SOIL SCIENCE ANNUAL
2024, 75(1), 186453

https://doi.org/10.37501/soilsa/186453

Functional group diversity of soil macroarthropods in tropical rainforest areas of Bukit Pinang-Pinang Padang, Indonesia: implications for ecosystem balance

Fenky Marsandi[1]*, Hidayatul Fajri[2,4], Hermansah[3]

[1] National Research and Innovation Agency (BRIN), Research Organization for Life Sciences and Environment, Research Center for Ecology and Ethnobiology, Cibinong 16911, Bogor, Indonesia
[2] National Research and Innovation Agency (BRIN), Research Organization for Health, Center for Biomedical Research, Cibinong 16911, Bogor, Indonesia
[3] Andalas University, Faculty of Agriculture, [3]Department of Soil Science, Limau Manih 25163, Padang, Indonesia
[4] Universitas Nasional, Faculty of Biology and Agriculture, Department of Biology, Pejaten 12520, South Jakarta, Indonesia

* Corresponding author: Dr. Fenky Marsandi, fenkysandi90@gmail.com, ORCID iD: https://orcid.org/0000-0001-9690-8125

Received: 2023-06-28
Accepted: 2024-03-25
Published online: 2024-03-25
Associated editor: A. Józefowska

Keywords:

Functional
Macroarthropods
Ecosystem
Inceptisol
Herbivore

Abstract

This study assessed the abundance and diversity of soil macroarthropod functional groups in various land types within tropical rainforest areas. The results showed that out of 12 identified taxa, 2,794 individuals of soil macroarthropods were found, with hymenoptera dominating each land type with a relative abundance of 69.29%. The functional grouping of soil macroarthropods consisted of herbivores, predators, parasitoids, and detritivores. The highest variation in the number of functional group types was found in predators and herbivores, with seven taxa each. The highest individual abundance was found in predators, with 210 individuals. The highest diversity and evenness index of soil macroarthropod functional groups were found in herbivores, with values of 2.729 ± 0.056 and 0.578 ± 0.011, respectively, in monoculture gardens. In contrast, predator dominance was found in land that had been cleared, with a value of 0.754 ± 0.071. The significant correlation between soil pH, N, SMC, and BD with the observed species and individual abundance reinforces the argument that differences in micro-environmental conditions in each land type significantly influence the presence of soil macroarthropod functional groups. Forests that are rich in Inceptisol provide a natural habitat for diverse predator groups, ensuring protection of their diversity. On the other hand, monoculture gardens have the potential to increase herbivore diversity, but can also pose a threat to cultivated plants. These findings help to uncover the tendency of the roles and functions of soil macroarthropods in maintaining ecosystem balance and provide important support for evaluating soil quality.

1. Introduction

Soil serves as a habitat for soil macroarthropods, forming a complex system with heterogeneous properties that contribute to various ecosystem processes, particularly the decomposition of organic matter and nutrient cycling. Each group of soil macroarthropods plays a distinct and vital role in ensuring the sustainability of ecosystem processes. The diversity of soil macroarthropods emerges as a critical factor in maintaining ecosystem sustainability and serves as an indicator of soil health. The presence of soil macroarthropods in a particular land type demonstrates their remarkable adaptability to their habitat (Maggiotto et al., 2019). Consequently, a more comprehensive understanding of the specific roles and functions of soil macroarthropods is imperative in this context.

The role and function of soil macroarthropods, as delineated through the functional diversity of soil macroarthropods in a specific land type, needs to be comprehensively and systematically elucidated to address global challenges related to soil health (Wolters, 2001). Hence, the classification of soil macroarthropods based on their respective roles and functions can facilitate the assessment of soil health and provide insights into ecosystem quality within a given land type. Specifically, the energy flow within the soil ecosystem is explicated through the intricate interplay of feeding and being fed processes among predator and herbivore macroarthropod communities, supplemented by the involvement of soil detritivores as decomposers of organic matter on the soil surface (Letnic and Ripple, 2017). Additionally, parasitoids are essential contributors to ecosystem regulation, as their presence is indispensable for the biological control of soil organisms. Each functional group of soil macroarthropods contributes to the maintenance of ecosystem stability, and any disturbance in the presence of a particular group may potentially jeopardize soil health, disrupt the soil ecosystem, and ultimately impact the environment and human well-being (Menta and Ramelli, 2020).

The tropical rainforest area is home to a diverse range of organisms, including soil macroarthropods. However, these areas are under serious threat from land-use change, which has a major impact on the stability of soil ecosystems. Indirectly, this is driven by increasing human populations and their needs, which are shrinking forests and increasing the potential for disturbances to soil health (Decaens et al., 2018). One notable example is Bukit Pinang-Pinang, located in the Bukit Barisan mountain range in West Sumatra. This region has been a focal point for ecological research since 1986, particularly for Japanese researchers. It boasts remarkable plant diversity, with hundreds of distinct tree species thriving within a single hectare of forest. Furthermore, the area experiences exceptionally high rainfall, averaging around 6,500 mm/year, qualifying it as a super-wet tropical rainforest (Hermansah, 2003).

The impact of land use changes on soil ecosystem quality has a significant influence on soil health, particularly with regards to soil macroarthropods. The presence and abundance of soil community components alone are insufficient for accurately characterizing their response to land disturbances across different land types in the Bukit Pinang-Pinang tropical rainforest area. This paper aims to evaluate and compare the abundance of macroarthropods grouped by food type on several land types in the tropical rainforest area, Bukit Pinang-Pinang which has an impact on their role in maintaining the balance and health of the soil ecosystem.

2. Materials and methods

2.1. Study Area

The research sampling was conducted in the tropical rainforest area of Bukit Pinang-Pinang, West Sumatra, Indonesia (Fig. 1). Samples were collected from four different land types: forest (F), Logged Forest Areas (LFA), Mixed Gardens (MG), and Monoculture Gardens (Mo). The study area is situated at coordinates 100°29'40" to 100°30'20" E and 0°54'55" to 0°55'45" S, with an elevation ranging from 460 to 550 meters above sea level. It experiences a wet tropical (Monsoon) climate, characterized by an average annual temperature of 27°C and a relative humidity of 73% to 80%. The soils of the area are classified as Inceptisol, characterized by dark brown soil color, acidic soil pH, and a relatively high amount of litter (Hermansah et al., 2010).

The tropical rainforest area of Bukit Pinang-Pinang has undergone various land use transformations, encompassing logged forest areas, mixed gardens, and monoculture plantations. Forests, consisting of different tree compositions filled with litter on the ground surface, are the natural habitat for most living things. The logged forest areas contain residual wood and branch debris, whereas the mixed gardens comprise a diverse range of fruit species with organic fertiliser (mostly) and chemical fertiliser (in addition). On the other hand, monoculture plantations consist of cocoa plants that are about 10 years old and are intensively cultivated.

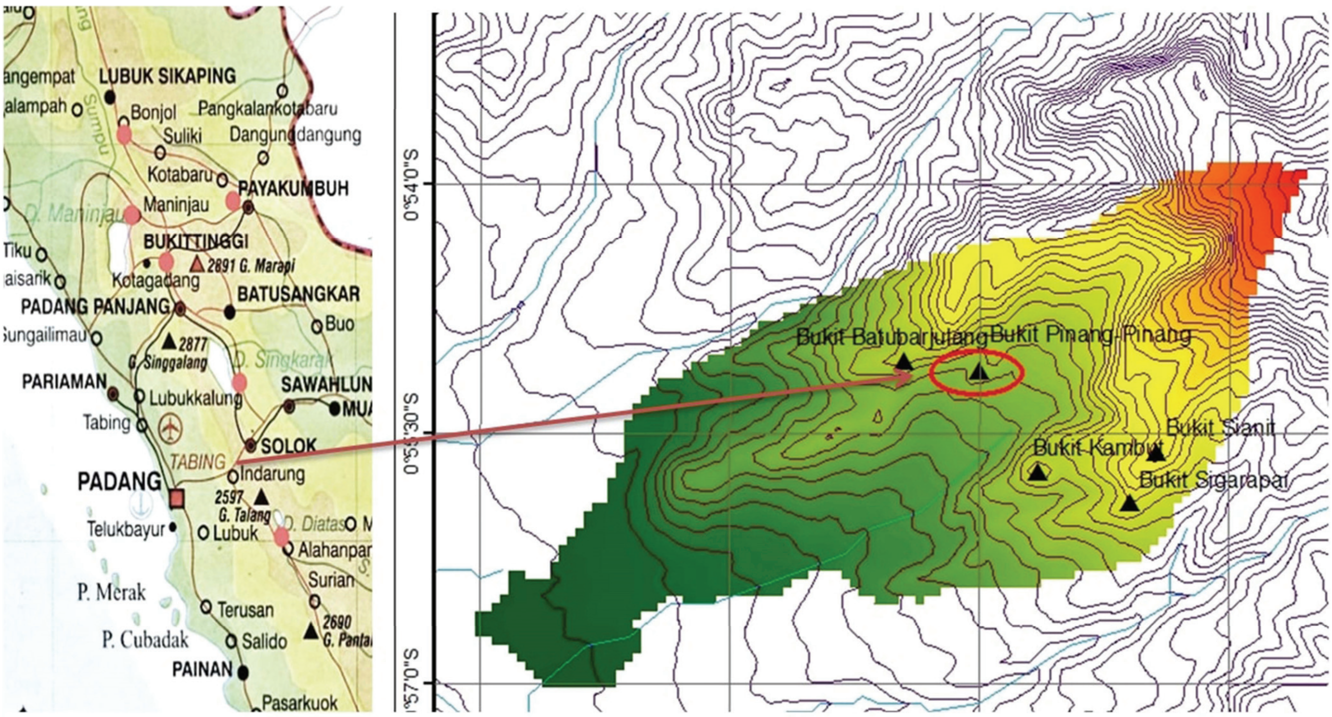

Fig. 1. Location map of the sampling area in the tropical rainforest of Bukit Pinang-Pinang, Padang, Indonesia

2.2. Research Methodology

The determination of sampling points was conducted using purposive sampling, based on the representation of an area by dividing one land use type into three plots according to the slope of the land: top, middle, and bottom, each measuring 40 x 40 m. Within each plot, four subplots were designated as composite sampling points. Consequently, a total of 12 soil samples were collected from each land use type, resulting in a cumulative total of 48 samples across all observed land types. Disturbed soil samples were obtained at a depth of 10 cm using a soil auger, while intact soil samples were collected at the same depth using a soil ring. The measurement of soil abiotic factors encompassed soil pH (measured through an electrometric pH meter method), soil N (determined using the Kjeldahl method), soil P (assessed using the Bray 1 method), soil K (extracted using the ammonium acetate method), soil C (analyzed with the Walkey and Black method), soil bulk density (measured employing the ring sample method), and soil moisture content (determined through the gravimetric method) (Balai Penelitian Tanah, 2009).

Four sampling points were selected, with each plot having an area of 40 x 40 m. (Fig. 2). The pitfall trap method was employed using propylene glycol. The collected soil macroarthropods were transported to the laboratory for further processing, which included specimen collection, identification, and analysis. The soil fauna were carefully placed in 100cc V-pot collection tubes containing 96% alcohol, and each tube was labeled with its specific location. The identification of soil fauna was conducted using a microscope and reference materials, such as the 7th edition of Borror's identification book (Triplehorn and Jhonson., 2005), Insect of South-Eastern Australia (Farrow, 2016), Web Taxonomy (Bold System), and Bug Guides (BugGuide.net).

2.3. Data Analysis

The analysis of abiotic soil factors was conducted using the Statistical Program for Social Science (SPSS). The abiotic soil factors, which encompassed the physical and chemical properties of the soil, underwent a one-way ANOVA test at a significance level of 95% to compare the soil conditions across four different land types. The abundance of soil macroarthropods was quantified for each land type, and their functional identification was based on the data collected from the Insect Recognition Book, Insects of Australia (Melbourne University), and the Journal of Soil Faunal Diversity at IPB. The results were graphically presented using the Prism 8 application. The functional diversity index of soil macroarthropods was determined using the Shanon-Wiener index, the functional evenness was calculated using the Pielou index, and the dominance was assessed using the Simpson index.

Shannon-weener index : $H = -\sum pi \ln pi$
Formula Description: H = Diversity index pi = ni/N ni = the number of individuals of the i-th species N = the total number of individuals.

Pielou index: $e = \frac{H'}{H\ max}$
Formula Description: e = Evenness index H' = Diversity index H max = Maximum diversity index (ln S) S = Number of species.

Simpson index: $D = \Sigma\,(ni/N)^2$
Formula Description: D = Dominance index ni = the number of individuals of the -i, N = the total number of individuals.

We analyzed the relationship between soil macroarthropod functional groups and soil physical/chemical characteristics using Pearson correlation analysis at a significance level of α 5% ($p < 0.05$).

3. Results

3.1. Characteristics of soil physical and chemical properties

The results of measuring the characteristics of soil physical and chemical properties show relatively different variations and dynamics that are significant in each land use (Table 1).

The soil chemical properties of P, K, and C did not differ among the different land types, whereas the soil chemical properties of pH and N exhibited variations between each land type. Similarly, the soil physical properties, as represented by

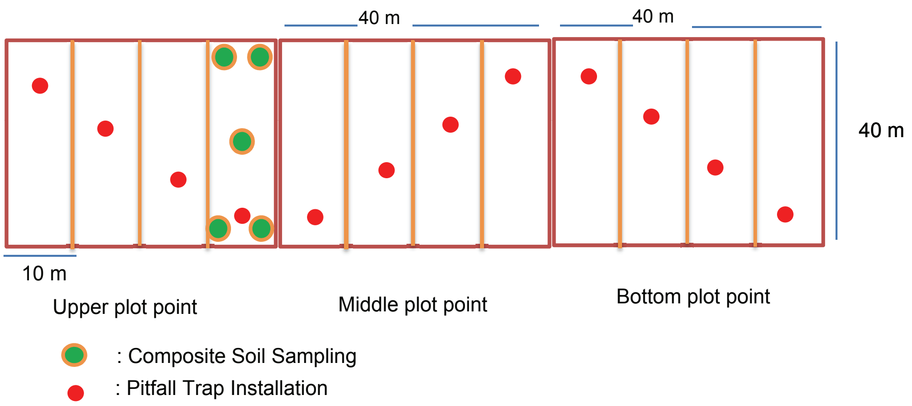

Fig. 2. Illustration of sampling on several land use types in the Bukit Pinang-Pinang Tropical Rainforest area

Table 1
Characteristics of soil physical and chemical properties

Soil Physical/Chemical Properties	Land Type's			
	F	LFA	MG	Mo
pH	4.85a ± 0.394	5.00a ± 0.232	5.68b ± 0.330	5.78b ± 0.323
N (%)	0.44a ± 0.101	0.34a ± 0.076	0.47ab ± 0.064	0.56b ± 0.107
P (ppm)	15.23a± 4.523	14.45a ± 6.439	14.77a ±6.234	20.64a ± 7.731
K (me/100 g)	0.14a ± 0.035	0.12a ± 0.020	0.15a ± 0.047	0.14a ± 0.045
C (%)	5.88a ± 2.569	5.83a ± 3.517	7.32a ± 3.068	6.88a ± 1.892
BD (gr/cm^3)	0.73a ± 0.080	0.79b ± 0.058	0.70a ± 0.059	0.66a ± 0.046
SMC (%)	0.37b ±0.127	0.24a ± 0.082	0.26a ± 0.109	0.24a ± 0.067

Explanations: pH: potensial of hydrogen, N: Soil Nitrogen, P: Soil Soil phosphorus, K: Soil Potassium, C: Soil Carbon, BD: Bulk Density, SMC: Soil Moisture Content; BD: Bulk Density, and F: Forest, LFA: Logged Forest Area, MG: Mixed Garden, Mo: Monoculture.

Soil Moisture Content (SMC) and Bulk Density (BD), displayed differences across the various land types in the Bukit Pinang-Pinang tropical rainforest area. Specifically, the pH, N, and P levels in the monoculture agricultural land type were significantly higher compared to the other land types ($P < 0.05$). Soil K and C concentrations in the mixed garden land use were significantly higher than those in the monoculture garden land use ($P < 0.05$). Conversely, the BD in the forest-clearing land type was higher than that in the agricultural land, including both mixed garden and monoculture garden land types ($P < 0.05$). Moreover, the SMC in the forest land type was higher compared to the logged forest area, mixed garden, and monoculture land types.

3.2. Effect of land use change on soil macroarthropods

3.2.1. The Total Soil Macroarthropods Found

A total of 2,794 soil macroarthropods, belonging to one phylum, five classes, and twelve groups, were collected in the study area. The dominant group was Hymenoptera, accounting for 69.29% of the total abundance. Coleoptera (11.13%), Orthoptera (5.51%), Diptera (5.44%), and Araneae (5.05%) were the most commonly encountered groups, while the remaining individuals belonged to rarely observed groups. The abundance of soil macroarthropods varied significantly across different habitat conditions. The Fig. 3 illustrates the abundance of soil macroarthropods in the Bukit Pinang-Pinang tropical rainforest area.

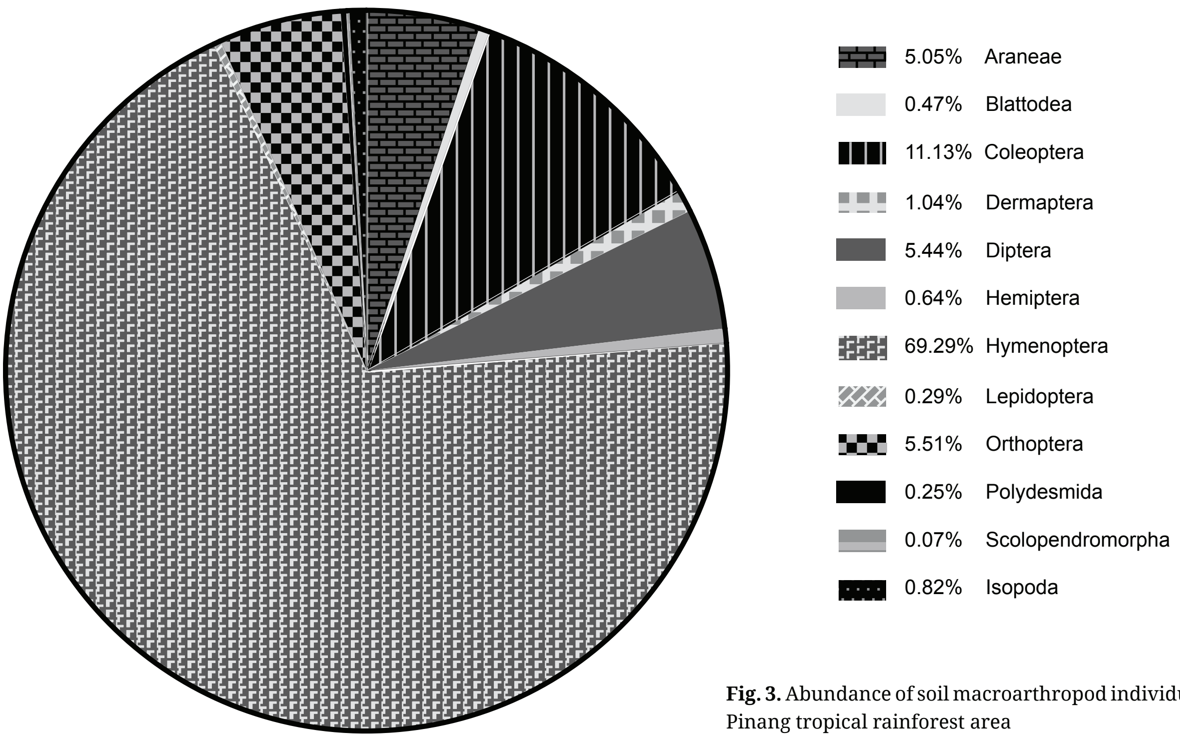

Fig. 3. Abundance of soil macroarthropod individuals in the Bukit Pinang-Pinang tropical rainforest area

Twelve groups of soil macroarthropods were identified in the Bukit Pinang-Pinang tropical rainforest area, namely Araneae, Blattodea, Coleoptera, Dermaptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera, Orthoptera, Polydesmida, Scolopendromorpha, and Isopoda. Eight groups of twelve orders of soil macroarthropods were observed in each land use type in the Bukit Pinang-Pinang tropical rainforest area. Among these groups, Hymenoptera was the dominant one in all land types, while Araneae, Coleoptera, Diptera, and Orthoptera were relatively evenly distributed or less abundant. Dermaptera, Hemiptera, and Polydesmida were found in low numbers. Lepidoptera occurred in mixed gardens, monoculture, and logged forest habitats, while Isopoda was present in forest, mixed gardens, and monoculture. Scolopendromorpha was exclusively found in logged forest habitats, while Blattodea was only observed in forest habitats and not in agricultural land types such as mixed gardens or monoculture gardens.

3.2.2. Total Functional Groups of Soil Macroarthropods

Each land use showed different numbers of soil macroarthropod functional group types (Fig. 4).

The variation in functional groups of soil macroarthropods is dominated by Herbivores (HB) and Predators (PD), with 7 orders each (Fig. 4). Among them, the PD group exhibits the highest number of functional groups of soil macroarthropods (Fig. 4). Detritivores (DT) exhibit variation in functional groups of soil macroarthropods with 4 orders, while the Parasitoid (PRs) group comprises only 1 order. The HB types are relatively evenly distributed, with Coleoptera, Diptera, and Orthoptera being the dominant groups with 10, 7, and 7 types, respectively. The PD group is predominantly represented by the Araneae group, encompassing 17 types. Parasitoids consist of a single type within the Hymenoptera group. The DT group is dominated by 9 types of Diptera. Our findings from the collection indicate that each functional group of soil macroarthropods in the Bukit Pinang-Pinang tropical rainforest area is dominated by HB and PD (Fig. 5).

HB exhibit the highest functional diversity among soil macroarthropods, with an average of 23.75 species. PD, on the other hand, demonstrate an average of 23.25 species within their functional group. In contrast, parasitoids display the lowest and least diverse average number of species in their functional group, with a value of 3.5 compared to other soil macroarthropod functional groups. Additionally, soil DTshowcase an average functional group diversity of 12 species. The extent of functional group diversity in soil macroarthropods varies and is determined by the number of macroarthropod individuals obtained in each land type (Fig. 6).

Figure 6 illustrates the predominance of PD in the abundance of functional groups of soil macroarthropods across different land types in the Bukit Pinang-Pinang tropical rainforest area. The forest land type exhibits the highest number of PD individuals, reaching 210 individuals. Likewise, the forest land type exhibits the highest abundance of HB individuals, totaling 147 individuals. Additionally, the forest land type records the highest number of detritivore individuals, comprising 65 individuals. Conversely, the Logged forest area reveals the highest number of PRs group individuals, amounting to 12 individuals.

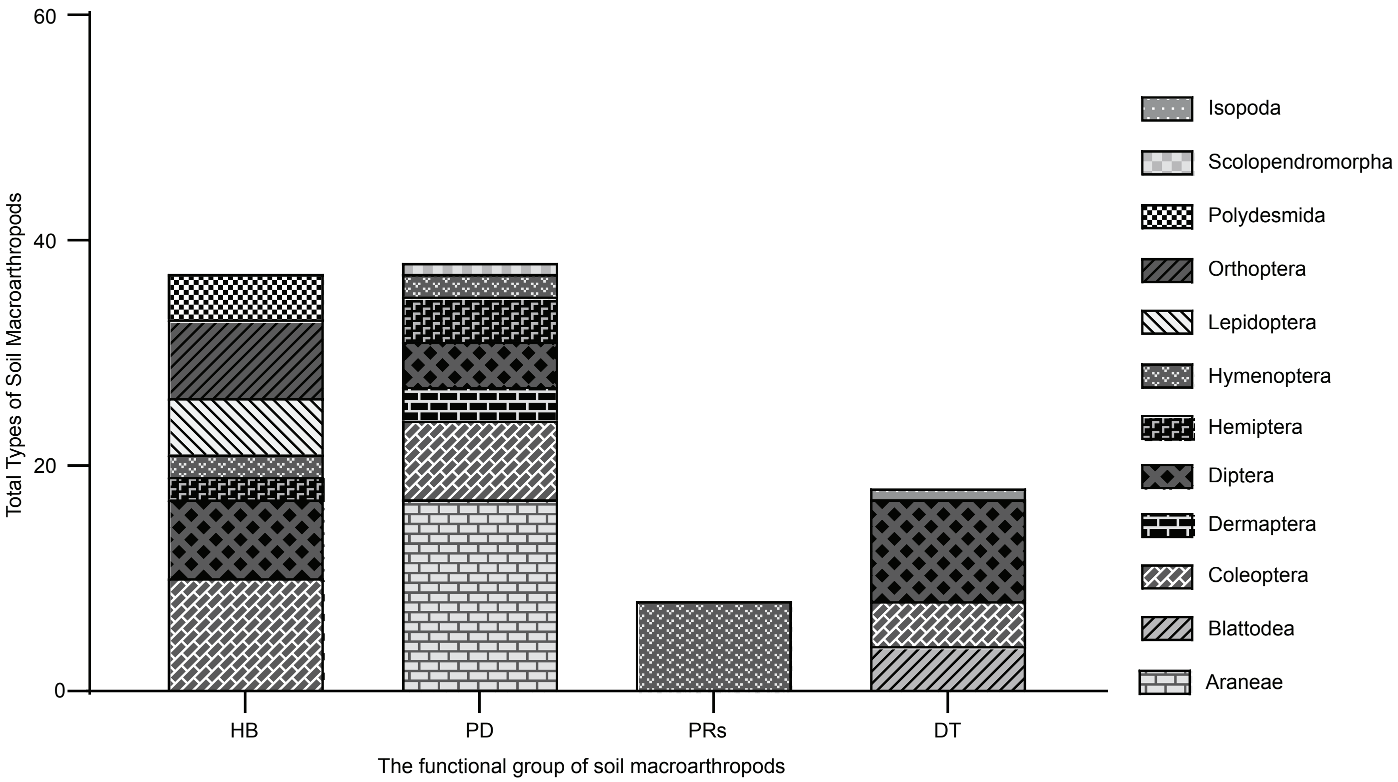

Fig. 4. Number of functional group types of soil macroarthropods in each land use type of the Bukit Pinang-Pinang area

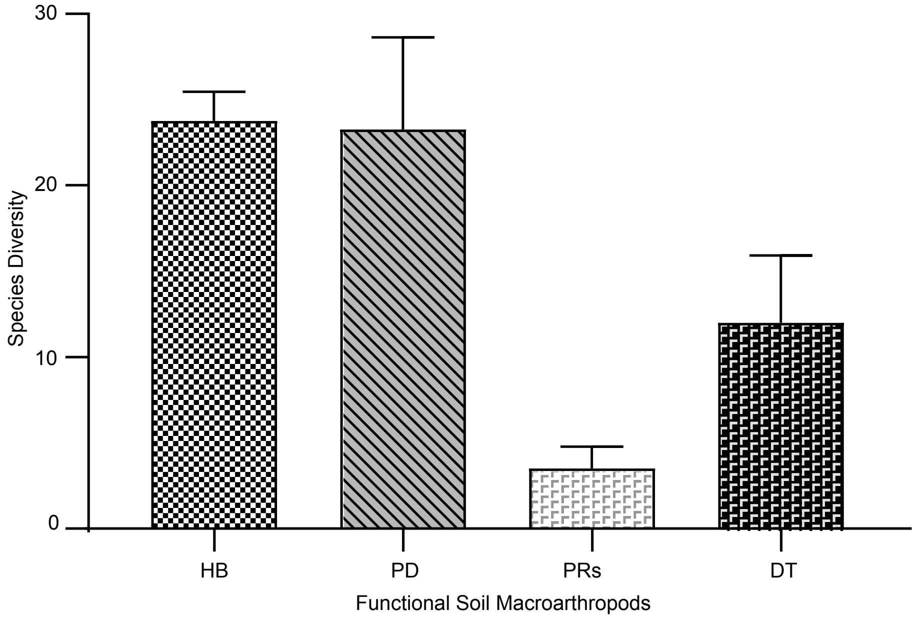

Fig. 5. Number of species for each functional group of soil macroarthropods

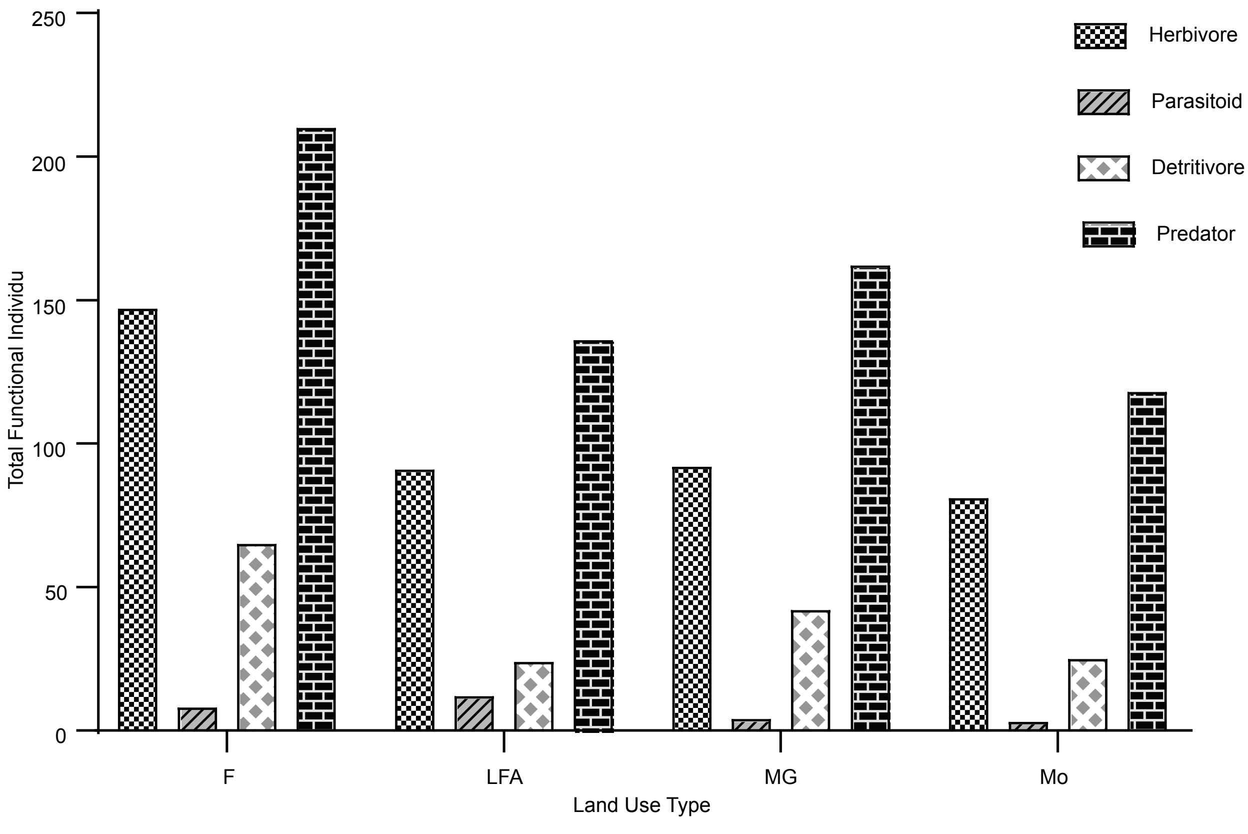

Fig. 6. Abundance of soil macroarthropod functional groups in each land use type in the Bukit Pinang-Pinang tropical rainforest area

3.2.3. Functional Group Diversity of Soil Macroarthropods

The data on the functional diversity of the soil macro-arthropods in the different soil types of the study area are presented in Table 2.

The highest diversity index (H') of soil macroarthropod functional groups was observed in the herbivore group across all land use types in the Bukit Pinang-Pinang tropical rainforest area (Table 2). Among these land use types, monoculture exhibited the highest herbivore diversity index, recorded as

Table 2
Functional diversity of soil macroarthropods in several land types of the tropical rainforest area of Bukit Pinang-Pinang Padang, Indonesia.

Functional Soil Macroarthropods	Parameters	Land Type's in Bukit Pinang-Pinang			
		F	LFA	MG	Mo
HB	H'	2.494 ± 0.058	2.458 ± 0.061	2.559 ± 0.058	2.729 ± 0.056
	D	0.123 ± 0.007	0.115 ± 0.005	0.119 ± 0.006	0.109 ± 0.007
	E	0.528 ± 0.012	0.523 ±0.013	0.542 ± 0.012	0.578 ± 0.011
PD	H'	0.902 ± 0.022	0.701 ± 0.020	0.743 ± 0.018	0.779 ± 0.022
	D	0.696 ± 0.065	0.754 ± 0.071	0.751 ± 0.071	0.728 ±0.068
	E	0.190 ± 0.004	0.148 ± 0.04	0.157 ± 0.003	0.165 ± 0.004
PRs	H'	1.067 ± 0.050	0.000 ± 0.000	0.968 ± 0.046	0.828 ±0.038
	D	0.086 ± 0.005	0.160 ± 0.015	0.083 ± 0.005	0.028 ± 0.001
	E	0.226 ± 0.10	0.000 ± 0.000	0.205 ± 0.009	0.175 ± 0.008
DT	H'	1.655 ± 0.042	1.085 ± 0.043	0.868 ± 0.030	1.048 ± 0.035
	D	0.032 ± 0.002	0.082 ± 0.006	0.018 ± 0.001	0.021 ± 0.001
	E	0.351 ± 0.008	0.229 ± 0.009	0.184 ± 0.006	0.222 ± 0.007

Explanations: H': Shannon-Weaver diversity index, D: dominance index, and e: evenness; F: Forest, LFA: Logged Forest Area, MG: Mixed Garden, Mo: Monoculture; HB: Herbivore, PD: Predator, PRs: Parasitoid, DT: Detritivore

2.729 ± 0.056. The highest dominance index (D) of soil macroarthropods was found in the predator group for each land use type, with the highest value observed in the former forest logging land use type at 0.754 ± 0.071. Additionally, the herbivore group displayed the highest evenness index of soil macroarthropod functional groups for each land use type, with monoculture showing the highest evenness index. The significant differences of macroarthropod functional groups among each land use type are presented in Table 3.

3.2.4. Correlation between Soil Physical/Chemical Characteristics and Abundance/Diversity of Soil Macroarthropods

Herbivores and parasitoids in the functional groups of soil macroarthropod individuals exhibit significant correlations ($P < 0.05$) and ($P < 0.01$) with soil physical and chemical properties, as presented in Table 3. The abundance of soil herbivore individuals demonstrates a significant negative correlation ($P < 0.05$) with soil nitrogen (N) and a significant posi-

Table 3
Correlation between soil physical/chemical characteristics and abundance/diversity of soil macroarthropods

Functional soil macroarthropods (Individu)	pH	N	P	K	C	SMC	BD
HB	–0,280	–0,348*	–0,231	–0,035	–0,067	0,311*	–0,002
PD	–0,203	–0,277	0,002	–0,028	–0,175	0,127	0,126
PRs	–0,406**	–0,354*	–0,101	–0,089	–0,163	–0,066	0,529**
DT	–0,128	–0,259	–0,138	0,079	–0,061	0,279	0,397
Functional soil macroarthropods (Species)							
HB	–0,289*	–0,231	–0,134	–0,023	0,140	0,308*	0,092
PD	–0,269	–0,251	–0,099	0,129	0,035	0,343*	0,132
PRs	–0,412**	–0,349*	–0,068	–0,131	–0,068	0,006	0,301*
DT	–0,129	–0,173	–0,187	0,045	0,150	0,352*	–0,092

Explanations: pH: potential of hydrogen, N: Soil Nitrogen, P: Soil phosphorus, K: Soil Potassium, C: Soil Carbon, BD: Bulk Density, SMC: Soil Moisture Content; BD: Bulk Density and F: Forest, LFA: Logged Forest Area, MG: Mixed Garden, Mo: Monoculture; HB: Herbivore, PD: Predator, PRs: Parasitoid, DT: Detritivore (* $P < 0.05$; ** $P < 0.01$)

tive correlation ($P < 0.05$) with soil moisture content. Similarly, parasitoids within the functional groups of soil macroarthropod individuals also display significant correlations ($P < 0.05$) and ($P < 0.01$) with soil physical and chemical properties. Specifically, parasitoids exhibit a significant negative correlation ($P < 0.01$) and ($P < 0.05$) with soil pH and N, respectively, while demonstrating a significant positive correlation ($P < 0.01$) with soil bulk density (BD). Furthermore, herbivores in the functional groups of soil macroarthropod species exhibit a significant negative correlation ($P < 0.05$) with soil pH and a significant positive correlation ($P < 0.05$) with soil moisture content. Predators, on the other hand, display a significant positive correlation ($P < 0.05$) with soil moisture content. Parasitoids demonstrate a significant negative correlation ($P < 0.05$) with soil N and ($P < 0.01$) with soil pH, and a significant positive correlation ($P < 0.05$) with BD. Lastly, soil detritivores exhibit a significant positive correlation ($P < 0.05$) with soil moisture content.

4. Discussion

4.1. Characteristics of soil physical and chemical properties in various land use types.

In this study, significant differences were observed in the physical and chemical properties of soil among different land types within the Bukit Pinang-Pinang tropical rainforest area. Soil pH, and soil nitrogen, were found to be significantly higher in monoculture land types compared to other land types. While the soil P value in monoculture garden shows the highest value although the difference is not significant compared to other land types. These findings are consistent with the research conducted by Liu et al. (2022), which reported higher levels of soil organic matter, soil phosphorus, and soil C/N content in agricultural land compared to other land types. Similarly, Kwiatkowski and Harasim (2020) found that both organic and conventional agricultural land improved the quality of soil chemical properties. In contrast, Horáková et al. (2020) found that forests and grasslands had higher carbon and nitrogen accumulation compared to fertile agroecosystem land. Furthermore, Yeneneh et al. (2022) demonstrated that the quality of soil, including pH, nutrient content, and electrical conductivity, deteriorated in agroecosystem land types. The application of chemical and organic fertilizers by farmers resulted in increased soil nutrient levels and altered chemical properties in monoculture plantations.

The mixed garden land type exhibits relatively higher soil chemical characteristics, specifically soil K and soil C, compared to other land types, although soil K and soil C does not show a significant difference. The elevated soil C content can be attributed to the dominant use of organic fertilizers in mixed gardens, as opposed to chemical fertilizers. Kwiatkowski and Harasim (2020) reported in their research on agricultural land predominantly treated with organic materials that productivity and soil carbon quality were superior to conventional treatments. Agroecosystems treated with either organic or chemical fertilizers demonstrated improved soil fertility in physical terms. The research findings indicate better soil density quality in both monoculture and mixed garden lands in comparison to other land types. This facilitates enhanced absorption of soil nutrients by plant root systems, resulting in improved growth and development. Consequently, this land type tends to exhibit lower groundwater levels.

The highest soil water content was observed in the forested land in comparison to other land types. Living organisms necessitate a significant amount of water, rendering the forest a habitat for a multitude of organisms. The elevated soil water content at a depth of 0–20 cm within the forest can be attributed to the presence of leaf litter, which serves as the primary source of soil organic matter. The existence of leaf litter on the soil surface aids in the preservation of soil moisture. As stated by Lal (2020), the abundance of organic matter on the soil surface enhances water retention, resulting in water-filled soil pores and increased soil humidity. These findings indicate that diverse land management practices yield distinct habitat variations characterized by unique physical and chemical soil properties, as well as microclimates formed during ecological processes.

4.2. Abundance of Soil Macroarthropods in Each Land Use Type

The habitat characteristics, including variations in soil physical and chemical properties, as well as differences in vegetation types within each land use type, influence the impact on the composition of soil macroarthropod communities in the tropical rainforest area of Bukit Pinang-Pinang. Distinct habitat characteristics give rise to diverse microenvironments, thereby influencing the abundance and diversity of soil macroarthropods in each land use type across the study area (Yang et al., 2021).

The variation in soil macroarthropod abundance among different land types indicates the adaptive importance of each type of soil macroarthropod within specific land conditions, which is dependent on the soil quality parameters. This can be seen from the more abundant groups of soil macroarthropods in mixed gardens compared to monoculture gardens, due to the influence of the frequency of use of different organic and chemical fertilisers. The dominance of the Hymenoptera group, characterized by a high number of individuals in forests, logged-over areas, and agroecosystems, aligns with previous findings by Leksono et al. (2019), Wasis et al. (2018), and Marsandi et al. (2023). These studies suggest that the Hymenoptera group dominates the soil surface and decaying wood in the primary forest ecosystem of the tropical rainforest region, exhibiting a clustering distribution pattern. The strong cohesion within this group, along with the adaptive abilities of soil macroarthropods to environmental conditions, are crucial factors for their survival. Additionally, Ponge (2003) highlights the mutualistic interactions within the soil community, including food resource associations and habitat combinations that facilitate the coexistence and interaction of various animal groups. These interactions contribute to the consistent density variation and dominance of specific soil macroarthropod groups in different land types within the tropical rainforest area. Each group of soil macroarthropods plays a vital role in maintaining the sustainability of the soil ecosystem.

4.3. Functional Groups of Soil Macroarthropods

The functional groups of soil macroarthropods (Fig. 4) play a crucial role in maintaining the balance and sustainability of soil ecosystems. The classification of macroarthropods into functional groups, including herbivores, predators, parasitoids, and detritivores, has been meticulously considered to support their directed roles and functions within the food web structure. The significance of macroarthropods' function in terrestrial ecosystems has been elucidated by Maggiotto et al. (2019), who identify macroarthropods as key components of the food web that indicate species relationships and energy flow, as well as diagnose the impacts of land use changes. The highest variation in the number of macroarthropod species is observed within the herbivore and predator groups, which play a critical role in maintaining the sustainability of soil ecosystems. The balanced availability of food sources for each land type facilitates the formation of groupings, which also demonstrate social-ecological interactions or associations within the functional groups of herbivore and predator macroarthropods (Briones, 2014).

The dominance of herbivore and predator groups is highlighted in Fig.s 5 and 6. We did not include the presence of vertebrate groups in controlling the abundance of macroarthropod functional groups because we did not specifically examine the food chain. However, we believe that the dominance of herbivores and predator peaks in macroarthropods is also influenced by this, although not significantly and negatively (Quist et al., 2020). In the food chain system, the presence of soil predators is influenced by the availability of herbivores that serve as a food source for them. The high number of predator individuals in each type of land indicates the presence of herbivores as a source of nutrition (predator-prey relationship). The balance between predator and herbivore numbers is crucial to the success of the ecosystem. An increase in herbivores in response to scarce or absent predators leads to a decrease in primary productivity, and vice versa, abundant predator productivity leads to a decrease in herbivore availability (Letnic and Ripple, 2017). We believe that in the context of soil macroarthropods, apex predators play a crucial role in controlling ecosystem structure regulation at the trophic level below them. This is in line with Carbone et al.'s (1999) statement that predator groups play a crucial role in regulating prey species such as herbivores and omnivores. The dynamic interaction of "prey-predator" is one of the main factors contributing to the sustainability of ecosystem health and balance.

The soil detritivore and parasitoid groups exhibit the lowest numbers among the different land types in the Bukit Pinang-Pinang tropical rainforest area compared to other soil macroarthropod functional groups. The scarcity of detritivore individuals in tropical rainforests can be attributed to the dominance of soil mesofauna and microbes, whereas macroarthropods are predominantly herbivores and predators. According to Lavelle et al. (1997), soil detritivores play a crucial role in soil ecological processes by facilitating organic matter decomposition and providing ecosystem goods and services. Additionally, Hattenschwiler et al. (2005) state that these organisms are vital for leaf litter decomposition, with detritivore density decreasing as vegetation matures and land use patterns change (Joly et al., 2020). Parasitoids also function as natural enemies of plants, and their abundance is influenced by the variety of understory vegetation types within a specific land type. The availability of suitable food sources and hosts in an area further impacts the abundance of parasitoid groups (Fraser et al., 2007).

4.4. Correlation between Soil Physical and Chemical Characteristics and Abundance of Soil Macroarthropod Functional Groups

The presence and abundance of soil macroarthropod functional groups are determined by habitat conditions consisting of the physical and chemical properties of the soil in which the macroarthropod functional community resides. Healthy soils naturally selects macroarthropod functional groups capable of surviving and adapting to the environment, particularly in relation to nutrient sources. The reciprocal relationship between the physical and chemical characteristics of the soil and the abundance of macroarthropod functional groups is responsible for nutrient cycling, decomposition, and other soil functions (Yan et al., 2012). The presence of plant species plays a crucial role in soil macroarthropod functional groups, especially for soil herbivores, as they rely on them as their main source of nutrition (Wardle et al., 2004). Changes in land use in tropical rainforests impact the dynamics of soil herbivore abundance and activity, which in turn affects the physical and chemical soil properties. Our results show that the abundance of soil macroarthropod herbivores in a habitat has an influence on low soil N concentrations. The use of nitrogen-rich leaves by herbivores causes plants to require more nitrogen.. Additionally, soil fauna abundance is influenced by soil pH and moisture content. Lower soil pH is associated with relatively higher abundance of soil herbivores, whereas increased soil moisture content attracts soil herbivores (Riutta et al., 2012). In acidic tropical soil conditions, soil plant-eating invertebrates exhibit high activity and population (Lavelle et al., 2006).

Predator groups utilize soil herbivores and other smaller biotic components as prey for nutritional purposes. Therefore, predator groups establish a close association with soil moisture content. The abundance of herbivores in areas with high soil moisture content attracts the presence of predators. Predators rely on water for their metabolic processes, and alterations in land use have led to the decline of most soil macroarthropod predator groups, rendering them more vulnerable to disturbances and land management practices, particularly the introduction of chemical compounds into the soil. These alterations can serve as indicators that reflect environmental changes (Rizk et al., 2017).

Although relatively small in number and lower compared to other soil macroarthropod functional groups, parasitoid groups have a significant relationship with the physical and chemical properties of the soil. Soil pH, nitrogen (N) content, moisture content, and bulk density (BD) affect parasitoid abundance (Waschke et al., 2014). While not directly related to plant species, parasitoids require suitable hosts for their growth and development. The presence of suitable hosts, along with specific physical and chemical soil characteristics, greatly supports the abundance of soil macroarthropod parasitoid functional groups. Herbivores serve as hosts for the majority of parasitoids, contributing to the biological control of plants (Pebrianti et al., 2016). Soil macroarthropod detritivores play a crucial role in litter decomposition on the soil surface, as they interact with soil microbes to break down various organic compounds.

5. Conclusions

Based on the results of this study, it can be concluded that the habitat characteristics of different land use types within the Bukit Pinang-Pinang tropical rainforest have an important influence on the community composition of soil macroarthropods. Predators and herbivores were more abundant. This suggests that ecosystem balance and soil health are still maintained in the Bukit Pinang-Pinang area. These findings provide valuable insights into the role and function of soil macroarthropods in maintaining ecosystem balance and provide important support for assessing soil health. These findings have important implications for the assessment and management of soil quality in the Bukit Pinang-Pinang tropical rainforest area.

Acknowledgments

The article was generated as a result of the research project under the PMDSU scheme, Contract number: No. 03/UN.16.17/PP.PMDSU/LPPM/2018, which received funding from Kemenristekdikti, Indonesia. The authors would like to express their gratitude to Dr. Ir. Agustian and Dr. Ir. Syafrimen Yasin, MS, M.Sc for their valuable feedback during the development of this paper. Additionally, the Laboratory of Soil Fertility and Insect Bioecology, Faculty of Agriculture, Universitas Andalas, is acknowledged for providing the necessary research facilities and support throughout the study.

References

Bold Systems. 2023. https://v3.boldsystems.org/index.php/TaxBrowser_Home

Briones, M.J.I., 2014. Soil fauna and soil functions : a jigsaw puzzle. Environment Science 2(7), 1–22. https://doi.org/10.3389/fenvs.2014.00007

BugGuide. 2023. https://bugguide.net/node/view/15740

Carbone, C., Roberts, S.C., Macdonald, D., Carbone, C., Mace, G.M., Roberts, S.C., Macdonald, D.W., 1999. Energetic constraints on the diet of terrestrial carnivores. Letters to nature 402, 286–288. https://doi.org/10.1038/46266

Decaens, T., Martins, M., Feijoo, A., Oszwald, J., Mathieu, J., Sartre, X.A. De, Bonilla, D., Andrea, Y., Criollo, C., Decaens, T., Martins, M., Feijoo, A., Oszwald, J., Dolédec, S., 2018. Biodiversity loss along a gradient of deforestation in Amazonian agricultural landscapes. Conservation of Biology 36(2), 1380–1391. https://doi.org/10.1111/cobi.13206.

Farrow, R., 2016. Insects of South-Eastern Australia: An Ecological and Behavioural Guide. Australia. CSIRO Publishing, 441 pp.

Fraser, S.E.M., Dytham, C., Mayhew, P.J., 2007. Determinants of parasitoid abundance and diversity in woodland habitats. Journal Application of Ecology 44, 352–361. https://doi.org/10.1111/j.1365-2664.2006.01266.x

Hattenschwiler, S., Tiunov, A.V, Scheu, S., 2005. Biodiversity and Litter Decomposition in Terrestrial Ecosystems. Annual Review Ecology, Evolution, & Systematic 36, 191–218. https://doi.org/10.1146/annurev.ecolsys.36.112904.151932

Hermansah, 2003. Micro spatial distribution pattern of litterfall and nutrient flux in relation to soil chemical properties in a super wet tropical rain forest plot, West Sumatra. Tropics 12(2), 131–146. https://doi.org/10.3759/tropics

Horáková, E., Pospíšilová, L., Vlček, V., Menšík, L., 2020. Changes in the soil's biological and chemical properties due to the land use. Soil and Water Research 15(4), 228–236. https://doi.org/10.17221/44/2019-SWR.

Balai Penelitian Tanah., 2009. Petunjuk Teknis: Analisis Kimia Tanah, Tanaman, Air, dan Pupuk. Balai Penelitian Tanah. Bogor: 246 pp

Joly, F., Coq, S., Coulis, M., David, J., Hättenschwiler, S., Prater, I., Subke, J., 2020. Detritivore conversion of litter into faeces accelerates organic matter turnover. Communications Biology 3, 1–9. https://doi.org/10.1038/s42003-020-01392-4

Kwiatkowski, C., Harasim, E., 2020. Chemical Properties of Soil in Four-Field Crop Rotations under Organic and Conventional Farming Systems. Agronomy 10(1045), 1–16. https://doi.org/10.3390/agronomy10071045

Lal, R., 2020. Soil Organic Matter and Water Retention. Agronomy Journal 112(5), 3265– 3277. https://doi.org/10.1002/agj2.20282

Lavelle, P., Bignell, D., Heal, W., Lepage, M., Ineson, P., Dhillion, S., 1997. Soil function in a changing world: The role of invertebrate ecosystem engineers. European Journal of Soil Biology 33(4), 159–193.

Lavelle, P., Decaëns, T., Aubert, M., Barot, S., Blouin, M., Bureau, F., Margerie, P., 2006. Soil invertebrates and ecosystem services 42, 1–15. https://doi.org/10.1016/j.ejsobi.2006.10.002

Leksono, A., Putri, N., Gama, Z., Yanuwiyadi, B., Zairina, A., 2019. Soil Arthropod Diversity and Composition Inhabited Various Habitats in Universitas Brawijaya Forest in Malang East Java Indonesia. Journal of Tropical Life Science 9(1), 15–22. https://doi.org/10.11594/jtls.09.01.03

Letnic, M., Ripple, W.J., 2017. Large-scale responses of herbivore prey to canid predators and primary productivity. Global Ecology and Biogeography, 1–7. https://doi.org/10.1111/geb.12593

Liu, Y., Fu, L., Lu, X., Yan, Y., 2022. Characteristics of Soil Nutrients and Their Ecological Stoichiometry in Different Land Use Types in the Nianchu River Basin. Land 11(1001), 1–16. https://doi.org/10.3390/land11071001

Maggiotto, G., Sabatté, L., Marina, T.I., Fueyo-sánchez, L., Ramírez, A.M., Díaz, M., Rionda, M., Domínguez, M., Perelli, R., Momo, F.R., 2019. Soil fauna community and ecosystem's resilience : A food web approach. Acta Oecologica 99, 1–8. https://doi.org/10.1016/j.actao.2019.103445.

Marsandi, F., Hermansah, Fajri, H., Sujarwo, W., 2023. Distribution of Soil Macroarthropods in Differently Using Land Parts of Tropical Rainforest Padang, Indonesia. Plant, Soil and Environment 69(6), 291–301.

Menta, C., Ramelli, S., 2020. Soil Health and Arthropods: From Complex System to Worthwhile Investigation. Insect 11(1), 1–21. https://doi.org/10.3390/insects11010054

Pebrianti, H.D., Maryana, N., Winasa, I.W., 2016. Keanekaragaman Parasitoid Dan Artropoda Predator Pada Pertanaman Kelapa Sawit Dan Padi Sawah Di Cindali, Kabupaten Bogor. Jurnal HPT Tropika 16(2), 138–146.

Ponge, J.-F., 2003. Humus forms in terrestrial ecosystems : a framework to biodiversity. Soil Biology & Biochemistry 35, 935–945. https://doi.org/10.1016/S0038-0717(03)00149-4

Quist, C. W., Putten, W.H. Van Der, Thakur, M.P., 2020. Soil predator loss alters aboveground stoichiometry in a native but not in a related range-expanding plant when exposed to periodic heat waves. Soil Biology & Biochemistry 150, 1–10. https://doi.org/10.1016/j.soilbio.2020.107999

Riutta, T., Slade, E.M., Bebber, D.P., Taylor, M.E., Malhi, Y., Riordan, P., Macdonald, D.W., Morecroft, M.D., 2012. Experimental evidence for the interacting effects of forest edge, moisture and soil macrofauna on leaf litter decomposition. Soil Biology and Biochemistry 49, 124–131. https://doi.org/10.1016/j.soilbio.2012.02.028

Rizk, M., Mikhail, W., Ghallab, M., Zaki, A., Habashi, N., Iskander, A., 2017. A Review Article : The Effect of Agricultural Practices on The Abundance and Biodiversity of Soil Fauna. Egyptian Academic Journal of Biological Science A Entomology 10(7), 357–376. https://doi.org/10.21608/eajb.2017.12121

Tripelhorn, C.A., Johnson, N.F., 2005. Borrors and Delongs Introduction of The Study of Insects 7th Edition. Belment: Thomson Brooks/Cole: 879 pp.

Wardle, D., Klironomos, J., Wall, D.H., 2004. Ecological Linkages Between Aboveground and Belowground Biota. Science. 304(2004), 1629–1633. https://doi.org/10.1126/science.1094875

Waschke, N., Hardge, K., Hancock, C., Hilker, M., Obermaier, E., Meiners, T., 2014. Habitats as Complex Odour Environments : How Does Plant Diversity Affect Herbivore and Parasitoid Orientation ? PLoS ONE 9(1), 1–10. https://doi.org/10.1371/journal.pone.0085152

Wasis, B., Winata, B., Marpaung, D.R., 2018. Impact of land and forest fire on soil fauna diversity in several land cover in Jambi Province, Indonesia. Biodiversitas 19(2), 740– 746. https://doi.org/10.13057/biodiv/d190249

Wolters, V., 2001. Biodiversity of soil animals and its function. Eurpean Journal of Soil Biology 37, 221–227.

Yan, S., Singh, A. ., Fu, S., Liao, C., Wang, S., Li, Y., Cui, Y., Hu, L., 2012. A soil fauna index for assessing soil quality. Soil Biology & Biochemistry 4, 158–155. https://doi.org/10.1016/j.soilbio.2011.11.014

Yang, X., Li, T., Gan, M., Chen, M., 2021. Community characteristics and distribution patterns of soil fauna after vegetation restoration in the northern Loess Plateau. Ecological Indicators 122, 1–11. https://doi.org/10.1016/j.ecolind.2020. 107236

Yeneneh, N., Elias, E., Feyisa, G.L., 2022. Assessment of the spatial variability of selected soil chemical properties using geostatistical analysis in the north-western highlands of Ethiopia. Acta Agriculturae Scandinavica, Section B. Soil & Plant Science 72(1), 1009–1019. https://doi.org/10.1080/09064710.2022.2142658