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Impact of land and forest fire on soil fauna diversity in several land cover in Jambi Province, Indonesia

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Abstract. *Wasis B, Winata B, Marpaung DR. 2018. Impact of land and forest fire on soil fauna diversity in several land cover in Jambi Province, Indonesia. Biodiversitas 19: 740-746.* Forest fire is one of the primary disturbances that damage forest and disturb forest sustainability. Land and forest fire may lead to die-offs, declines and in general influence the development of abundant of soil fauna on the ground. This research aims to identify and assess the diversity, wealth, evenness, and the pattern and spread of land fauna in various ecosystems, both burnt and unburnt by the fire. Research was conducted in some districts in Jambi Province, Indonesia. Sampling methods for soil diversity were done by hand-sorting methods in three burnt and unburnt ecosystems. Those ecosystems were primary forest, industrial plantation forest, and oil palm plantation. Generally, we found 519 individual species included in 46 genera, 33 families, 20 orders of 8 classes, and 3 phyla in whole ecosystem observed. The highest soil fauna diversity was primary forest with value of DMg = 4.243, H'=2.664, E=0.862. Meanwhile, the lowest soil fauna diversity was found in burnt palm plantation with value of DMg=2.102, H'=1.520, and E=0.692. Environmental factors like abiotic and biotic affected to the diversity level of soil fauna.

Keywords: Forest fire, industrial plantation industry, land fire, oil palm plantations, primary forest, soil fauna diversity

INTRODUCTION

Land forest is a circumstance where the flaming of fire occurs in a land ecosystem, whereas forest fire is a condition where the forest ecosystem is struck by the fire. Both land and forest fire phenomenon causes the damage for environment such as a loss economically, ecologically, socially, even causes a disturbing to develop the science (Saharjo 2016). Forest fire is one of primary causes of the forest destruction and disturbing its sustainability. Impact of fire is ecologically and economically high. It has frequently occurred in Kalimantan and Sumatera and it gives negative impacts to environment, which are the loss of forest and land resource, social economy, and other losses due to smoke (pollution) moving to nearest countries such as Malaysia and Singapore (Saharjo 2016).

Basically, the causes of the forest fire in Indonesia is mostly due to human activities, such as land conversion, shifting agricultural land, transmigration, and by nature begin from the fast reaction processes of oxygen and fuel in the forest indicated by the increasing temperature and combustion (Chandler et al. 1983; Saharjo and Wasis 2006; Saharjo 2016).

Forest fire and land fire has impacts on soil properties, such as the soil biology (soil fauna, bacteria, and fungi which live in the soil and on the soil surface). Forest and land fire causes the dying, decreasing, and disturbing the population of the soil biology diversity (microorganisms and microorganisms), which are essential in the forest and land ecosystem, especially to maintain and improve the soil fertility (quality). (Barrow 1991, Suciatmih 2006, Saharjo and Nurhayati 2006, Saharjo et al. 2011) . Impacted soil biology (especially soil fauna) by forest fire needs significant time to recovery. Whereas, soil fauna is an important section of the soil properties to recover soil fertility and soil condition after land or forest fire phenomenon occurred. Soil fauna is a connector among the elements on the environmental and support the material and energy cycles (such as: soil nutrient cycle and food chain cycle in the environmental). Because of those, we need data and information about the influence of land and forest fire toward the soil fauna. This research aims to identify and assess the diversity, wealth, evenness, and the pattern and spread of land fauna in various ecosystems, both burnt and unburnt by the fire in Jambi Province, Indonesia.

MATERIALS AND METHODS

Time and location

This research was conducted in November 2014 in Muaro Bungo, Western Tanjung Jabung, and Eastern Tanjung Jabung, Jambi Province, Indonesia. Sample analysis was conducted from November 2014 to January 2015 in the Laboratory of Entomology, Department of Silviculture, Bogor Agricultural University, Bogor, Indonesia.

Materials and tools

Tools used in this research were Berlis funnel-pour, stereo microscope, petri plates, tweezers, film bottles, a digital camera, gloves, measuring tape, ruler, soil sample ring, hoe, plastic box, tally sheet, digital thermometer, pH indicator paper, stationaries, GPS (global positioning system), densitometer, alcohol (70%), and insect identification books.

Procedure

Plot positioning

Three observation plots (20 m x 20 m) were placed in the burnt and unburnt ecosystem (primary forest, industrial plantation forest, and oil palm plantation). Each plot also contained three sub-plots (1 m x 1 m). In the plot 20 m x 20 m was conducted vegetation analysis, such as inventory the number of individual and species and measurement of height of the plants (trees) (Soerianegara and Indrawan 2005). This data was used to know the structure (vegetation strata) and species composition. In the sub-plots (1 m x 1 m), the observation of soil fauna was conducted.

The observation plots were placed by purposive sampling method. Then the observation plots were marked by GPS (type: Garmin E trex) for mapping purposes.

Soil fauna sampling

We used hand-sorting method to catch the soil faunas on the surface and inside the soil. The soil fauna sampling was conducted in the sub-plot (1 m x 1 m plot) with the soil depth of 5 cm. Collected organisms (samples) were put inside plastic bags to be later identified in the laboratory.

Extraction of soil fauna

To extract soil macro-fauna, we used a Barlese-Tullgren funnel-pour method. Soil samples (included the organic matters) were put in funnel-pour. With this method, we could use a heat source (lamp) to made the soil fauna move down into the bottle under the funnel. We used 70% alcohol solution inside the bottle to preserve the soil fauna.

Identification of environmental parameters

The samples were observed by using the stereomicroscope. For the identification process, we used the identification key (identification books), i.e., Jocque and Dippenaar-Schoeman (2006), Plowes and Patrock (2000), and Borror et al. (1989)

Assessment of environmental parameters

Air temperature. Air temperatures assessment was conducted by using a digital thermometer. Digital thermometer was placed in the plot observation, and we observed the temperature degree (scale) in the thermometer. When the temperature degree (scale) had been constant, we recorded the data (temperature). These procedures were conducted with three times repetitions for every 10 minutes (Yuniar 2014).

Soil pH. Soil pH assessment used pH indicator kit by dipping the pH indicator paper into the soil solution (mixture between soil samples with aquadest) for the three minutes. After that, we compared the colour that shows on the pH indicator paper to the colour scale in the pH indicator to determine the soil pH (Yuniar 2014).

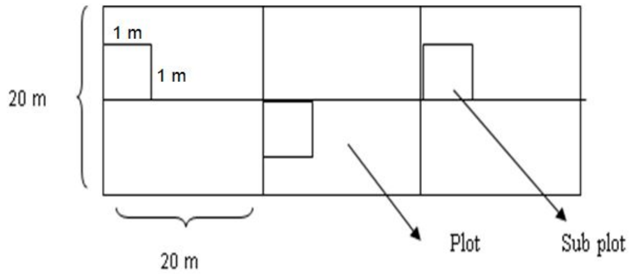

Figure 1. Plot and n sub-plot illustration for sampling soil biology

Table 1. Strata classifications of vegetation in research ecosystem

Classification	Explanation
I	Very low, consisting of 1-2 strata Only few vegetation with the lowest strata
II	Low, consisting of 2 vegetation strata
III	Medium, consisting of 3 vegetation strata
IV	High, consisting of 4 vegetation strata
V	Very high, the most complete strata

Organic matter. Organic matter parameter was assessed by measuring the depth of organic matter on the soil. This procedure was conducted in three assessment locations in each observation plots (Yuniar 2014).

Air humidity. Air humidity levels were measured by collecting temperature data with a dry and wet ball thermometer; then data was converted into an air humidity value (Yuniar 2014).

Trees (forest) crown density. The forest crown density was measured by using the Densitometer (a kit to measure the trees crown density). The forest crown density measuring was conducted by four repetitions (one time measuring in each direction, such as north, east, south, and west). The average of those forest crown density measuring was the value of the forest canopy cover level (degree) (Haneda et al. 2013).

Vegetation strata. The measurement of vegetation strata was measured by the composition of vegetation in each ecosystem like as trees, shrubs, lower plants, epiphytes, and lianas (Yuniar 2014). The vegetation strata category was classified based on the research by Room (1975) in Table 1.

Data analysis

Data processing was conducted to observe the diversity of the soil fauna. The soil fauna diversity in this research would describe through species diversity index, species richness index, species evenness index, and Morisita index.

Species diversity index (H') was calculated by applying the Shannon-Wiener index, to know species diversity level in an ecosystem (Ludwig and Reynold 1988):

$$H' = -\sum_{i=1}^{s}(Pi\ln Pi$$

Where:
Pi was following this formula:

$$Pi = \frac{ni}{N}$$

Where:
H’ = *Shannon-Wiener* species diversity index
Ni = Number of individual per species
N = Number of whole individual (total) of species

Margalef richness index (DMg) was used to determine the richness level of species based on the number of species in an ecosystem:

$$DMg = \frac{S - 1}{\ln N}$$

Where:
DMg = Margalef species richness index
S = Number of species found
N = Number of whole individual of species

Species evenness index (E) was used to describe the species distribution level toward another species (dominant or not dominant) in an ecosystem. This parameter was determined by using this formula (Magguran 2004):

$$E = \frac{H'}{\ln S}$$

Where:
E = Species evenness index
H'= *Shannon-Wiener* species diversity index
S = Number of species found

If the value of species evenness index (E) approaches to 0, it means that the spread of the species was dominant. In the other hand, if the value of species evenness index (E) approaches to 1, it means that the spread of the species was evenly distributed.

Morisita index was used to show the distribution pattern of a species in an ecosystem (Morishita 1956), namely:

$$Id = n(\frac{\sum_{X} 2 - N}{N(N - 1)}$$

Where:
Id = Index of Morisita
N = Number of plot
Σx2 = Sum of squares of all species for each plot
N = Total number of individual (all species)

If the Morosita Index (Id) = 1, it means that the distribution of a species was random. On the other hand, if the Morosita Index (Id) > 1, it means that the spread of a species was cluster. If Morosita Index (Id) < 1, it means that the distribution of a species was regular.

RESULTS AND DISCUSSION

Soil animal genus composition in several land cover

The results of this research showed that the soil fauna species abundance (total) in all ecosystem type, both in the burnt and unburnt area (primary forest, industrial plantation forest, and palm oil plantation ecosystem) was 519 individuals, belonging to 46 genus, 33 families, 20 orders from 8 classes namely Arachnida, Chilopoda, Collembola, Clitellata, Gastropoda, Hirudinida, Insecta, and Malacostraca. This research also found 3 phyla, such as: Arthropoda, Annelida and Mollusca.

Based on the genus, Pheidole, Solenopsis, Reticulitermes, and Coptotermes were the dominant genus in this study (Figure 2). The genus of Pheidole showed the largest number of individuals in this study (consisting of 86 individuals). The genus of Pheidole was included in the Myrmicinae sub-family. Myrmicinae was a sub-family with largest number of species in the world (Holldobler and Wilson 1990). Myrmicinae was also found to be dominant in previous studies were conducted by Ito et al. (2001) and Herwina and Nakamura (2007) at the Bogor Botanical Gardens. Anderson (2000) said that generally, the Pheidole were found on the land surface of tropical rainforest throughout the world.

In the unburnt primary forest ecosystem, the results were 141 individuals of soil fauna from 22 genera, 18 families, 15 orders, 7 classes and 3 phyla. The genus with the largest number of individual which found in unburnt primary forest ecosystem was Pheidole (24 individuals), followed by Anoplolepis (17 individuals) (Figure 3). Pheidole was included in the Myrmicinae subfamily. This subfamily was the second largest genus in the world with 893 species, and almost could be found in the whole of the world. In the tropical rainforest ecosystem, usually, it could be found in the decayed of woods on the forest floor (Shattuck 2001).

The soil fauna spread pattern based on its genus in the unburnt primary forest ecosystem was cluster pattern. The Id value was > 1. This indicated that every individual of soil fauna could live together in a habitat that was appropriate to their necessary.

In the burnt primary forest ecosystem, soil fauna was found as 75 individuals from 11 genera, 7 families, 7 orders, 2 classes and 1 phyla (Figure 4). The dominant genera in the burnt primary forest ecosystem were Pheidole with 20 individuals followed by Reticulitermes with 14 individuals. In burnt areas, there were many residuals of woods (organic matters) from the forest fire remnants, and those were available as foods for the Reticulitermes. This condition contributes to the high number of Reticulitermes individuals in the burnt areas.

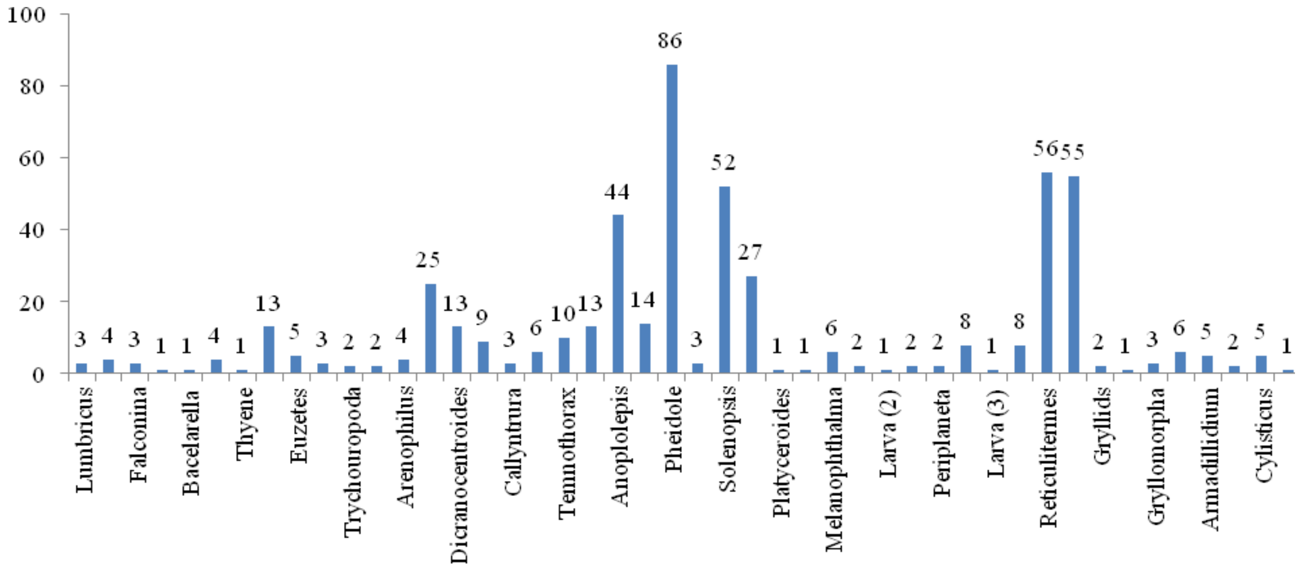

Figure 2. Composition of soil fauna based on the genus in the in all ecosystem type burnt and unburnt area (primary forest, industrial plantation forest, and oil palm plantation)

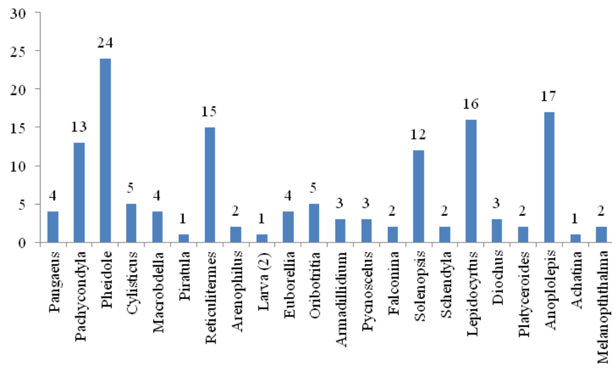

Figure 3. The composition of soil fauna based on the genus in the unburnt primary forest ecosystem

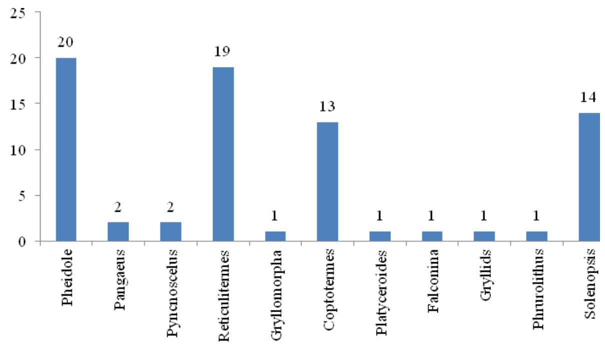

Figure 4. The composition of soil fauna based on the genus in the burnt primary forest ecosystem

Id value of the soil fauna in the burnt primary forest ecosystem was > 1. It means that the spread of the species was cluster.

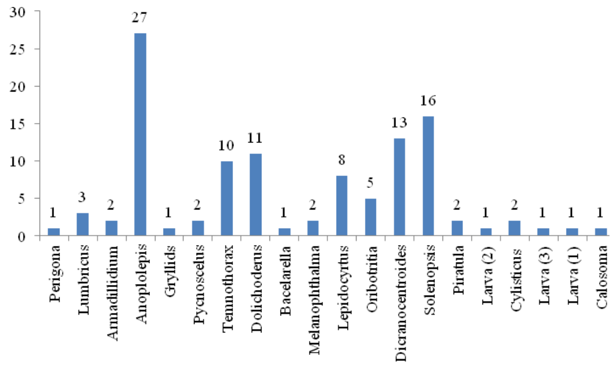

Figure 5. The composition of soil fauna based on the genus in the unburnt industrial forest plantation ecosystem

In the unburnt industrial forest plantation ecosystem, the soil faunas which found were 110 individuals from 20 genus, 17 families, 10 order, 5 classes, and 2 phyla. The dominant genus in this ecosystem was Anoplolepis (27 individuals) (Figure 5).

Domination of Formicidae family occurred throughout the whole ecosystem, whereas for other families often were found as one individual only in an ecosystem. Probably, it was caused by the hand-sorting method that used in the collection of soil fauna. For some species of soil fauna which could move (jump) rapidly, tend could not be observed. In this ecosystem, the genus Lumbricus was found too with 3 individuals. Ecological factors had a great impact on both breeding and growth of earthworms. Environmental factors that affect the growth, breeding, and health of earthworms were the availability of food, temperature, humidity, acidity (pH), and aeration (Martin and Hawthorne 1981).

The Id value in unburnt industrial forest plantation ecosystem was = 1. It indicated that all plots have a random distribution pattern for the soil fauna. This showed that every individual of the soil faunas was spreading in several places and clustered elsewhere. Michael (1994) said that this distribution occurred if the environment was homogenous.

In the burnt industrial forest plantation ecosystem, soil faunas were found as many as 60 individuals from 10 genus, 9 families, 9 orders, 4 classes and 1 phylum (Figure 6). The dominant genera in this ecosystem were Reticulitermes (22 individuals). In this observation, plot termites were found in the large number relatively, because the termite's foods (woods and branches) were available in large enough number here. Termite lives in a colony. It builds its nest like a small hill. In the ecosystem, the termite's activities to construct its nest were the key in the soil nutrient translocation which affects the soil fertility (Jones 1990).

The distribution pattern in the ecosystem of burnt industrial forest plantation was regularly spread (Id < 1). Soerianegara and Indrawan (2005) said that the regularly spread pattern can occur when the intense competition happened and encourages the sharing of the same living space (niche).

In the unburnt palm oil plantation ecosystems, soil faunas were found in 109 individuals, 15 genera, 13 families, 11 orders, 4 classes, and 1 phylum (Figure 7). The 13 families who found in this ecosystem were Euzitidae, Homidia, Lathridiidae, Cylisticidae, Formicidae, Anisolabididae, Entomobryidae, Staphylinidae, Blattidae, Salticidae, Gryllidae, Chthoniidae, and Rhinotermitidae. Dominant genera of soil faunas in this place were Pheidole (39 individuals), and followed by Plagiolepsis (23 individuals). The number of individual of soil fauna in this location was the largest individual number which found in two other ecosystems (unburnt and burnt). The Formicidae’s individual number was also found predominantly in this research.

In unburnt oil palm plantation ecosystem, we also found the genus of Homidia (Entomobryomorpha order). The individual number and the genus diversity of Entomobryomorpha orders doe to the species of this ordo can move actively with a slim body and long furkula (Hopkin 1997). Besides that, the high number of individual of Collembola on the ground surface which found on the oil palm plantation ecosystem indicated that this fact was related to the existence of organic matter in the oil palm plantation. Lawrence and Wise (2000) said that the existence of Collembola on the ground was able to decompose the organic matter. Based on the Morisita Index in palm oil plantation ecosystems showed that all the plots had cluster pattern with Id > 1.

In the burnt oil palm plantation ecosystem, we found 45 individuals of soil fauna from 9 genera, 7 families, 6 orders, 3 classes and 1 phylum. The families found were Euzitidae, Homidia, Salticidae, Formicidae, Trematuridae, Staphylinidae and Paronellidae (Figure 8). The dominant genus in this ecosystem was the genus of Coptotermes (26 individuals). Borror et al. (1989) stated that the Rhinotermitidae family (termites) are often found in trees, soil (around the root system), and other places. Termites are very fast in their development, so the population is very large and centred in their nest. In ex-burnt area, Termites were found due to this area had the food resources for the termites such as the wood.

The distribution pattern of the burnt palm oil plantation ecosystem was uniform (Id < 1). This indicated that no soil fauna colony dominated in any one of the observation plots. All genera distributed evenly in the observed ecosystem and did not cluster at the certain point.

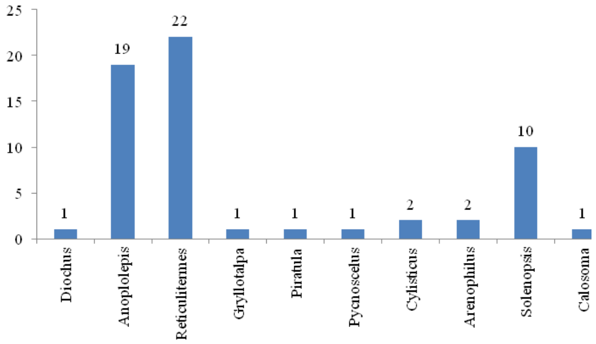

Figure 6. The composition of soil fauna based on the genus in the burnt industrial plantation forest ecosystem

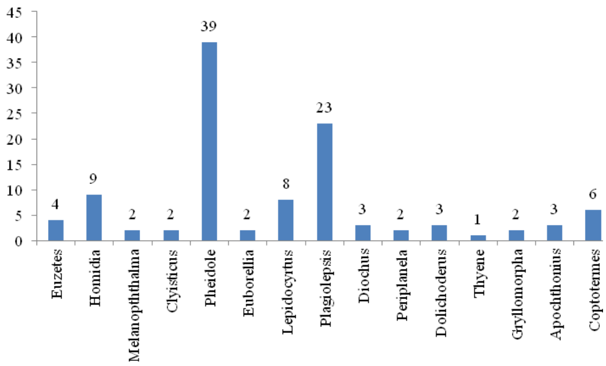

Figure 7. The composition of soil fauna based on the genus in the unburnt palm oil plantation ecosystem

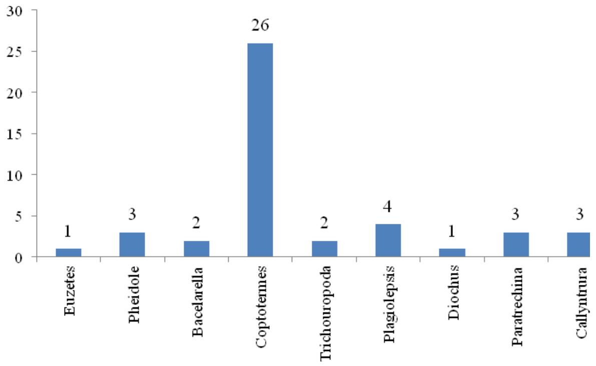

Figure 8. The composition of soil fauna based on the genus in the burnt palm oil plantation ecosystem

Diversity, wealth, and evenness of soil fauna

The diversity observed in this study was the index of diversity (H'), the index of richness (DMg), and the index of evenness (E). The diversity index value for each ecosystem was shown in Table 2.

According to Soerianegara and Indrawan (2005), diversity is a combination of the number of species found in an ecosystem or species richness and the number of individuals in each species or evenness. Besides that, Karmana (2010) stated that the diversity index of the species depends on the richness and equality of the species.

Based on the study, the number of genera found in a primary forest ecosystem was 22 genera, industrial forest plantation was 20 genera, and palm oil plantation was 15 genera. The number of genera decreased when the fire happened (Table 2). Fuller (1991) stated that in general, forest fire has impact on the soil fauna, such as the demise of soil fauna, or move and adapt in new habitat. That condition might cause the decrease of soil fauna abundance.

This study showed that the unburnt primary forest ecosystem had highest diversity (DMg = 4.243, H' = 2.664, E = 0.862), and the lowest diversity belonging to oil plantation ecosystem (DMg = 2.102, H' = 1.520, E = 0.692). This fact indicated that primary forest ecosystem had high biodiversity; it was shown from the diversity value. Compare to the forest ecosystem biodiversity, palm oil plantation ecosystem had lower biodiversity, and it was shown by the diversity value. This phenomenon might cause the land form difference from forest with diverse vegetation and the palm oil plantation with few vegetation and mostly dominated by palm trees only. Besides that, this phenomenon also might cause by land fire (fire in the non-forest ecosystem, e.g. oil palm plantation land) which killed the vegetation. Vegetation is the producer (food resource) for fauna, include the fauna soil.

The effect of ecosystem characteristics on soil fauna

The existence of soil fauna was strongly influenced by the environmental factor in a habitat (biotic and abiotic) (Jones 1990; Haneda et al. 2005). Abiotic environmental factors were the air temperature, soil acidity (pH), and air humidity. Biotic environmental factors were strata of vegetation, litter thickness, and crown (canopy) density. Therefore, it was necessary to observe abiotic and biotic environmental factors to know its effect on the soil fauna (Tabel 3).

The level of vegetation strata in each ecosystem was difference, depending on the species composition. Based on this study, the vegetation strata classification which included in the Classification I (very low) in each ecosystem were: oil palm plantation ecosystem (burn and unburnt area), burnt industrial plantation forest ecosystem, and burnt primary forest ecosystem. On the other hand, the vegetation strata classification with high category (IV) was primary forest ecosystem. Primary forest has many species compositions such as tree, pole, and other plants. Vegetation strata and (plants) species composition in each ecosystem caused the difference in the soil fauna number. In the primary forest was found the most individual number of soil fauna as many as 141 individuals.

In the other hand, other environmental factors like the temperature and the humidity have influences on soil fauna diversity, because every organism of soil fauna had different optimal point on temperature and humidity to survive in their life. The data showed that temperature in the unburnt ecosystems was 26°C-30.3°C, while in the burnt ecosystems were 30°C-32.4°C. Riyanto (2007) said that the temperature range of 25°C-32°C is the optimal temperature and tolerant for the activities of soil fauna in the tropical region.

Table 2. Biodiversity of soil fauna in three ecosystems (unburnt and burnt) in several regions in Jambi Province, Indonesia

Category	Primary forest		Industrial forest plantation		Palm oil plantation	
	Unburnt	Burnt	Unburnt	Burnt	Unburnt	Burnt
Number of Genus	22	11	20	10	15	9
DMg	4.243	2.316	4.042	2.198	2.984	2.102
H'	2.664	1.799	2.419	1.590	2.081	1.520
E	0.862	0.750	0.807	0.694	0.768	0.692

Table 3. Comparison of environmental factors affecting diversity of soil fauna in three ecosystems (unburnt and burnt) in several regions in Jambi Province, Indonesia

Factor	Primary Forest		Industrial Forest Plantation		Palm Oil Plantation	
	Unburnt	Burnt	Unburnt	Burnt	Unburnt	Burnt
Vegetation strata	IV	I	III	I	I	I
Litter thickness (cm)	5.80	1.3	4.20	0.9	2.6	0.7
Temperature (°C)	26°C	30°C	28°C	32°C	30.3°C	32.4°C
Crown density (%)	85	0	74	0	64	0
Soil pH	4.3	5.5	4.3	6.0	4.8	6.2
Air humidity	81	56	59	70	71	58

The three of unburnt ecosystems (primary forest, industrial plantation forest, and oil palm plantation) showed a slightly acidic of pH (4.3-4.8). Beside that, on the three of burnt ecosystems (primary forest, industrial plantation forest, and oil palm plantation) showed higher a soil pH (5.5-6.2). These pH conditions were tolerant of the soil fauna, so the soil faun still could live and survive well in this soil (habitat). There is soil fauna which lives in low pH (acidic soil), while there is soil fauna which able to survive in high pH (alkali soil) (Rahmawati 2004).

Furthermore, the highest litter thickness was 5.80 cm (found in unburnt primary forest), and the lowest litter thickness was 0.7 cm (found in burnt oil palm plantation). Litter thickness affects to amount of decomposable litter, and litter thickness will produce more organic matter (Mataix-Solera et al. 2011). Organic matter also affects abundance the soil fauna in the ecosystem. This fact was indicated by the diversity of soil fauna in primary forest was higher than the diversity of soil fauna in burnt oil palm plantation.

To conclude, in three types of ecosystems, it were found 519 individuals belonging to 46 genera, 33 families, 20 orders from 8 classes, namely Arachnida, Chilopoda, Collembola, Clitellata, Gastropoda, Hirudinida, Insecta, and Malacostraca, and 3 phyla, namely Arthropoda, Annelida, and Moluska. Pheidole genus was the predominant genus with 86 individuals. The highest soil fauna diversity was found in the unburnt primary forest ecosystem with DMg = 4.243, H '= 2.664, E = 0.862. Meanwhile, the lowest soil fauna diversity was found in the burnt palm oil plantation ecosystem with the value of DMg = 2.102, H '= 1.520, E = 0.692. Characteristics of ecosystems were also influenced by environmental factors, such as abiotic and biotic. Abiotic factors were temperature, humidity, and pH. Meanwhile the biotic factors were vegetation strata, litter thickness, and crown density.

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