CHAPTER 8

Comparison of soil microfauna diversity between a burnt and unburnt peatland in Indonesia

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Abstract: Approximately 95 percent of peatlands in Indonesia have been degraded by forest fires or converted for cultivation. Forest fires release huge volumes of carbon dioxide into the atmosphere and have caused severe damage to Indonesia's ecosystems and biodiversity, particularly in Kalimantan and Sumatra. Even though understanding post-fire environmental dynamics and biodiversity changes would be highly beneficial in determining restoration processes, baseline analyses on biodiversity and soil moisture content in burnt and degraded peatlands remain limited. Consequently, this research explores and assesses soil macrofauna diversity and properties, and changes in soil fauna patterns in a burnt peatland area currently undergoing restoration with the establishment of a bioenergy plantation in Buntoi Village, Central Kalimantan Province, Indonesia. Results from the study site show peatland fires causing hugely reduced numbers of soil mesofauna and macrofauna individuals, and bioenergy tree survival rates being higher in plots on unburnt than burnt peatland. Fauna species diversity, gauged using the Shannon diversity index (*H*), was lower in burnt than unburnt areas, though some orders – such as Hymenoptera – appear to adapt well to burned areas as we found them in both burnt and unburnt plots. Results show a significant correlation between peat fires and biodiversity. We also found that the more seriously fire damaged bioenergy trees were, the higher the likelihood of biodiversity decreasing. Generally, soil moisture and nutrient availability are key factors supporting higher soil invertebrate diversity in unburnt areas. However, results showed no significant correlation between soil moisture content and soil fauna diversity in our research site. In conclusion, understanding the severe impacts of fire on peatlands will make people more aware and less likely to use fire for clearing and preparing peatlands, thereby prolonging their use.

Keywords: forest fire, biodiversity, soil fauna, bioenergy, soil moisture, restoration

8.1 Introduction

Tropical peatlands play a significant role in global ecosystem dynamics by providing ecological, social and climate benefits (Harrison et al. 2019). Around 50–70% of the world's wetland areas are peatlands, which cover a total area of approximately 38 million hectares (ha). Many of these peatlands (14.9 million ha) are located in Indonesia, with provinces in Sumatra and Kalimantan having the highest proportions of peatlands at 34–43% and 28–32%, respectively (BBPPSDLP 2011). Southeast Asia's peatlands are recognized globally as reservoirs of biodiversity (Posa et al. 2011).

However, peatlands have undergone drastic transformations and been critically degraded by forest fires and land conversion. Forest fires are a key driver of peatland deforestation and degradation, release huge volumes of carbon dioxide into the atmosphere and have caused severe damage to Indonesia's ecosystems and biodiversity, particularly in Kalimantan and Sumatra (Saharjo 2016). Severe peat fires on drained peatlands converted for cultivation in Indonesia have caused serious environmental and economic damage both locally and globally (Carmenta et al. 2017). Peat forests in Indonesia were degraded at a rate of around 2.6% per year between 2007 and 2015 (Miettinen et al. 2016), and only 4,000 km^2 (7.4%) of Kalimantan's 57,000 km^2 of peatlands remained in pristine condition in 2015 (Miettinen et al. 2016). More than 90 percent of Indonesia's peat swamp forests have been devastated or degraded (FAO 2012), accounting for the largest proportion of degradation among all forest types (Budiharta et al. 2014).

Fires in forests and peatlands disturb and dry out soil, adversely affecting micro- and macro-organism populations and diversity. In forests and peatlands, soil biodiversity is essential and critical for improving and supporting soil quality (Barrow 1991; Saharjo and Nurhayati 2006; Suciatmih 2006; FAO 2008; Saharjo et al. 2011), ecological functions and ecosystem services (Anderson 1975; Usher et al. 1979; Giller 1996). Following a peatland fire, soil fauna require a significant length of time to recover, but also contribute to soil recovery and fertility, and improved properties and condition (Wasis et al. 2018) as they have both direct and indirect effects on nutrient cycling and litter decomposition (Winsome 2005). Even though understanding post-fire environmental dynamics and biodiversity changes would be highly beneficial in determining restoration processes, baseline analyses on biodiversity and soil moisture content in burnt and degraded peatlands remain limited.

This research aimed to identify soil macrofauna diversity in a peatland area restored with bioenergy trees in Buntoi Village, Central Kalimantan Province, Indonesia, and compare this diversity in burnt and unburnt peatland areas. Environmental indicators relating to soil properties were also assessed and compared between the burnt and unburnt peatlands. An objective was to establish baselines for faunal diversity, soil biology and change in pre- and post-fire peatlands restored with bioenergy trees.

8.2 Materials and methods

8.1.1 Study area

Kalimantan and Sumatra in Indonesia, which form parts of the Sundaland biodiversity hotspot (Myers et al. 2000), are estimated to host up to 15,000 flowering plant, 37 endemic bird, and 44 mammal species (MacKinnon et al. 1996). IUCN (International Union for Conservation of Nature) has classified 415 of the regions' species as threatened. The research site in Buntoi Village, Central Kalimantan Province is located at 2° 048' 059.4" S and 114° 010' 47.3" E (Figure 1) and has a humid tropical climate (BVG 2014). Larges areas of forest and peatlands in Buntoi Village were severely degraded as a result of fires in 2015. Since then, the Center for International Forestry Research (CIFOR) has established the area as one of the most important pilot project sites for planting bioenergy crops as a means for peatland restoration. In February 2016, CIFOR established two hectares of trial plots for the bioenergy tree species *Calophyllum inophyllum*, known locally as *nyamplung*, to measure its suitability for planting on degraded peatlands in Central Kalimantan. The trial plots were affected by fires twice in 2019. Trial Plot 1 was badly damaged during the first fire in July 2019, while the second fire in October that year affected trial Plot 2. The two plots in the two-hectare trial plot area are separated by a canal.

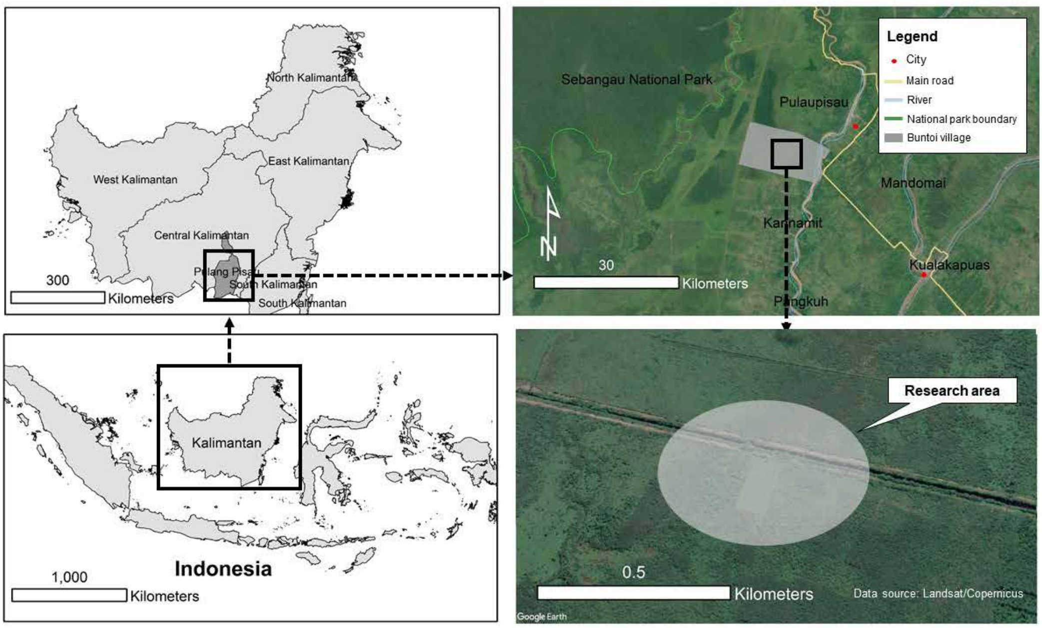


Figure 1. Study area in Buntoi Village, Pulang Pisau District, Central Kalimantan Province, Indonesia

8.1.2 Sampling design

Nyamplung trees were planted on the two-hectare plantation area with a plant spacing of 8 m x 8 m. A canal separates the plantation area into two one-hectare plots. A random sampling method was used to collect soil fauna specimens (Goehring et al. 2002; Witmer et al. 2003; Mathews et al. 2004). Sampling was conducted twice. The first samples were collected in August 2019 following a fire in Plot 1, while the second samples were collected in November 2019 after another fire in Plot 2. Equal numbers of sampling points (12) were established in each plot. In Figure 2 below, L1 to L12 represent planting rows, while each box with an 'X' represents a single tree. To ensure uniqueness in data collection, three different sampling point positions were employed: near trees; between trees in the same row; and between trees in different rows.

Four sampling categories (A, B, C and D) were established for this study, differentiated by plot conditions following the 2019 fires. A was the first sampling of Plot 1 (3 weeks after being fire affected), B was the second sampling of Plot 1 (15 weeks after being fire affected), C was the first sampling of Plot 2 (unburnt), and D was the second sampling of Plot 2 (3 weeks after being fire affected).

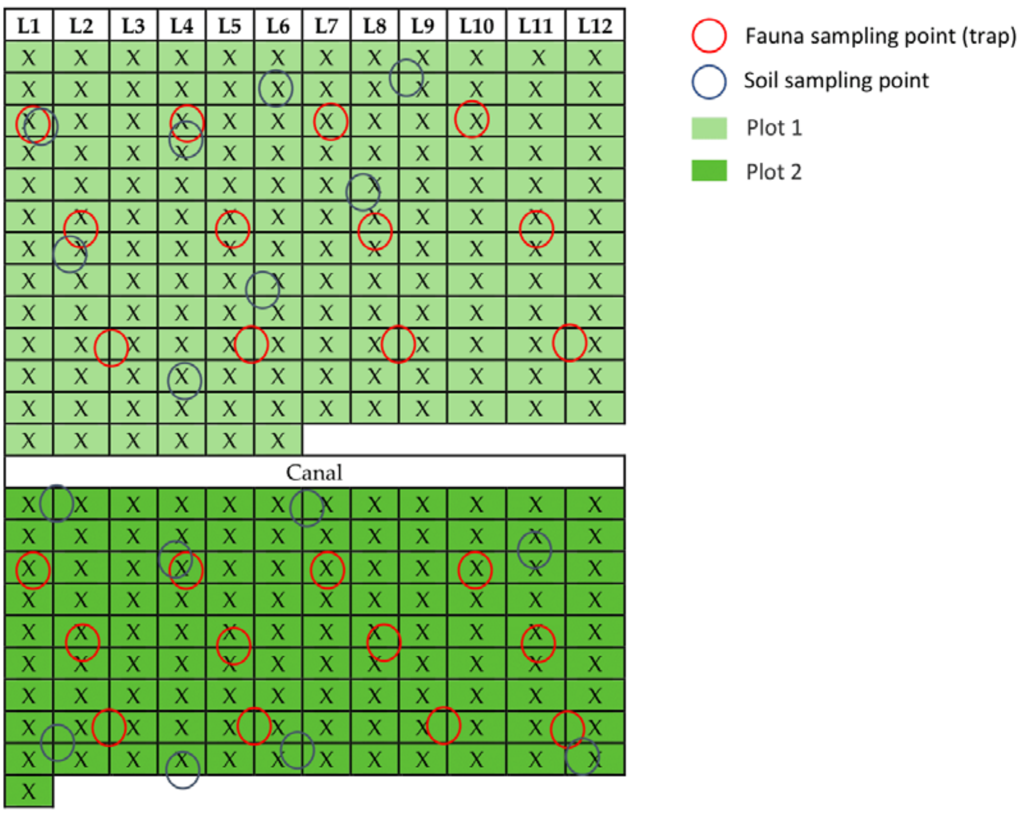


Figure 2. Sampling design

8.1.3 Soil fauna sampling

This study focused primarily on soil mesofauna and macrofauna. Soil macrofauna comprises insects, earthworms, isopods, molluscs and Myriapoda above 2 mm in size, while mesofauna consists of arthropods, mites, enchytraeids and Collembola below 2 mm in size (Maftu'ah et al. 2005). The pitfall trap method (Domingo-quero 2010) was used to trap surface macro/mesofauna. Pitfall containers were positioned by digging holes measuring 15 cm deep and 7 cm in diameter at the selected sampling points. Containers were placed at the defined sampling points and labelled. The pitfall traps collected hypogean and epigean fauna that crawled over the surface. These traps, called wet traps/kill traps and equipped with killing-preservative liquid, were used for the study. Considering the hazardous effects of chemical preservation (Weeks and McIntyre 1997), liquid detergent mixed with water was employed as it reduced surface tension allowing captured fauna to sink (Domingo-quero, 2010). The traps were set for 24 hours, following which the trapped fauna was hand sorted in the field (Suin 1997; Maftu'ah et al. 2005). Once sorted, trapped individuals were preserved in vials filled with 95% alcohol (FAO 2008) and delivered to the CIFOR laboratory in Bogor for identification.

For the first stage of identification, images of collected specimens were taken using a microscope fitted with a Leica MC170 HD camera operated with the help of Leica software (LEICA 2011). The Leica Application Suite (LAS) Version 4.4.0 used for this study provided easy-to-use research analysis with real-time, high-resolution images. Images focusing on key body parts (legs, wings/elytra) at different levels of magnification were necessary for identification at the order level. The second stage of identification employed a taxonomic system following morphological character according to Zhang (2011) by referencing the identification key for macro/mesofauna developed by Dr Antov Potapov from the University of Göttingen, Germany.

8.1.4 Soil sampling

Soil samples were collected from random sampling points at depths of 5 cm in August 2019 and November 2019 (Figure 2). Three replicate soil samples were taken from each sampling point and collected to examine their soil moisture content. In addition to soil moisture, the samples were collected to assess soil properties such as bulk density, soil temperature, pH, total micro-organisms, and water table depth in burnt and unburnt peat soils meeting standard criteria for environmental degradation under Republic of Indonesia Government Regulation No. 4/2001 (Wasis et al. 2019).

8.1.5 Data analysis

Soil fauna biodiversity data was processed using a species diversity index (H) and calculated using the Shannon-Wiener index (Shannon 1948) to show species biodiversity level (Ludwig and Reynold 1988). Species richness and species evenness data were also generated by employing the Margalef index (Margalef 1958) and Pielou index (Pielou 1966), respectively.

$H = -\sum_{I=0}^{S} p_i \ln \ln (p_i)$ = Shannon-Wiener species diversity index

$p_i = \frac{N_i}{N}$ = proportion of the total sample belonging to the i^{th} species.

$H_{max} = \ln \ln S$ = Maximum diversity possible

$E = \frac{H}{H_{max}}$ = Evenness

N_i = Number of individuals per species

N = Total number of individuals for all species

S = number of species = species richness

The gravimetric method (Reynolds 1970) was used to determine soil water content by drying soil samples at 105°C for 48 hours. Gravimetric water content (θ_g) is the water mass per dry soil mass. Measurements were taken firstly by weighing soil samples (m_{wet}); dehydrating them, and weighing the resulting dried soil (m_{dry}) (Bilskie and Scientific 2001). Similarly, soil pH was analysed by using a 1:2 ratio soil water suspension method (Jackson 1973).

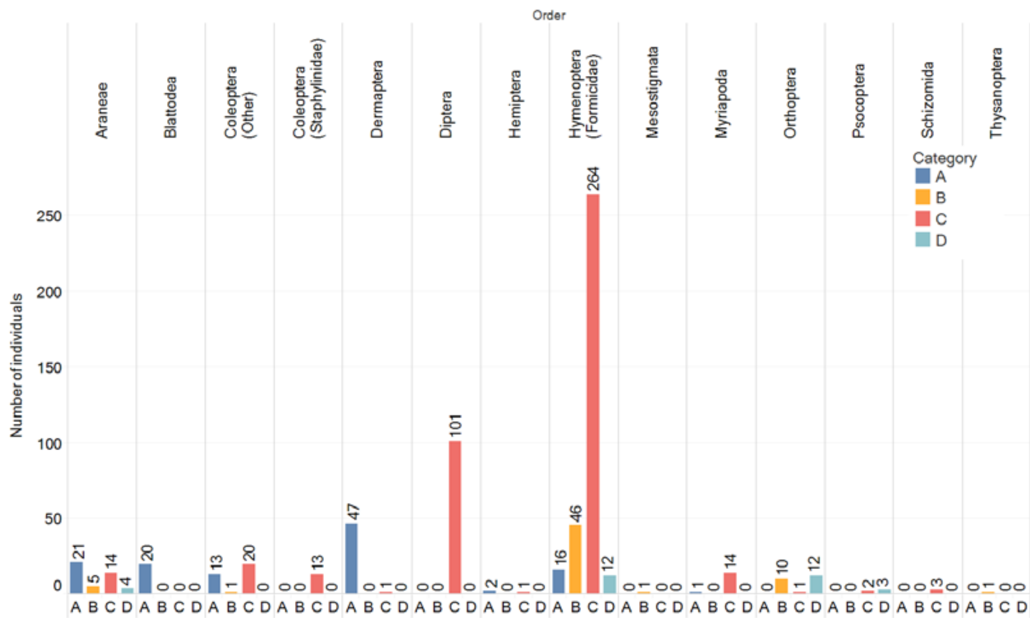
$$\theta_g = \frac{m_{water}}{m_{soil}} = \frac{m_{wet} - m_{dry}}{m_{dry}}$$

A total of 90 samples were collected from the four plot categories (A, B, C and D). Initially, research analysed correlations between variables with 95% confidence intervals to explore whether or not the different variables overlapped. Next, mean H and mean difference were calculated by category, by fire occurrence and by survival rate. STATA Version 14 was used to perform the data analyses.

8.3 Results

8.1.6 Soil fauna identification

A total of 649 soil fauna individuals were trapped during the study; 554 individuals from the first sampling period and 95 individuals from the second. A total of 24 species were collected from the first sampling period and 12 species from the second. These were categorized by order for comparative analysis. Later, during the laboratory identification process, they were classified as 14 orders of soil fauna (Figure 3). The most prevalent order was Hymenoptera (Formicidae), which was found in every plot. Of the 14 identified orders, only two – Coleoptera (Staphylinidae) and Schizomida – were exclusive to the unburnt area.



Note: A is the first sampling of Plot 1 (burnt), B is the second sampling of Plot 1 (burnt), C is the first sampling of Plot 2 (unburnt), D is the second sampling of Plot 2 (burnt)

Figure 3. Number of individuals by sampling category (A, B, C and D)

8.1.7 Soil fauna diversity

Numbers of individuals of every order in the burnt and unburnt areas as well as diversity indices for these areas are presented in Table 1. The Shannon diversity index showed greater species diversity (H) at sampling points where tree survival rates were higher than where they were lower (Table 1). Results show a significant correlation between peat fire occurrence and biodiversity (Table 2). We found the greater the fire damage to bioenergy trees, the higher the likelihood of diminished biodiversity. Further, peat fire had a detrimental impact on species richness.

Table 1. Soil fauna species diversity, species richness and species evenness

Order	Category											
	A			B			C			D		
	High (n=5)	**Medium (n=4)**	**Low (n=3)**	**High (n=9)**	**Medium (n=2)**	**Low (n=1)**	**High (n=8)**	**Medium (n=3)**	**Low (n=1)**	**High (n=6)**	**Medium (n=2)**	**Low (n=4)**
Araneae	19	0	2	4	1	0	12	1	1	2	2	0
Blattodea	20	0	0	0	0	0	0	0	0	0	0	0
Coleoptera (other)	10	1	2	0	1	0	15	5	0	0	0	0
Coleoptera (Staphylinidae)	0	0	0	0	0	0	3	10	0	0	0	0
Dermaptera	46	1	0	0	0	0	1	0	0	0	0	0
Diptera	0	0	0	0	0	0	39	62	0	0	0	0
Hemiptera	1	0	1	0	0	0	1	0	0	0	0	0
Hymenoptera (Formicidae)	12	1	3	25	14	7	36	228	0	10	0	2
Myriapoda	0	1	0	0	0	0	7	7	0	0	0	0
Orthoptera	0	0	0	8	1	1	1	0	0	5	4	3
Psocoptera	0	0	0	0	0	0	2	0	0	1	2	0
Schizomida	0	0	0	0	0	0	2	1	0	0	0	0
Total	108	4	8	37	17	8	119	314	1	18	8	5
S	6	4	4	3	3	2	11	7	1	4	3	2
H	**1.49**	**1.39**	**1.32**	**0.84**	**0.66**	**0.38**	**1.74**	**0.85**	**0.00**	**1.09**	**1.04**	**0.67**
$Hmax$	1.79	1.39	1.39	1.10	1.10	0.69	2.40	1.95	0.00	1.39	1.10	0.69
E	0.83	1.00	0.95	0.76	0.60	0.54	0.72	0.44	0.00	0.78	0.95	0.97

Note: High means high survival rate at the sampling point (all trees alive); Medium indicates one of two trees from the sampling point being dead; and Low means low survival rate (all trees dead). A is the first sampling of Plot 1 (burnt); B is the second sampling of Plot 1 (burnt); C is the first sampling of Plot 2 (unburnt); and D is the second sampling of Plot 2 (burnt).

Table 2. Correlation between variables

	H	S	E	Number of Individuals	Fire	Damage Level
H	1					
S	0.896**	1				
E	0.898**	0.702**	1			
Number of Individuals	0.083	0.353**	-0.016	1		
Fire occurrence	-0.447**	-0.565**	-0.241	-0.361**	1	
Survival rate	0.331**	-0.254	-0.279	-0.002	0.200	1

**high significance at a 95% confidence level

Average diversity index (H) value was highest for category C, where no fire had occurred (Table 3). By comparing the mean H values of categories A and B, we concluded that diversity recovers with time. Diversity index (H) values become higher as the level of damage decreases. Table 4 shows whether mean differences in diversity indices (H) were significant.

Table 3. Mean H by category, by fire occurrence and by tree survival rate

	Mean	Std Err	[95% Conf. Interval]	
By category				
A	0.373	0.120	0.131	0.616
B	0.451	0.120	0.208	0.694
C	0.842	0.120	0.599	1.085
D	0.309	0.120	0.066	0.552
By fire occurrence				
Unburnt	0.842	0.119	0.603	1.081
Burnt	0.378	0.069	0.240	0.516
By tree survival rate				
High	0.608	0.083	0.441	0.775
Medium	0.420	0.132	0.154	0.686
Low	0.228	0.146	-0.066	0.523

Table 4. Mean differences by category, by fire occurrence and by survival rate

	Contrast	Std Err	t	P>t	[95% Conf. Interval]	
By category						
C-A**	0.469	0.170	**2.75**	0.041	0.014	0.924
B-A	0.077	0.170	**0.45**	0.968	-0.377	0.532
D-A	-0.064	0.170	**-0.38**	0.981	-0.519	0.390
B-C	-0.391	0.170	**-2.3**	0.114	-0.846	0.064
D-C**	-0.533	0.170	**-3.13**	0.016	-0.988	-0.078
D-B	-0.142	0.170	**-0.83**	0.838	-0.597	0.313
By fire occurrence						
Burnt-Unburnt***	-0.464	0.137	**-3.39**	0.001	-0.740	-0.188
By tree survival rate						
Medium-High	-0.188	0.156	**-1.21**	0.455	-0.567	0.190
Low-High*	-0.380	0.168	**-2.26**	0.072	-0.788	0.027
Low-Medium	-0.192	0.197	**-0.97**	0.598	-0.670	0.286

* significant at a 90% confidence level; **highly significant at a 95% confidence level; *** very highly significant at a 99% confidence level

8.1.8 Soil properties

Soil moisture content for each category is presented in Table 5. Soil moisture content was higher during the second round of sampling than the first as rainfall was also higher. However, water table depth fell after fire. Table 5 shows the lower the survival rate, the lower the water level (water table depth).

Table 5. Comparison of environmental factors by category

		Properties						
Category		Water Table Depth	Soil Moisture	Bulk Density	WFPS*	Rainfall	Air Temperature	Air Humidity
A (n=8)	Mean	84.38	0.37	0.53	1.26	5.59	24.10	90.53
	Std Dev	18.17	0.18	0.07	0.26	0	0	0
B (n=8)	Mean	62.23	0.58	0.49	1.30	8.12	24.41	92.03
	Std Dev	10.38	0.13	0.06	0.21	0	0	0
C (n=8)	Mean	95.41	0.44	0.51	1.29	5.59	24.10	90.53
	Std Dev	20.19	0.24	0.13	0.46	0	0	0
D (n=8)	Mean	56.47	0.63	0.52	1.54	8.12	24.41	92.03
	Std Dev	13.00	0.15	0.11	0.63	0.00	0	0
Unburnt (n=8)	Mean	95.41	0.44	0.51	1.29	5.59	24.10	90.53
	Std Dev	20.19	0.24	0.13	0.46	0.00	0	0
Burnt (n=24)	Mean	67.69	0.53	0.51	1.37	7.28	24.31	91.53
	Std Dev	18.32	0.18	0.08	0.41	1.21	0.15	0.72
High (n=24)	Mean	77.34	0.50	0.52	1.37	6.86	24.26	91.28
	Std Dev	24.04	0.20	0.10	0.46	1.29	0.16	0.77
Medium (n=3)	Mean	67.63	0.67	0.50	1.39	7.28	24.31	91.53
	Std Dev	22.14	0.17	0.07	0.38	1.46	0.18	0.87
Low (n=5)	Mean	65.75	0.44	0.50	1.20	6.60	24.23	91.13
	Std Dev	6.86	0.20	0.06	0.25	1.38	0.17	0.82

* WFPS = Water-filled pore space

8.4 Discussion

Higher species richness and species diversity were recorded from samples taken in the unburnt plot than in those affected by fire, clearly signifying that peatland fires have significant impacts on soil mesofauna and macrofauna communities. A similar study in Mount Walat Education Forest in Sukabumi District, West Java Province, Indonesia, showed forest and land fires resulting in a decrease in soil macrofauna by an order of 17.65% (Syaufina 2008). Peat fire impacts can be even more severe, resulting in soil fauna mortality of 100% (Wasis et al. 2019). Another study in Indonesia also indicated similar results, with the average diversity index for soil fauna being lower in a burnt plot (0.76) than an unburnt plot (1.76) (Syaufina and Ainuddin 2011).

Burning peat increases soil porosity, decreases available water, increases soil permeability, and causes higher mortality in flora, fauna and microorganisms (Wasis et al. 2018). Burnt and dried peat soil is difficult to restore, and many lost soil fauna species are unlikely to return (Wibowo 2009). The presence of specific aboveground vegetation in unburnt areas helps in maintaining a greater diversity of soil organisms (Brennan et al. 2006). Unburnt habitats have displayed higher soil macrofaunal diversity in primary forest, palm oil plantation and industrial plantation forest ecosystems in comparison with burnt plots (Wasis et al. 2018), which supports the findings of this study.

Of the 12 orders recorded in burnt plots in our study area, individuals of Order Hymenoptera (Formicidae), representing most ant species, were recorded in high numbers (Figure 3, A-B) and were well adapted (Figure 3, C-D). This is because invertebrates, such as some ants, beetles, termites and spiders, can adapt to burning regimes (Swengel 2001) and are more likely to survive and evade heat because of belowground activity. In addition, burning and other disturbances, such as logging, provide open habitats as more favourable environments for ants (Andersen et al. 2009).

Soil moisture availability and related variables, including water table depth, are critical abiotic factors that affect soil animal communities and support soil invertebrates (York 1999; New et al. 2010; Keith 2012; Sylvain 2013). Soil moisture availability impacts soil fauna directly and indirectly by restructuring soil food webs and ecosystems (Sylvain 2013) – directly as fauna uses water for survival, and indirectly as soil moisture impacts the plants that fauna rely on (Xu et al. 2015). Given that burning and forest fires lead to topsoil moisture reduction and higher insolation levels (York 1999), we expected a negative response for fires on soil moisture. However, the study found no statistically significant correlation between soil moisture and peatland fires (Table 5). One possible explanation for this is that rainfall was higher in the burnt areas, resulting in more soil moisture (Table 5). Other reasons might be seasonal variables, soil nutrients, etc. In this regard, more comprehensive research into relationships between changes in soil conditions (nutrients, bacterial diversity, soil temperature, etc.) and soil fauna diversity is necessary.

8.5 Conclusions

Fires in Central Kalimantan Province have degraded peatlands and changed their biodiversity patterns. The peatland fires on community land in Buntoi Village adversely affected biodiversity indices and survival rates, thus having significant impacts on soil fauna biodiversity. Water table depth fell following the fires. We were able to establish which species are resilient and which species are vulnerable to fires in peatlands (Figure 3 and Table 1).

Overall, our results indicate that the changes in biodiversity and soil properties meet standard criteria for environmental degradation under Government Regulation No. 4/2001. Understanding the severe impacts of fire on peatlands will make people more aware and less likely to use fire for clearing and preparing peatlands, thereby prolonging their use.

This research had a number of limitations: (1) soil fauna was only identified to the order level due to time constraints; (2) sampling was only conducted twice due to budget and time constraints; and (3) no comparative research was conducted in other peatlands with different soil properties.

For more detailed insights into fire impacts on soil mesofauna and macrofauna communities, an intensive study with more replications and soil assessment considerations is recommended for future research. Comparisons of soil fauna biodiversity in different types of peatlands are also recommended for further study.

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