td>2.28 ± 2.67</td>
</tr>
<tr>
<td>Mg (me/100g)</td>
<td>0.61 ± 0.14</td>
<td>0.49 ± 0.15</td>
<td>0.30 ± 0.03</td>
<td>0.94 ± 0.02</td>
<td>0.58 ± 0.26</td>
</tr>
<tr>
<td>K (me/100g)</td>
<td>0.15 ± 0.03</td>
<td>0.16 ± 0.11</td>
<td>0.11 ± 0.01</td>
<td>0.14 ± 0.01</td>
<td>0.14 ± 0.02</td>
</tr>
<tr>
<td>Na (me/100g)</td>
<td>0.33 ± 0.05</td>
<td>0.33 ± 0.07</td>
<td>0.19 ± 0.02</td>
<td>0.44 ± 0.01</td>
<td>0.32 ± 0.10</td>
</tr>
<tr>
<td>Sand (%)</td>
<td>20.18 ± 2.25</td>
<td>23.41 ± 2.61</td>
<td>26.10 ± 4.44</td>
<td>26.77 ± 10.67</td>
<td>24.11 ± 6.54</td>
</tr>
<tr>
<td>Silt (%)</td>
<td>47.95 ± 3.52</td>
<td>46.22 ± 4.76</td>
<td>38.95 ± 9.14</td>
<td>41.93 ± 6.92</td>
<td>43.76 ± 7.33</td>
</tr>
<tr>
<td>Clay (%)</td>
<td>31.87 ± 4.19</td>
<td>30.30 ± 4.15</td>
<td>34.95 ± 8.16</td>
<td>31.30 ± 3.80</td>
<td>32.12 ± 5.63</td>
</tr>
</tbody>
</table>

### Table 3.3 Soil parameters affecting *Pn. corethrurus* abundance

<table>
<thead>
<tr>
<th>Soil parameter</th>
<th>Slope</th>
<th>Std. Error</th>
<th>Z value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>-2.888</td>
<td>1.168</td>
<td>-2.473</td>
<td>0.013</td>
</tr>
<tr>
<td>Water content</td>
<td>0.303</td>
<td>0.110</td>
<td>2.760</td>
<td>0.006</td>
</tr>
<tr>
<td>C-organic (%)</td>
<td>0.551</td>
<td>0.190</td>
<td>2.901</td>
<td>0.004</td>
</tr>
<tr>
<td>N (ppm)</td>
<td>-0.505</td>
<td>0.125</td>
<td>-4.049</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Sand (%)</td>
<td>-0.482</td>
<td>0.124</td>
<td>-3.900</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

Null deviance: 307.16 on 289 degrees of freedom
Residual deviance: 263.77 on 284 degrees of freedom
MG: 1084.20
Discussion

Severely disturbed habitat caused by anthropogenic practices such as deforestation or transformation into agricultural system often lead to soil inhabitation by exotic earthworm (Nath & Chaudhuri 2010). If the disturbance is severe, it is possible that the native species be extirpated leaving only the exotic species (Gonzalez et al. 2006) as in our study. In that case, the native earthworms were reduced because of failure to adapt to the new environment, and then the niche was colonized by exotic earthworms.

Colonization of *Pn. corethrurus* in Bungku Village might be also associated with the plant species in the area i.e., rubber and oil palm plantations, which do not support the other earthworm species (Sarlo 2006). In addition, *Pn. corethrurus* has better tolerance to fill the niche left by the natives (Gonzalez et al. 2006). Most earthworms tolerate narrow range of temperature. However, *Pn. corethrurus* can tolerate approximately 13-27 °C of temperature (Kale & Krishnamoorthy 1979) and even up to 29 °C in the present study. *Pn. corethrurus* is characterized as having constant oxygen consumption without diurnal rhythm and tolerance for low oxygen availability (Chuang & Chen 2008). The epidermal cells of *Pn. corethrurus* consist of more granules, so it can secret more mucus to provide the protection from UV light as compared to *Amynthas gracilis* and *Metaphire posthuma* (Chuang et al. 2006, Gonzalez et al. 2008). Parthenogenesis also occurs in *Pn. corethrurus* and it can enhance their colonization (Hendrix & Bohlen 2002). They are also able to enter diapause and regenerate the lost posterior segment regardless of soil moisture (Fragoso & Lozano 1992).

Our result showed no significant difference of *Pn. corethrurus* density in the four systems, and this was not in agreement with previous study which mentioned that earthworm density was higher in forest than plantation (Marichal et al. 2010, Chaudhuri & Nath 2011). Concerning the overall lower density of *Pn. corethrurus* than that reported in previous study, we speculate that it might be due to the higher soil pH (6.5) as *Pn. corethrurus* prefers lower pH (< 5.0) (Chaudhuri et al. 2008, Nath & Chaudhuri 2010). We also found boar tracks in the secondary forest. Hence, we hypothesize that in secondary forest, predation by wild boars, *Sus scrofa*, caused a lower *Pn. corethrurus* density in Jambi, as predation can become a limiting factor for the exotic earthworms to invade new habitat (Hendrix et al. 2006). Consequently, their lower density caused lower biomass. Moreover, we only assessed the adult *Pn. corethrurus* biomass. For comparison, the previously mentioned *Pn. corethrurus* from Tripura, India, had biomass of 26–30 g/m² (Chaudhuri et al. 2008, Chaudhuri & Nath 2011).

Our result showed that soil pH and water content were important soil physical factors. Most earthworms prefer normal soil pH (Edwards 2004), and few of them can live in acidic soil (Ismail & Murthy 1985). *Pn. corethrurus* is an earthworm which can tolerate or even prefer acidic soil (Nath & Chaudhuri 2010).
Hence, negative influence of soil pH in our result was in agreement with that theory. For positive influence of soil water content, it is not peculiar as water is essential to maintain Pn. corethrurus moisture.

Meanwhile, soil C-organic and Na content were important soil mineral factors. As organic matter is the main source for earthworm diet (Ismail & Murthy 1985, Edwards 2004), it is not surprising to have higher abundance of Pn. corethrurus in soil containing higher C-organic. Na showed negative influence on Pn. corethrurus abundance. Na is influenced in Na-K pump which regulates internal fluid (Barrett et al. 2005). Excess of Na causes unbalance of internal fluid.

High sand fraction was not preferred by Pn. corethrurus. Sandy soil cannot hold the water well and earthworms are susceptible to drought (Edwards 2004). Therefore, the negative influence of sand fraction supports the positive influence of soil water content to Pn. corethrurus abundance.

In summary, we propose that anthropogenic practice in Bungku Village causes the condition which does not support the native earthworm’s survival. Pn. corethrurus which have better tolerance than the native earthworms are favored by anthropogenic practice. Therefore, they are able to fill the niche left by natives and completely dominating oil palm plantation, rubber plantation, rubber jungle, and secondary forest in Bungku Village. Their abundance is influenced by soil pH, water, C-organic, sodium, and sand content. Sampling in larger area is needed to study about Pn. corethrurus domination in Indonesian disturbed forest.

Acknowledgement

This work was partly funded by Collaborative Research Center, George August University, Gottingen, Germany. Thank you to R.J. Blakemore for confirmation of the earthworm species.

References


COMPETITION OF TWO SURVIVED EXOTIC EARTHWORMS (*Ocnerodrilus occidentalis* Eisen, 1878 AND *Pontoscolex corethrurus* (Muller, 1857)) FROM DEFORESTATION IN MOUNT GEDE, INDONESIA

Andy Darmawan¹*, Tri Atmowidi¹, Wasmen Manalu², Bambang Suryobroto¹

¹Department of Biology, Faculty of Mathematics and Natural Sciences, Bogor Agricultural University, Darmaga Campus, Bogor 16680, Indonesia
²Department of Anatomy, Physiology and Pharmacology, Faculty of Veterinary Medicine, Bogor Agricultural University, Indonesia

*Corresponding author. E-mail: and.darm@gmail.com

Abstract

The Gause’s principle, whereby complete competitors cannot coexist leads to reduced biodiversity and less energy fluxes in a community. Here we will show that the anthropogenic disturbance of natural forests decreases diversity by adversely altering environmental conditions, causing most earthworms to die and leaving eurytopic ones to compete for reduced resources. Among 3787 individuals, we recovered five Oriental earthworm species in Mount Gede: *Dravida nepalensis*, *Notoscolex javanica*, *Pheretima pura*-group, *Polypheretima moelleri*, and *Polypheretima sempolensis*. We also recovered eighteen species which are reported to be have originally been distributed in the Neotropic (*including Ocnerodrilus occidentalis* and *Pontoscolex corethrurus*), Paleotropic, Afrotopics, or Australasia. The agricultural practices which bring exotic earthworms are analogue to transplant experiment of the original Gause’s work. Anthropogenic disturbance of forests due to transformation into plantations alters their environment by increasing soil temperature and phosphorous content while decreasing C-organic, and consequently kills many earthworm species. It left *N. javanica* out as the only native which survived the deforestation, while exotics *O. occidentalis* and *Pn. corethrurus* thrive to be the eudominant and competing species. In higher soil temperature, *O. occidentalis* is able to sustain viable population, ousting *Pn. corethrurus*, and ‘won’ the competition.

Key words: Gause’s principle, homogenous plantation, mixed plantation, Shannon’s diversity index, stenotypic.

Introduction

The Gause’s principle, whereby complete competitors cannot coexist leads to reduced biodiversity and less energy fluxes in a community (Gause 1932,
Hardin 1960, Barnes 2014). However, Gause’s principle affecting diversity had
only been proven in laboratory and, even so, it has recently been shown that the
underlying resource competition mechanism results in the coexistence of
functionally equivalent species in estuarine ecosystem of phytoplankton (Segura
2013). Here we will show that the anthropogenic disturbance of natural forests
decreases diversity by adversely altering environmental conditions, causing most
earthworms to die and leaving eurytopic ones to compete for reduced resources.

Indonesia experienced the world’s second largest net annual forest area loss
Gede in West Java is undergoing land-use change into mixed and homogenous
plantations, and we presumed that this process enhances the conversion of ‘limitless’ into limited resources for earthworms (sensu Darlington 1972). When
earthworms are incapable of adapting to the environmental change, they might be
driven to compete for reduced resources. However, it is possible for native and
exotic species to have an overlapping distribution when the resources are not fully
exploited by the natives (Hendrix et al. 2006). It is predicted that the extent of
deforestation into mixed and homogenous plantations reduces the diversity of the
exotic and native earthworms.

Among 3787 individuals, we recovered five Oriental earthworm species in
Mount Gede: Drawida nepalensis, Notoscolex javanica, Pheretima pura-group,
Polypheretima moelleri, and Polypheretima sempolensis, which are distributed in
India, southern China, Myanmar, and the Sunda Islands. We also recovered
eighteen species which are reported to be have originally been distributed in the
Neotropic (including Ocnerodrilus occidentalis and Pontoscolex corethrurus),
Paleotropics, Afrotopics, or Australasia (Tsai et al. 2000, Hendrix & Bohlen 2002,
Blakemore 2010) (Appendix 4.1–4.2). Rarefaction curves were parallel and
almost reaching the asymptote indicating that sampling effort reached the
estimated maximum species richness (Appendix 4.3). The agricultural practices
which bring exotic earthworms are analogue to transplant experiment of the
original Gause’s work. From the forest area to mixed and homogenous
plantations, the predicted decreasing diversity (Huston 1979) is shown by the
lowering trend of Shannon’s diversity index (Fig. 4.1). It left N. javanica out as
the only native which survived the deforestation, while exotics O. occidentalis and
Pn. corethrurus thrive to be the eudominant and competing species.
Figure 4.1 Forest (B1–B3, S1–S3) and mixed plantation (B4–B5) areas supported more earthworm species than homogenous plantations (B6–B9, S5–S9). B and S represent areas in Bodogol and Situ Gunung regions. The bigger circle denotes a higher species density. The dots (●) denote Shannon’s diversity index and their medians (—) in forest, mixed, and homogenous plantations. Crosses (x) denote total earthworm densities (excluding unknown species) and their medians (— — —). For genera abbreviation: A = Amynthas, Di = Dichogaster, Dr = Drawida, M = Metaphire, N = Notoscolex, O = Ocnerodrilus, Pe = Perionyx, Ph = Pheretima, Pn = Pontoscolex, Po = Polypheretima. Species with asterisks were natives of the Orient.

Material and Methods

Study Sites

As earthworm density reaches maximum value in wet season (Fragoso & Lavelle 1992), sampling was conducted between early July and the end of October 2012 and between early September and the end of December 2013 in the wet season in Mount Gede, West Java, Indonesia. The sampling area included two
regions, namely Bodogol (abbreviated as ‘B’, coordinates: S 06° 46’ 24.2″, E 106° 50’ 28.8″, 600–700 m asl) and Situ Gunung (abbreviated as ‘S’, coordinates: S 06° 50’ 09.6″, E 106° 55’ 38.4″, 1000–1050 m asl). The mean monthly (from July–December 2012) rainfall of those areas was 226.7 mm. Each region consisted of three forests (B1–B3 and S1–S3) and six adjacent plantation areas (B4–B9 and S4–S9) which are located less than three km from the forest. The plantations in Bodogol consisted of mixed (B4 and B5) and homogenous plantations (B6–B9). Mixed plantations consisted of several plantations cultivated simultaneously. Mixed plantations in Bodogol have been cultivated for about five years, and homogenous plantations in both regions for 10-30 years. The age of the current homogenous plantations were 1-3 months and fertilized with urea, chicken drop, goat dung, and cow dung. Forest areas reflected the least disturbed habitats and homogenous plantations were the most disturbed habitats.

**Earthworm Extraction**

Earthworm extraction was conducted using a digging and hand-sorting method. A single plot 900 cm² wide and 30 cm deep was set up, as earthworms are generally concentrated in the upper 30 cm (Fragoso & Lavelle 1992, Smith et al. 2008). Due to the different topographical conditions, the amount of plots made in each area varied from 10 to 75. Those plots in each area were placed randomly and were separated 100 cm apart from each other. Extracted earthworms were preserved in 70% ethanol prior to identification. Earthworm identification was based on criteria established by Stephenson (1923), Sims & Easton (1972), Easton (1979), and Blakemore (2010). Earthworms in juvenile stage and earthworms without anterior body part were grouped into unknown species.

**Earthworm Diversity Analysis**

The number of extracted earthworms has been presented in density (ind/m²). Furthermore, the density of unknown species has been omitted from calculations. Shannon’s diversity index (H’) was used and so was Simpson’s dominance index (D) to assess diversity and dominancy in each area (Magurran 1998). The indices were defined by:

\[
H' = - \sum p_i \ln p_i \\
D = \sum p_i^2
\]

where \( p_i \) is proportion of individual of \( i^{th} \) species (amount of \( i^{th} \) species / total number of earthworms). The expression 1 - D for Simpson’s dominance index was used, so the higher value reflected lower domination of certain species (Magurran 1998). Shannon’s diversity and Simpson’s dominance indices used density instead of the absolute number of earthworms (Gamito 2010).
The relative dominance of earthworm species in each area was calculated by this formula:

\[
\text{(Species density / Total earthworm density)} \times 100\%
\]

and the resulting dominancy class was followed the criteria established by Engelmann (1973) in which relative dominance < 1% = subrecendent, 1.1–3.1% = recendence, 3.2–10% = subdominant, 10.1–31.6% = dominant, and > 31.7% = eudominant. Meanwhile, species prevalence in Mount Gede was calculated by the formula:

\[
\text{(Number of areas where certain species occurred / Total number of areas)} \times 100\%
\]

where the total number of areas was 6 for forest and 12 for plantation.

The rarefaction curve is based on two regions (Bodogol and Situ Gunung) to assess whether the maximum species richness has been reached. The diversity calculation was performed using package ‘vegan’ (Oksanen et al. 2013) in R.3.0.0 (R Core Team 2013).

**Soil Parameters**

The measured soil parameters included physical (temperature and water content) and mineral (C-organic, P, Ca, and K). Physical soil parameters were measured using a soil thermometer and a soil humidity tester in each plot. Meanwhile, soil samples from each area were collected using a compositing method up to 1000 g (see Didden 2001). The samples were air dried prior to analyzing their mineral content. Carbon organic content was analyzed by following Walkley-Black method, phosphorus was analyzed using a solution of HCl 25%, Ca and K contents were analyzed using neutral 1 M ammonium acetate (NH₄OAc) (Sarkar & Haldar 2005). The resulting values were brought into the same scale (mg/kg) by multiplying Ca and K by 200 and 390 respectively. Soil analysis was conducted in the Laboratory of Department of Soil Science and Land Resource, Faculty of Agriculture, Bogor Agricultural University.

**Statistical Analysis**

**Soil parameters and their influence on earthworm diversity**

Earthworm density, number of species, and soil parameters were pooled in each area, making a total of 18 areas (9 Bodogol and 9 Situ Gunung). The difference of soil parameters in the forest, mixed plantation, and plantation areas were analyzed by Kruskal-Wallis’ rank sum test performed in R.3.0.0 (R Core Team 2013). Soil water content from B3 forest area was omitted from that analysis. It shows a very high value because sampling was done close to a waterfall.

We assessed whether the soil parameters determine Shannon’s diversity indices in each area using linear model (Zuur et al. 2009). Shannon’s diversity
indices from each area were set as a response. Boxplot of the response showed no outlier. The normality of response was tested using Shapiro-Wilk and the result showed that it followed normal distribution (p-value=0.1174). The predictors were soil physical (temperature and water content) and mineral (C-organic, P, Ca, and K) parameters. Those predictors were transformed logarithmic naturally to convert them into a similar scale and meet the normality assumption. Collinearity between predictors was assessed by the variance inflation factor (VIF) value. The VIF value of 5.00 was set as the threshold. All of the predictors had < 5.00 VIF value, so no predictor was omitted. Then, the model was simplified based on AIC.

The homogeneity of variance was assessed in terms of residual vs. fitted value plot, and independence was assessed in terms of residual vs. predictors plot. There was no clear pattern in these plots and therefore no violation of the homogeneity and independence assumptions was found. Linear mixed effect model (‘nlme’ package (Pinheiro et al. 2013) in R. 3.0.0 software (R Core Team 2013)) with random intercept and area as group was constructed to compare the resulting linear model. The comparison was conducted using ‘RLRsim’ package (Scheipl 2010) in R. 3.0.0 (R Core Team 2013), and the result showed no difference between linear and linear mixed effect model. Since linear model had lower AIC than linear mixed effect model (11.12573 vs. 13.12573), we decided to use linear model.

Density difference between *O. occidentalis* and *Pn. corethrurus*

The areas without *O. occidentalis* and *Pn. corethrurus* were omitted from the analysis (B1, B3, S1). The difference between *O. occidentalis* and *Pn. corethrurus* density was calculated by subtracting *O. occidentalis* with *Pn. corethrurus* density in each area. Hence, positive value indicates higher *O. occidentalis* over *Pn. corethrurus* density, and vice versa. These values were set as response. Boxplot of the response did not show any outlier. The response was tested using Shapiro-Wilk’s and it showed normal distribution (p-value=0.7114). All of the soil parameters were set as predictor and transformed logarithmic naturally. The response was also transformed logarithmic naturally to bring it into similar scale with the predictors. The collinearity between predictors was assessed by the VIF and all of them had < 5.00 value, therefore no predictor was omitted. Most of *O. occidentalis* densities were lower than *Pn. corethrurus* in Bodogol, but higher in Situ Gunung region. Due to that fact, it would be difficult to get the clear picture of the density difference between *O. occidentalis* and *Pn. corethrurus* if the data were grouped by region. Hence, we used linear model (Zuur et al. 2009) to characterize the soil parameters influencing the density difference between *O. occidentalis* and *Pn. corethrurus*. The model simplification was based on AIC. The plot of residual vs. fitted value and predictors did not show clear pattern, hence the assumptions of heteroscedasticity and independence were not violated. This analysis was conducted using R. 3.0.0 software (R Core Team 2013).
Result

Forests had higher diversity but lower density compared with mixed and most homogenous plantations. The lower diversity index in B3 was caused by high soil water content that reached > 70%. Additionally, *M. planata* appeared as the eudominant species in this area with a relative dominance of 83.33%. Hence, it is possible to consider that the *M. planata* prefers or maybe has better tolerance of high water content.

Among homogenous plantations, cucumber plantation (B8) had an unusually high diversity index. This was caused by the presence of two eudominant *O. occidentalis* and *Pn. corethrurus* among three earthworm species. Cabbage plantation (S4) also had a high diversity index, probably due to the low soil water content. In the meantime, the high diversity index in combination of avocado and cassava (B6) and avocado plantation (B7) was probably caused by the presence of bushes functioning as shade.

Most of the recorded soil parameters (Table 4.1) were able to support more earthworm species in forests compared to plantation areas. For instance, soil temperatures in forests (Bodogol area 1–3, Situ Gunung area 1–3) were lower and less fluctuated than in plantations (Bodogol area 4–9, Situ Gunung area 4–9). That trend was probably due to the presence of canopy. However, a linear model analysis (Zuur *et al*. 2009) shows that only soil water (slope = -1.420, p-value = 0.001), P (slope = -0.439, p-value = 0.001), and C-organic content (slope = 0.538, p-value = 0.018) influenced earthworm diversity. The other parameters were excluded due to model simplification. High level of C-organic, and low level of soil water and P in the soil had resulted in the highest diversity index in S3.

Table 4.1  Soil parameters, presented in minimum-maximum value, in forest and plantation areas in Mount Gede were tested by multiple comparison Kruskal-Wallis’ rank sum test (α = 0.05). Values with the same superscripts in a row are not significantly different. n indicates the amount of the plot

<table>
<thead>
<tr>
<th>Soil parameters</th>
<th>Forest (n=6)</th>
<th>Mixed plantation (n=2)</th>
<th>Homogenous plantation (n=10)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°C)</td>
<td>21.42 – 22.98&lt;sup&gt;b&lt;/sup&gt;</td>
<td>26.44 – 28.21&lt;sup&gt;a&lt;/sup&gt;</td>
<td>24.90 – 32.58&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.003</td>
</tr>
<tr>
<td>Water content (%)</td>
<td>44.72 – 59.20&lt;sup&gt;b&lt;/sup&gt;</td>
<td>30.60 – 47.40&lt;sup&gt;b&lt;/sup&gt;</td>
<td>41.20 – 69.50&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.002</td>
</tr>
<tr>
<td>C-organic (%)</td>
<td>2.31 – 7.02&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.47 – 2.51&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.49 – 3.14&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.028</td>
</tr>
<tr>
<td>P (mg/kg)</td>
<td>68.7 – 127.80&lt;sup&gt;b&lt;/sup&gt;</td>
<td>418.60 – 429.20&lt;sup&gt;a&lt;/sup&gt;</td>
<td>80.78 – 621.42&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.041</td>
</tr>
<tr>
<td>Ca (mg/kg)</td>
<td>1090.00 – 2524.00&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1120.00 – 1390.00&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1138.00 – 2046.00&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.435</td>
</tr>
<tr>
<td>K (mg/kg)</td>
<td>93.60 – 592.80&lt;sup&gt;b&lt;/sup&gt;</td>
<td>682.50 – 795.60&lt;sup&gt;a&lt;/sup&gt;</td>
<td>304.20 – 1271.40&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.051</td>
</tr>
</tbody>
</table>

Soil water content in forests and mixed plantations were the lowest in contrast to homogenous plantations. As forest and mixed plantations had higher
plant biomass (see Table 4.2), they also had high water uptake which caused lower soil water content (Wang et al. 2012). The earthworm’s body contains about 80% water (Grant 1955) and earthworms occurred in the greatest number in soil containing 10–40% moisture (Ismail & Murthy 1996, Tripathi & Bhardwaj 2004, Ivask et al. 2006, Gonzalez et al. 2007, Karmegam & Daniel 2007). Therefore, it is clear that the soil water content in this study, ranging from 30% to 77%, had negative influence to earthworm diversity.

Table 4.2 Sampling areas in Mount Gede. Bodogol region (B) was sampled in three forest (B1–B3), two mixed plantations (B4, B5), and four homogenous plantation areas (B6–B9). Situ Gunung region (S) was sampled in three forests (S1–S3) and six homogenous plantation areas (S4–S9)

<table>
<thead>
<tr>
<th>Area</th>
<th>Category</th>
<th>Dominant plantation(s) in each area</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>Forest</td>
<td>Rasamala (Altingia excelsa), grasses, bushes</td>
</tr>
<tr>
<td>B2</td>
<td>Forest</td>
<td>Calliandra (Calliandra sp.), grasses, bushes</td>
</tr>
<tr>
<td>B3</td>
<td>Forest</td>
<td>Coffee (Coffea sp.), tepus (Elateriospermum tapos), grasses, bushes</td>
</tr>
<tr>
<td>B4</td>
<td>Mixed plantation</td>
<td>Coffee (Coffea sp.), talas (Colocasia esculenta), jackfruit</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Artocarpus heterophyllus), papaya (Carica papaya)</td>
</tr>
<tr>
<td>B5</td>
<td>Mixed plantation</td>
<td>Coffee (Coffea sp.), talas (Co. esculenta), manglid</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Magnolia blumei), java tea (Orthosiphon aristatus)</td>
</tr>
<tr>
<td>B6</td>
<td>Homogenous plantation</td>
<td>Avocado (Persea americana) with some cassava plantations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Manihot esculenta), bushes</td>
</tr>
<tr>
<td>B7</td>
<td>Homogenous plantation</td>
<td>Avocado (P. americana), bushes</td>
</tr>
<tr>
<td>B8</td>
<td>Homogenous plantation</td>
<td>Cucumber (Cucumis sativus)</td>
</tr>
<tr>
<td>B9</td>
<td>Homogenous plantation</td>
<td>Cassava (M. esculenta)</td>
</tr>
<tr>
<td>S1</td>
<td>Forest</td>
<td>Rasamala (Al. excelsa), tepus (Et. tapos), grasses, bushes</td>
</tr>
<tr>
<td>S2</td>
<td>Forest</td>
<td>Dammar (Agathis dammara), grasses, bushes</td>
</tr>
<tr>
<td>S3</td>
<td>Forest</td>
<td>Rasamala (Al. excelsa), sago palm (Cycas sp.), grasses, bushes</td>
</tr>
<tr>
<td>S4</td>
<td>Homogenous plantation</td>
<td>Cabbage (Brassica oleracea capitata)</td>
</tr>
<tr>
<td>S5</td>
<td>Homogenous plantation</td>
<td>Cassava (M. esculenta)</td>
</tr>
<tr>
<td>S6</td>
<td>Homogenous plantation</td>
<td>Chili (Capsicum sp.)</td>
</tr>
<tr>
<td>S7</td>
<td>Homogenous plantation</td>
<td>Onion (Allium cepa)</td>
</tr>
<tr>
<td>S8</td>
<td>Homogenous plantation</td>
<td>Groundnut (Arachis hypogaea)</td>
</tr>
<tr>
<td>S9</td>
<td>Homogenous plantation</td>
<td>Chinese chard (Brassica rapa chinensis)</td>
</tr>
</tbody>
</table>

As for water content, soil P was the lowest in forest areas (Table 4.1). The effect of soil P to earthworm density or biomass was not consistent as in previous studies (Ismail & Murthy 1996, Gonzalez et al. 2007, Zeithaml & Sklenicka 2009, Iodarche & Borza 2010, Teng et al. 2013). This is probably caused by a different range of observed soil P content, or that different earthworm communities had a different response to this factor.

Conversely, forests had the highest C-organic and showed a decreasing trend in mixed and homogenous plantations. Since decaying organic matter is a
source of diet for earthworms, it is not surprising to find a positive correlation between C-organic content with earthworm diversity (Ismail & Murthy 1985, Tripathi & Bhardwaj 2004).

Under unfavorable conditions in the plantation areas, many earthworm species were in low dominance and prevalence (Table 4.3). They were at risk of eradication presumably because of their stenotopic characteristic. *Ph. pura*-group was the least abundant native which was found only in a plantation that combined avocado and cassava (B6). Conversely, *N. javanica* was the most abundant native species. They occurred mostly in mixed plantation (B5) and cassava plantation (B9) (Fig. 4.1), which had a relatively high soil temperature and P content (Appendix 4.4).

**Table 4.3** Relative dominance (RD) and prevalence (P) of earthworm species in forests and plantations in Mount Gede. All values are ranging from 0 (worst) to 100 (best). Species with asterisks are natives of the Orient.

<table>
<thead>
<tr>
<th>Species</th>
<th>Forest</th>
<th>Plantation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RD (%)</td>
<td>P (%)</td>
</tr>
<tr>
<td><em>A. aeruginosus</em></td>
<td>1.46</td>
<td>33.33</td>
</tr>
<tr>
<td><em>A. asiaticus</em></td>
<td>0.36</td>
<td>16.67</td>
</tr>
<tr>
<td><em>A. gracilis</em></td>
<td>1.82</td>
<td>33.33</td>
</tr>
<tr>
<td><em>A. hupiensis</em></td>
<td>0.91</td>
<td>33.33</td>
</tr>
<tr>
<td><em>A. ilotus</em> species-group</td>
<td>9.12</td>
<td>83.33</td>
</tr>
<tr>
<td><em>A. minimalis</em></td>
<td>9.49</td>
<td>50.00</td>
</tr>
<tr>
<td><em>A. morrisi</em> species-group</td>
<td>0.18</td>
<td>16.67</td>
</tr>
<tr>
<td><em>A. robustus</em></td>
<td>6.20</td>
<td>100.00</td>
</tr>
<tr>
<td><em>Di. affinis</em></td>
<td>1.46</td>
<td>33.33</td>
</tr>
<tr>
<td><em>Dr. barwelli</em></td>
<td>24.64</td>
<td>66.67</td>
</tr>
<tr>
<td><em>Dr. nepalensis</em></td>
<td>1.09</td>
<td>33.33</td>
</tr>
<tr>
<td><em>M. californica</em></td>
<td>5.66</td>
<td>66.67</td>
</tr>
<tr>
<td><em>M. javanica</em></td>
<td>0.55</td>
<td>50.00</td>
</tr>
<tr>
<td><em>M. planata</em></td>
<td>3.65</td>
<td>16.67</td>
</tr>
<tr>
<td><em>N. javanica</em></td>
<td>0.18</td>
<td>16.67</td>
</tr>
<tr>
<td><em>O. occidentalis</em></td>
<td>3.28</td>
<td>33.33</td>
</tr>
<tr>
<td><em>Pe. excavatus</em></td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td><em>Ph. darnleiensis</em></td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td><em>Ph. pura</em> species-group</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td><em>Po. bifaria</em> species-group</td>
<td>0.36</td>
<td>33.33</td>
</tr>
<tr>
<td><em>Po. moelleri</em></td>
<td>0.73</td>
<td>16.67</td>
</tr>
<tr>
<td><em>Po. sempolensis</em></td>
<td>2.55</td>
<td>50.00</td>
</tr>
<tr>
<td><em>Pn. corethrurus</em></td>
<td>26.28</td>
<td>50.00</td>
</tr>
</tbody>
</table>

The exotics *O. occidentalis* and *Pn. corethrurus* apparently had the most eurytopic characteristics as they dominated degraded areas which are not favorable for stenotopic earthworms. Both had the two highest dominance and prevalence and according to Engelmann’s (1973) scale, occurred as eudominant species in plantations (Table 4.3, see Appendix 4.5–4.6). Interestingly, the increasing density of one of the two caused lower density of the other (Fig. 4.1). The *O. occidentalis* was likely to have higher density than *Pn. corethrurus* in...
areas which had high soil temperature (slope = 17.369, p-value = 0.003) (Appendix 4.7). Meanwhile, their density difference were not affected by soil K (slope = -1.545, p-value = 0.073). The others soil parameters were excluded due to model simplification. *O. occidentalis* dominated all of the homogenous plantations in Situ Gunung (S4–S9) and two homogenous plantations in Bodogol, namely cucumber (B8) and cassava plantation (B9). *Pn. corethrurus* dominated B2 forest area and almost all of the plantation areas in Bodogol (B4–B8). Previous studies reported that *O. occidentalis* and *Pn. corethrurus* have a wide tolerance and effective adaptation mechanisms to colonize the unfavorable areas. *O. occidentalis* can live in very humid soil and soil which is low in organic matter (Talavera 1990). It also has parthenogenesis strategy (Blakemore 2010). Meanwhile, *Pn. corethrurus* tolerates low oxygen availability (Chuang & Chen 2008). It also has more granules on the epidermal cell to secrete more mucous (Chuang *et al.* 2006), it has parthenogenesis strategy (Hendrix & Bohlen 2002), and is able to enter diapauses and regenerate its posterior segment regardless of soil moisture (Fragozo & Lozano 1992).

**Discussion**

Humans, deliberately or not, transplant exotic earthworm species by introducing horticultural plantations (Rota 2013, Plisko 2010). The exotics may disperse and live together with natives in forests where resources are adequate (Hendrix *et al.* 2006) and environmental conditions are favorable. Anthropogenic disturbance of forests due to transformation into plantations alters their environment by increasing soil temperature and phosphorous content while decreasing C-organic (as shown in our study), and consequently kills many earthworm species. The inherent growth rates, which are equivalent to the density, of these species can not compete with the frequency of destruction (Huston 1979) which are sudden and massive. The inability to adapt to environmental changes also shows that physiologically the earthworms were stenotopic. The leftover niche is occupied by a few eurytopic earthworms.

This study shows that *O. occidentalis* and *Pn. corethrurus* are the two most successful earthworms in plantations, due to their eurytopic physiological characteristics (see Talavera 1990, Blakemore 2010). Both are endogeic exotic species and they have been shown to occur in many anthropogenically disturbed areas (Talavera 1996, Gonzalez *et al.* 2006, Jian-Xiong *et al.* 2009). *O. occidentalis* origin was uncertain, either it is originates from Central America or Central Africa (Rota 2013), while *Pn. corethrurus* is possibly from Amazonian Brazil (Plisko 2010).

Both species might be expected to compete in the plantations. The competitive exclusion principle was devised in the laboratory (Huston 1979), and here we report that when two species (*O. occidentalis* and *Pn. corethrurus*)
without niche differentiation occur together, they expel each other in the real
world. It has been shown experimentally that the one which survives the
competition in replicated trials was not always the same species (Hardin 1960).
However, this study shows that wider physiological tolerance may determine the
outcome. It is shown that in higher soil temperature, *O. occidentalis* is able to
sustain viable population, ousting *Pn. corethrurus*, and ‘won’ the competition.

**Acknowledgements**

We thank the Laboratory of Department of Soil Science and Land Resource,
Faculty of Agriculture, Bogor Agricultural University for assistance in our
laboratory work. We also thank the plantation owners and local guides for helping
in the field work.

**References**

Barnes AD, Jochum M, Mumme S, Haneda NF, Farajallah A, Widarto TH, Brose
U. 2014. Consequences of tropical land use for multitrophic biodiversity and

839.

Chaudhuri PS, Nath S. 2011. Community structure of earthworms under rubber
plantations and mixed forests in Tripura, India. *J Environ Biol.* 32: 537-541.

Chuang SC, Chen JH. 2008. Role of diurnal rhythm of oxygen consumption in
emergence from soil at night after heavy rain by earthworms. *Invertebr Biol.*
127: 80-86.

Chuang SC, Lai WS, Chen JH. 2006. Influence of ultraviolet radiation on selected

Nat Acad Sci.* 69: 3151-3155.

Didden WAM. 2001. Earthworm communities in grasslands and horticultural

Easton EG. 1979. A revision of the ‘acaecate’ earthworms of the *Pheretima* group
(Megascolecidae: Oligochaeta): Archipheretima, Metapheretima,
*Planapheretima*, *Pleionogaster*, and *Polypheretima*. *Bull Br Mus Nat Hist
(Zool).* 35: 1-126.

Engelmann HD. 1973. Untersuchungen zur Erfassung predozoogener
Naturkde., Gorlitz*.

Assessment 2010 Country Report Indonesia Forest Resource Assessment
(FRA) 2010/095 (Rome: UNFAO).


Marichal R, Martinez AF, Praxedes C, Ruiz D, Carvajal AF, Oszwald J, Hurtado MDeP, Brown GG, Grimaldi M, Desjardins T, Sarrazin M, Decaens T,


Appendices

Appendix 4.1  Earthworms recovered (ind/m²) from each area in Bodogol. Species with asterisks are natives of the Orient. See Table 4.2 for explanation of the areas. n indicates the amount of the plot. Unknown species was excluded from diversity and dominance indices analysis.

<table>
<thead>
<tr>
<th>Species</th>
<th>B1 (n=25)</th>
<th>B2 (n=25)</th>
<th>B3 (n=25)</th>
<th>B4 (n=50)</th>
<th>B5 (n=25)</th>
<th>B6 (n=14)</th>
<th>B7 (n=36)</th>
<th>B8 (n=75)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. asiatica</td>
<td>0.89</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>A. hungricanus</td>
<td>1.78</td>
<td>0.44</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>A. illicis species-group</td>
<td>2.67</td>
<td>0.44</td>
<td>0.00</td>
<td>14.67</td>
<td>6.00</td>
<td>7.56</td>
<td>3.17</td>
<td>0.00</td>
</tr>
<tr>
<td>A. robustus</td>
<td>1.78</td>
<td>1.33</td>
<td>0.44</td>
<td>0.44</td>
<td>0.22</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Di. affinis</td>
<td>0.00</td>
<td>3.11</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.59</td>
</tr>
<tr>
<td>Dr. barnelli</td>
<td>7.56</td>
<td>30.22</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>*Dr. nepalensis</td>
<td>0.00</td>
<td>0.00</td>
<td>0.89</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>M. californica</td>
<td>5.33</td>
<td>1.33</td>
<td>0.00</td>
<td>4.89</td>
<td>0.67</td>
<td>0.00</td>
<td>0.79</td>
<td>0.00</td>
</tr>
<tr>
<td>M. javanica</td>
<td>0.44</td>
<td>0.00</td>
<td>0.44</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>M. planeta</td>
<td>0.00</td>
<td>0.00</td>
<td>8.89</td>
<td>0.44</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>*N. javanica</td>
<td>0.00</td>
<td>0.44</td>
<td>0.00</td>
<td>0.00</td>
<td>5.11</td>
<td>0.00</td>
<td>0.00</td>
<td>7.41</td>
</tr>
<tr>
<td>O. occidentalis</td>
<td>0.00</td>
<td>6.67</td>
<td>0.00</td>
<td>38.67</td>
<td>16.00</td>
<td>2.67</td>
<td>11.90</td>
<td>11.42</td>
</tr>
<tr>
<td>Pe. excavatus</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>2.67</td>
<td>4.00</td>
<td>0.00</td>
<td>1.23</td>
<td>0.00</td>
</tr>
<tr>
<td>Ph. darwinensis</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>2.38</td>
<td>0.00</td>
</tr>
<tr>
<td>*Ph. pura species-group</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.44</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Pe. corinthurus</td>
<td>0.00</td>
<td>53.78</td>
<td>0.00</td>
<td>75.11</td>
<td>100.44</td>
<td>64.89</td>
<td>82.54</td>
<td>8.02</td>
</tr>
<tr>
<td>Unknown</td>
<td>7.11</td>
<td>13.33</td>
<td>3.11</td>
<td>9.33</td>
<td>5.78</td>
<td>4.44</td>
<td>0.79</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Number of earthworms: 62, 250, 31, 329, 624, 180, 128, 67, 748

Density: 27.56, 111.11, 13.78, 146.22, 138.67, 80.00, 101.59, 20.68, 110.81

Number of identifiable species: 7, 9, 4, 7, 8, 4, 5, 3, 5

Shannon's diversity index (H') 1.628, 1.175, 0.624, 1.159, 0.893, 0.509, 0.651, 0.864, 0.309

Simpson's dominance index (1- D) 0.761, 0.596, 0.295, 0.606, 0.410, 0.251, 0.314, 0.541, 0.143
Appendix 4.2 Earthworms recovered (ind/m²) from each area in Situ Gunung. Species with asterisks are natives of the Orient. See Table 4.2 for explanation of the areas. n indicates the amount of the plot. Unknown species was excluded from diversity and dominance indices analysis.

<table>
<thead>
<tr>
<th>Species</th>
<th>S1 (n=25)</th>
<th>S2 (n=25)</th>
<th>S3 (n=25)</th>
<th>S4 (n=75)</th>
<th>S5 (n=22)</th>
<th>S6 (n=23)</th>
<th>S7 (n=20)</th>
<th>S8 (n=10)</th>
<th>S9 (n=36)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. aeruginosus</td>
<td>1.33</td>
<td>0.00</td>
<td>2.22</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>A. gracilis</td>
<td>0.00</td>
<td>2.67</td>
<td>1.78</td>
<td>0.15</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Po. affinis</td>
<td>7.56</td>
<td>4.44</td>
<td>7.11</td>
<td>0.30</td>
<td>0.00</td>
<td>0.48</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Po. minimus</td>
<td>0.00</td>
<td>0.44</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Di. caudatus</td>
<td>2.67</td>
<td>0.89</td>
<td>8.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.48</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Dr. barwelli</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>1.11</td>
<td>0.62</td>
<td>0.00</td>
</tr>
<tr>
<td>*Po. moelleri</td>
<td>1.78</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Go. californica</td>
<td>0.00</td>
<td>20.89</td>
<td>1.33</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>*N. javanica</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>2.53</td>
<td>0.48</td>
<td>1.11</td>
<td>0.00</td>
<td>1.23</td>
<td>0.00</td>
</tr>
<tr>
<td>*Po. robustus</td>
<td>0.00</td>
<td>0.44</td>
<td>0.44</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Po. bifaria species</td>
<td>0.00</td>
<td>0.44</td>
<td>0.44</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Po. melarius</td>
<td>1.78</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>*Po. sempenatus</td>
<td>3.56</td>
<td>1.33</td>
<td>1.33</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Po. corethrurus</td>
<td>0.00</td>
<td>2.22</td>
<td>8.00</td>
<td>1.93</td>
<td>9.60</td>
<td>2.90</td>
<td>0.56</td>
<td>1.23</td>
<td>0.00</td>
</tr>
<tr>
<td>Unknown</td>
<td>24.00</td>
<td>27.55</td>
<td>14.22</td>
<td>0.00</td>
<td>6.57</td>
<td>1.45</td>
<td>0.00</td>
<td>1.54</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Appendix 4.3 Rarefaction curve in Bodogol (B) and Situ Gunung (S) region.
Appendix 4.4  Soil parameter from each area in Bodogol (B1–B9) and Situ Gunung (S1–S9). For soil physical factors: data ± SD.

<table>
<thead>
<tr>
<th>Area</th>
<th>Temperature (°C)</th>
<th>Water content (%)</th>
<th>C-org (%)</th>
<th>P (mg/kg)</th>
<th>Ca (mg/kg)</th>
<th>K (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>21.96 ± 0.94</td>
<td>47.92 ± 26.19</td>
<td>4.30</td>
<td>127.80</td>
<td>2524.00</td>
<td>237.90</td>
</tr>
<tr>
<td>B2</td>
<td>21.42 ± 0.53</td>
<td>44.72 ± 26.21</td>
<td>3.63</td>
<td>101.60</td>
<td>1334.00</td>
<td>93.60</td>
</tr>
<tr>
<td>B3</td>
<td>22.58 ± 0.53</td>
<td>77.60 ± 32.54</td>
<td>2.31</td>
<td>103.20</td>
<td>2070.00</td>
<td>319.80</td>
</tr>
<tr>
<td>B4</td>
<td>26.44 ± 3.95</td>
<td>30.60 ± 21.13</td>
<td>2.47</td>
<td>429.20</td>
<td>1390.00</td>
<td>795.60</td>
</tr>
<tr>
<td>B5</td>
<td>28.21 ± 3.82</td>
<td>47.40 ± 25.92</td>
<td>2.51</td>
<td>418.60</td>
<td>1120.00</td>
<td>682.50</td>
</tr>
<tr>
<td>B6</td>
<td>24.90 ± 1.42</td>
<td>64.40 ± 25.26</td>
<td>2.15</td>
<td>92.10</td>
<td>1706.00</td>
<td>1205.10</td>
</tr>
<tr>
<td>B7</td>
<td>25.13 ± 1.80</td>
<td>66.07 ± 20.30</td>
<td>1.70</td>
<td>81.39</td>
<td>1432.00</td>
<td>1271.40</td>
</tr>
<tr>
<td>B8</td>
<td>32.58 ± 4.42</td>
<td>69.31 ± 14.79</td>
<td>1.71</td>
<td>80.78</td>
<td>1384.00</td>
<td>1267.50</td>
</tr>
<tr>
<td>B9</td>
<td>29.51 ± 2.74</td>
<td>51.33 ± 13.47</td>
<td>1.49</td>
<td>621.42</td>
<td>1138.00</td>
<td>994.50</td>
</tr>
<tr>
<td>S1</td>
<td>21.69 ± 0.84</td>
<td>59.20 ± 13.52</td>
<td>7.02</td>
<td>97.90</td>
<td>1320.00</td>
<td>397.80</td>
</tr>
<tr>
<td>S2</td>
<td>22.00 ± 0.96</td>
<td>51.80 ± 14.21</td>
<td>4.22</td>
<td>70.40</td>
<td>2074.00</td>
<td>491.40</td>
</tr>
<tr>
<td>S3</td>
<td>22.98 ± 0.89</td>
<td>47.60 ± 16.02</td>
<td>4.46</td>
<td>68.70</td>
<td>1090.00</td>
<td>592.80</td>
</tr>
<tr>
<td>S4</td>
<td>27.25 ± 4.45</td>
<td>41.20 ± 17.28</td>
<td>3.14</td>
<td>391.88</td>
<td>1242.00</td>
<td>702.00</td>
</tr>
<tr>
<td>S5</td>
<td>27.70 ± 1.81</td>
<td>59.55 ± 11.94</td>
<td>2.88</td>
<td>210.57</td>
<td>1532.00</td>
<td>471.90</td>
</tr>
<tr>
<td>S6</td>
<td>29.43 ± 2.51</td>
<td>59.78 ± 12.01</td>
<td>3.00</td>
<td>219.21</td>
<td>1496.00</td>
<td>702.00</td>
</tr>
<tr>
<td>S7</td>
<td>27.95 ± 1.01</td>
<td>64.25 ± 6.34</td>
<td>2.79</td>
<td>204.20</td>
<td>1566.00</td>
<td>315.90</td>
</tr>
<tr>
<td>S8</td>
<td>27.98 ± 1.16</td>
<td>69.50 ± 7.98</td>
<td>2.31</td>
<td>182.90</td>
<td>2046.00</td>
<td>304.20</td>
</tr>
<tr>
<td>S9</td>
<td>29.20 ± 3.21</td>
<td>65.69 ± 8.63</td>
<td>2.92</td>
<td>508.62</td>
<td>1960.00</td>
<td>686.40</td>
</tr>
</tbody>
</table>

Appendix 4.5  Relative dominance (%) of earthworm species in each area from Bodogol. Species with asterisks are natives of the Orient. See Table 4.2 for explanation of the areas.

<table>
<thead>
<tr>
<th>Species</th>
<th>B1</th>
<th>B2</th>
<th>B3</th>
<th>B4</th>
<th>B5</th>
<th>B6</th>
<th>B7</th>
<th>B8</th>
<th>B9</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. asiaticus</td>
<td>4.35</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>A. hupeiensis</td>
<td>8.70</td>
<td>0.45</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>A. illotus species-group</td>
<td>13.04</td>
<td>0.45</td>
<td>0.00</td>
<td>10.71</td>
<td>4.52</td>
<td>10.00</td>
<td>3.15</td>
<td>0.00</td>
<td>0.13</td>
</tr>
<tr>
<td>A. robustus</td>
<td>8.70</td>
<td>1.36</td>
<td>4.17</td>
<td>0.32</td>
<td>0.17</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>D. affinis</td>
<td>0.00</td>
<td>3.18</td>
<td>0.00</td>
<td>0.00</td>
<td>0.33</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.54</td>
</tr>
<tr>
<td>Dr. barbelli</td>
<td>36.96</td>
<td>30.91</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>*D. nepalensis</td>
<td>0.00</td>
<td>0.00</td>
<td>8.33</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>M. californica</td>
<td>26.09</td>
<td>1.36</td>
<td>0.00</td>
<td>3.57</td>
<td>0.50</td>
<td>0.00</td>
<td>0.79</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>M. javanica</td>
<td>2.17</td>
<td>0.00</td>
<td>4.17</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>M. planata</td>
<td>0.00</td>
<td>0.00</td>
<td>83.33</td>
<td>0.32</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>*N. javanica</td>
<td>0.00</td>
<td>0.45</td>
<td>0.00</td>
<td>0.00</td>
<td>3.85</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>6.75</td>
</tr>
<tr>
<td>O. occidentalis</td>
<td>0.00</td>
<td>6.82</td>
<td>0.00</td>
<td>28.25</td>
<td>12.04</td>
<td>3.53</td>
<td>11.81</td>
<td>55.22</td>
<td>92.31</td>
</tr>
<tr>
<td>Pe. excavatus</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>1.95</td>
<td>3.01</td>
<td>0.00</td>
<td>0.00</td>
<td>5.97</td>
<td>0.00</td>
</tr>
<tr>
<td>Ph. damleiensis</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>2.36</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>*Ph. pura species-group</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.59</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Pn. corethratus</td>
<td>0.00</td>
<td>55.00</td>
<td>0.00</td>
<td>54.87</td>
<td>75.59</td>
<td>85.88</td>
<td>81.89</td>
<td>38.81</td>
<td>0.27</td>
</tr>
</tbody>
</table>
Appendix 4.6  Relative dominance (%) of earthworm species in each area from Situ Gunung. Species with asterisks are natives of the Orient. See Table 4.2 for explanation of the areas.

<table>
<thead>
<tr>
<th>Species</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
<th>S7</th>
<th>S8</th>
<th>S9</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. aeruginosus</td>
<td>3.66</td>
<td>0.00</td>
<td>5.62</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>A. gracilis</td>
<td>0.00</td>
<td>6.90</td>
<td>4.49</td>
<td>1.12</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>A. illoitus species-group</td>
<td>20.73</td>
<td>11.49</td>
<td>17.98</td>
<td>2.25</td>
<td>0.00</td>
<td>0.60</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>A. minimus</td>
<td>47.56</td>
<td>6.90</td>
<td>7.87</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>A. morrisi species-group</td>
<td>0.00</td>
<td>1.15</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>A. robustus</td>
<td>7.32</td>
<td>2.30</td>
<td>20.22</td>
<td>0.00</td>
<td>0.60</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Di. affinis</td>
<td>0.00</td>
<td>0.00</td>
<td>1.12</td>
<td>0.00</td>
<td>0.29</td>
<td>0.00</td>
<td>0.00</td>
<td>3.03</td>
<td>0.71</td>
</tr>
<tr>
<td>Dr. barwelli</td>
<td>0.00</td>
<td>54.02</td>
<td>3.37</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>*Dr. nepalensis</td>
<td>4.88</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>M. californica</td>
<td>0.00</td>
<td>3.45</td>
<td>14.61</td>
<td>4.49</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>M. javanica</td>
<td>1.22</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>*N. javanica</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>1.46</td>
<td>0.60</td>
<td>6.67</td>
<td>0.00</td>
<td>1.42</td>
</tr>
<tr>
<td>O. occidentalis</td>
<td>0.00</td>
<td>3.45</td>
<td>0.00</td>
<td>77.53</td>
<td>92.69</td>
<td>94.58</td>
<td>90.00</td>
<td>96.97</td>
<td>87.90</td>
</tr>
<tr>
<td>Po. bifaria species-group</td>
<td>0.00</td>
<td>1.15</td>
<td>1.12</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>*Po. moelleri</td>
<td>4.88</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>*Po. sempolensis</td>
<td>9.76</td>
<td>3.45</td>
<td>3.37</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Pn. corethrurus</td>
<td>0.00</td>
<td>5.75</td>
<td>20.22</td>
<td>14.61</td>
<td>5.56</td>
<td>3.61</td>
<td>3.33</td>
<td>0.00</td>
<td>9.96</td>
</tr>
</tbody>
</table>

Appendix 4.7  It was more probable to found higher O. occidentalis density than Pn. corethrurus along increasing of soil temperature (inside rectangle). Arrows pointing left indicates higher O. occidentalis density over Pn. corethrurus in certain area (see Appendix 4.4 for detailed soil parameters in each area), and vice versa. The areas without O. occidentalis and Pn. corethrurus (B1, B3, and S1) were omitted.
5 GENERAL DISCUSSION

The increase of human population renders environmental alteration through expanding of land-use change into agricultural systems to yield goods and services. At the same time, it drives the loss of biological diversity (Vitousek et al. 1997). On the other hands, humans deliberately or not introducing earthworms along with agricultural plantations (Talavera 1996, Hendrix & Bohlen 2002, Tripathi & Bhardwaj 2004, Talavera 2007, Rota 2013). Seven earthworms are reported for the first time in Indonesia and they are most likely introduced by human.

Deforestation into plantations, which definitely alters the environment, is a consequence of the expanding of land-use change by humans. The noticeable alteration as shown in this study is soil parameters changing. The constant results of this alteration are increasing of soil temperature, pH, and water content, while C-organic content is decreasing. Moreover, the landowners prefer to apply organic rather than inorganic fertilizers. Since earthworm number and biomass are greater in organic compared to inorganic fertilized area (Whalen et al. 1998), we believe that the application of organic fertilizers in our study areas does not reduce earthworm diversity. Hence, we propose that the degraded environmental caused by deforestation is not able to support stenotopic earthworms, expelling them from the community or driving them to die, and therefore resulting in diversity reduction.

The relationship between deforestation and diversity as shown in our study is supported with the model proposed by Huston (1979). In the forests, population disturbance may come from predation and mortality. However, the earthworms are able to reach the minimum growth rate to recover their population between the disturbances. This condition leads to high diversity of earthworm. On the other hand, the plantations reflect severely permanent disturbed habitat. The growth rates of most earthworms, which are stenotopic, are not high enough to maintain their population size. Hence, the disturbed habitat leads the survived eurytopic species to reach the equilibrium competition and consequently drives them to compete each other. It is shown in our study where the density of *O. occidentalis* inversely correlates with *Pn. corethrurus* in Mount Gede. *O. occidentalis* is able to sustain viable population over *Pn. corethrurus* in area with higher soil temperature.

The Gause’s principle, whereby two species without niche differentiation expel each other, has been devised in laboratory (Mooney & Cleland 2001), and agricultural plantations in our study act as transplant experiment for that principle. When the environmental disturbance is severe, it is possible to leave a single species out as happened in Bungku Village. It is difficult to prove the competition due to lack of previous observation. Nevertheless, *Pn. corethrurus* can survive
over *O. occidentalis* in Bungku Village probably due to lower soil temperature than Mount Gede. The other possibility is *O. occidentalis* has not introduced yet to that area. *O. occidentalis* is believed introduced through avocado plantation (Rota 2013) and there is no avocado plantation in Bungku Village. *Pn. corethrurus* is supposed to be introduced through rubber plantation and rubber plantations are abundant in Bungku Village. Hence, it is not surprising that *Pn. corethrurus* has higher density and it put them in advantage.

References


6 CONCLUSION

Struggle for existence of earthworms is shown in transplant experiment. Agricultural practices lead to deforestation and drive stenotopic earthworms to die and leave the eurytopics with the overlapping niche compete each other. It is sensible to conclude that deforestations may cause Gause’s principle to work in nature and consequently reduce the diversity of earthworms.
The author was born in Bogor at 1985. At 2008, he studied *Monocystis* as earthworm parasite and achieved his Bachelor of Science in Bogor Agricultural University. At 2010, he studied bioecology of earthworm *Pheretima darnleiensis* and published an article about morphoogical character of *Pheretima darnleiensis*. He achieved his Master of Science at the same year from Bogor Agricultural University. He continued to pursuit his doctoral at Bogor Agricultural University with scholarship from Directorate General of Higher Education (DIKTI) at 2011. At 2013, he did a collaborative research with Collaborative Research Center, George August Universtat Gottingen, Germany and published a paper about domination of earthworm *Pontoscolex corethrurus*. He was currently doing a research about struggling for existence in earthworms.