Journal of Tropical Biodiversity and Biotechnology
Volume 08, Issue 03 (2023): jtbb79496
DOI: 10.22146/jtbb.79496

Research Article

Comparison of Soil Arthropod Diversity and Community Structure in Various Types of Land Cover in Malang Region, East Java, Indonesia

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Keywords:
Arthropods
diversity
heterogeneity
land cover
Malang
Submitted:
29 November 2022
Accepted:
21 February 2023
Published:
17 November 2023
Editor:
Miftahul Ilmi

ABSTRACT
Land cover heterogeneity can affect the structure of soil arthropod communities that are critical in maintaining the stability of soil ecosystems. This study aimed to understand the effect of land cover variation on the diversity and community structure of soil arthropods. The types of habitats used include urban areas, agroforestry, gardens, and natural forests which are determined in the Malang Region, East Java, Indonesia. Hand sorting and hay-bait traps were applied in this study to obtain a variety of arthropod soils and the Berlese -Tullgren funnel was used to extract them. As a result, there are 25 families from 15 orders collected based on their ecological roles. The abundance of Philoscidae in sites S1 and S2 (urban green space), Talitridae in site S6 (agroforestry), and Isotomidae in sites S3, S4, and S5 (highland mixed forest) was highest and dominant. Site S7 has the highest diversity even though its family richness is lower. The site S3 counter-site had relatively high taxa richness, but low diversity. Mixed forest habitats contain a more complex diversity of soil arthropods, which can serve as a model for improving the fertility of disturbed ecosystems.

INTRODUCTION
Land cover heterogeneity has a close relationship with biodiversity due to its positive effect in providing niche habitats (Katayama et al. 2014). Biodiversity increases due to vegetation heterogeneity which will lead to a series of gradual changes in ecological processes and functions (Tylianakis et al. 2008; Stein et al. 2014). The relationship between diversity and ecosystem stability also depends on the intrinsic response of species to environmental fluctuations, the speed of response from disturbances, and the reduction of competition between species (Loreau & Mazancourt 2013). In terrestrial ecosystems, heterogeneity shows an impact not only on soil arthropod communities but also on their abundance, richness, and diversity (Tao et al. 2019).

The soil arthropod community has a different ecological role in each taxon. Based on their soil characteristics, arthropods are divided into 3 main roles, namely herbivores (leaf chewers & leaf piercers), predators (ambush predators & hunting predators), and detritivores (detritus shredders, bioturbators, and detritus grazers) (McCary & Schmitz 2021). Detritivores are referred to as soil dominant arthropods and are important in carrying out biogeochemical processes to maintain soil health and nutrient cycling (Joly et al. 2018; Lindsey-Robbins et al. 2019). Because it has a close relationship with soil ecosystems, soil arthropods have the potential to be able to respond sensitively to changes due to a relative decrease in environmental factors from their activities (Coyle et al. 2017). For example, the conversion of conventional land to organic can lead to an increase in the abundance and richness of taxa as a bioindicator response to environmental change (Ghiglieno et al. 2020).

Soil arthropods play an important role in maintaining the stability of terrestrial ecosystems (Bagyaraj et al. 2016). They participate in processing nutrient cycles and energy flows in the soil and participates in terrestrial ecosystem services (Yin et al. 2010). Soil arthropod activity aims to decompose and humify organic matter into fragmented materials (Zan et al. 2022). They break down dead organic matter with endogenic enzymes and facilitate microbes to stimulate nutrient mineralization (Griffiths et al. 2021). This collaborative activity results in soil formation processes, increased nutrition, and biotic regulation, and promotes plant growth (Briones 2018). Soil-digging arthropods such as termites and ants also participate in increasing soil porosity by facilitating aeration, and root penetration, preventing surface crust and erosion of the topsoil (Culliney 2013). Some of the existence of various arthropod soils can provide complex benefits in maintaining the balance of the ecosystem.

This study aims to understand the effect of land cover variations on the diversity and community structure of soil arthropods. The differences in land cover were selected based on the type of habitat, including urban green space, agroforestry, gardens, and natural mixed forests. We hypothesize that areas with preserved ecosystems will have higher soil arthropod diversity than disturbed locations. This ecosystem's high biodiversity can serve as a model for fixing land and making it fertile.

MATERIALS AND METHODS

Study Site

Malang Region is organized by 3 administration areas, consisting of Malang City, Malang Regency, and Batu City. This area has various ecological landscapes from a coastal ecosystem in the lowland to a highland mixture of a forest. Because of that, the types of soil are very different depending on the microclimate they constitute. Sampling sites were determined at as many as 7 location points by differentiating several types of habitats for comparison (Table 1) (Figure 1).

Data Collection

From July to September 2022, three repetitions of soil microarthropod sampling were accomplished at every site. Three plots were chosen via purposive sampling as the sampling sites for each type of site. The samples were taken with hand sorting methods and hay-bait traps. The hand sorting method was conducted at a 3x3 meter area for each plot in site sampling. The sample was collected with a fork to separate rocks or rot-

Table 1. List of sampling sites in Malang region, East Java, Indonesia.

Site	Latitude	Longitude	Elevation (masl)	Description
S1	-7.952354°	112.614273°	495	Urban green space surrounded by buildings.
S2	-7.968484°	112.626708°	465	Urban green space near the urban street
S3	-8.013325°	112.853480°	1254	Highland mixed forest and some vegetable plantations
S4	-7.740722°	112.534447°	1608	Highland mixed forest near some vegetable plantations
S5	-7.991934°	112.823548°	1170	Highland mixture forest
S6	-7.823920°	112.579372°	1262	Dominated by coffee agroforestry plantation
S7	-8.250536°	112.884328°	430	Mixed forest and part of it becomes coffee agroforestry

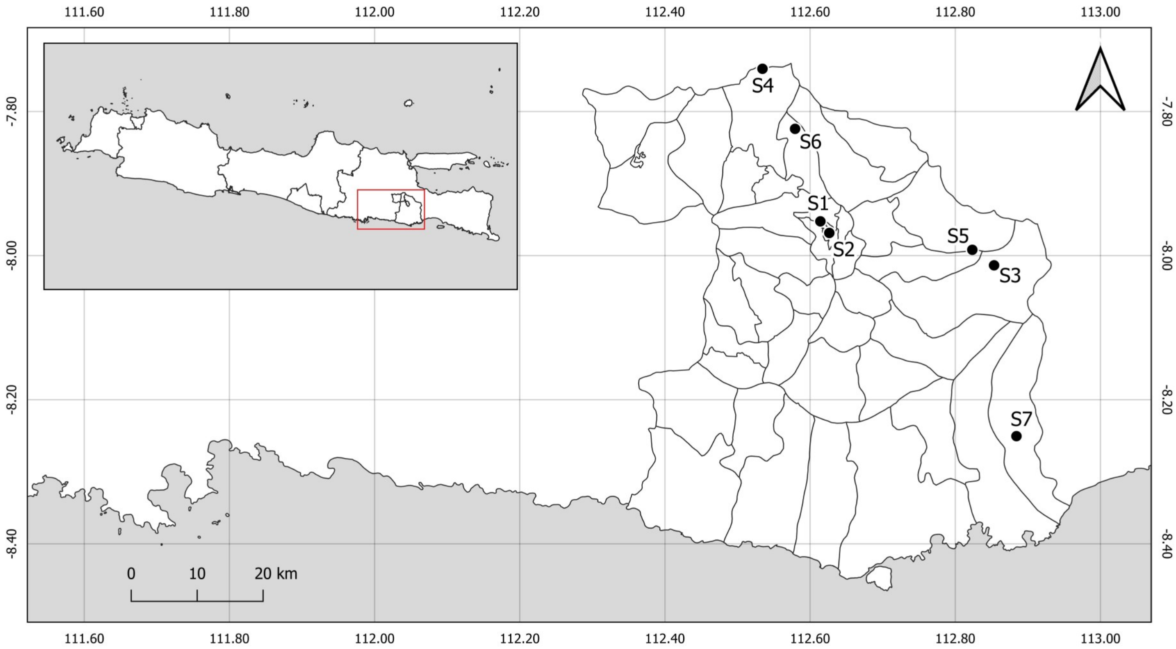

Figure 1. Soil microarthropod sampling sites in Malang Region, East Java, Indonesia.

ten wood, while a shovel took samples of soil for arthropods (Upton & Mantle 2010). This sampling activity will be limited to 15 minutes at each sampling site. All samples were entered into a separate sample bottle of 50 mL which was filled with 70% ethanol for preparation. Then, the sample can be distributed to the laboratory for identification.

Hay-bait trap with modification is made from a mesh plastic container with a height of 10 cm and diameter 8 cm (Tuf et al. 2015). The mesh plastic container was filled with dry leaf litter (*Terminalia cattapa*) and mixed with a pellet. Dried leaf litter soaked for up to 2 days before being installed in the sampling site. A total of 3 traps were used in the study and installed at each site on different land cover types. Its trap is installed around 10 cm into the soil until the mouth container is level with the soil surface. This trap was left for 2 weeks until leaf litter shrank and was filled by soil arthropods. After that, the trap was taken out and placed in a plastic bag to be transported to the laboratory.

Samples from the hay-bait trap were extracted using Berlese-Tullgren funnels for 3 days. The soil arthropods were examined under a stereo microscope Leica MZ75 and isolated and quantified as morphospecies (family level). To identify soil microarthropod samples, soil arthropod identification references were used (Krantz 1971; Gunadi 1994; Schmalfuss 2003; Gibb & Oseto 2006; Decker 2013). The whole process (extraction, observation, and identification) was carried out at the Fauna Diversity Laboratory, Brawijaya University. The coordinates and elevation of each sampling site are determined by GPS (Global Positioning System). Soil samples from where soil arthropods were extracted were processed in the laboratory to determine some edaphic parameters such as soil temperature, soil humidity, and pH. While air parameters were measured as air humidity and air temperature with a thermo-hygrometer.

Data Analysis

One-way analysis of variance (ANOVA) is used to test differences in abundance and diversity at different sites. The diversity differences tested were including, taxa richness (TR), Shannon diversity index (H'), Simpson diversity index (1-D), and Pielou's evenness index (J') (Simpson 1949; Hill 1973; Magurran 2004). Then, Tukey's post hoc was used to compare the significance of the average diversity index values between sampling sites. This test was carried out at a significance level of $\rho \leq 0.05$ using IBM SPSS Statistics (version 26) software (IBM Corp. 2019). The similarity of habitat types at each site was determined by clustering analysis. This analysis is made into a simple tree construction using the UPGMA clustering method based on the Bray-Curtis similarity (Michener & Sokal 1957). Furthermore, Non-Metrix Dimensional Scaling (NMDS) analysis was performed to coordinate the location with environmental factors (soil temperature, air temperature, air humidity, soil humidity, and pH) (Clarke 1993). Ordination between sampling sites and environmental factors based on the abundance of soil arthropods and described by Canonical Correspondence Analysis (CCA) (ter Braak 1986). The clustering analysis and ordination were tested using Paleontological Statistics (PAST) software (Hammer et al. 2001).

RESULTS AND DISCUSSION

Family Diversity and Abundance

The arthropod soils obtained in this study belong to 25 families from 15 different orders (Table 2; Figure 2). Of these taxa, if sorted from the group with the highest composition, namely detritivores (15 families), predators (9 families), and herbivores (4 families). Detritivores are the most dominant group of soil arthropods in composing the composition of soil fauna communities (Lindsey-Robbins et al. 2019). The more detritivores in an environment can indicate that the land has high fertility. This is because their job is to transform dead organic matter into microfragments through the process of excretion in the form of faeces. This fragmentation change has a positive effect on the rates of carbon (C) and nitrogen (N) in decomposition. These two contents can increase substantially in biogeochemical cycles and the ratio can vary depending on the type of litter (Joly et al. 2018).

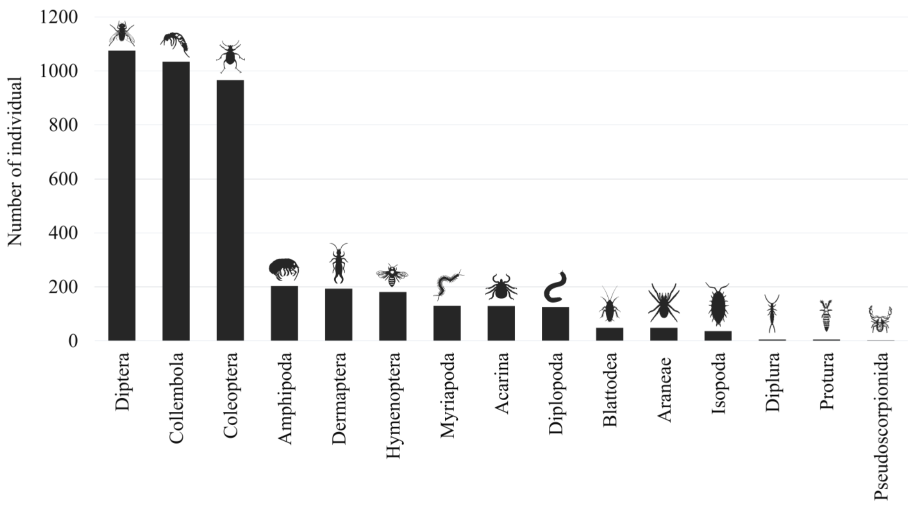

Figure 2. The number of individuals in each order of arthropods.

The highest abundance of soil arthropods was found at sites S1 (596 individuals) and S2 (613 individuals) compared to other sites. The Philoscidae family is very abundant in sites S1 (48.83%) and S2 (76.35%) which are classified as urban green space habitats. The selected site was taken from one of the urban green spaces which are in an area with a high anthropogenic level. Most of the Philoscidae have been identified as having high adaptation to disturbed habitat conditions (Kenne & Araujo 2015). This response also does not indicate any negative impact from the surrounding human activities. This adaptive condition causes members of the Philoscidae taxa to have cosmopolitan and synanthropic characteristics with a very wide distribution range. The high abundance of species is also supported by the invasion of exotic species with high reproduction rates, but only on a local scale (Karasawa 2022). Meanwhile, terrestrial isopods can also be bioindicators in urban areas because they can accumulate metals (Cd, Cr, Cu, Fe, Pb, and Zn) in their bodies (Gál et al. 2008).

Sites S3 (72.76% individual), S4 (50.64% individual), and S5 (66.47% individual) have the most abundant taxa in the Collembola order of the Isotomidae family (Table 2). Collembola (springtail) as taxa with abundant individuals requires high humidity in the soil ecosystem. This is also supported by the three sites which are classified as highlands with

Table 2. The relative abundance (%) of soil arthropods in each sampling site in Malang Region, East Java, Indonesia.

Taxa	Relative abundance (%)							Guild
	S1	S2	S3	S4	S5	S6	S7	
Acarina								
Macrochelidae	0.17	0.16	0.18	0.64	2.35	0	6.00	P
Tetranychidae	1.01	1.31	1.58	1.29	2.06	1.07	6.00	P
Amphipoda								
Talitridae	0	0.16	0	1.50	0	69.40	0	D
Araneae								
Lycosidae	0.17	0	0	0	0	0	0	P
Lyniphiidae	1.34	0.98	0.53	1.50	1.47	1.07	10	P
Blattodea								
Blattellidae	0.67	2.61	0	0.64	0	0	0	H/D
Termitidae	1.85	0	0	0.64	0	0	0	D
Coleoptera								
Carabidae	1.51	0.33	0.18	0.21	2.65	1.78	2.00	H/D
Curculionidae	0	0	0.35	2.79	0	0.71	6.00	H
Collembola								
Tomoceridae	1.17	4.57	7.03	14.38	0	0.71	2.00	D
Isotomidae	1.01	2.12	72.76	50.64	66.47	3.20	4.00	D
Neanuridae	0	0	0	7.30	5.29	2.85	0	D
Dermaptera								
Anisolabididae	21.31	7.34	1.93	0.21	0.59	1.78	4.00	H
Diplopoda								
Harpagophoridae	11.41	1.96	2.28	1.72	4.12	2.14	8.00	D
Diplura								
Japygidae	0.17	0	0.53	0	0	0	2.00	D
Diptera								
Drosophilidae	0.50	0	0	0.43	0.29	0	2.00	D
Chironomidae	0.17	0	0.53	0.21	0	0.36	2.00	D
Cecidomyiidae	0	0	0.35	0.21	0	0.36	2.00	P
Hymenoptera								
Formicidae	6.38	1.47	6.85	7.08	12.35	4.63	14.00	P/D
Isopoda								
Philoscidae	48.83	76.35	2.81	7.73	0	8.90	18.00	D
Armadillidae	0	0	0	0	2.06	0.36	0	D
Myriapoda								
Scolopocryptopidae	1.85	0.16	1.58	0	0	0.36	10	P
Geophilidae	0.17	0.49	0.35	0.64	0	0	0	P
Protura								
Protentomidae	0.34	0	0.18	0.21	0	0	2.00	D
Pseudoscorpionida								
Neobisiidae	0	0	0	0	0.29	0.36	0	P
Number of individuals	596	613	569	466	340	281	50	

Notes: P = predator, H = herbivore, and D = detritivore.

most of them covered in a dense canopy of tree vegetation. The abundant leaf litter from fallen trees facilitates collembola for finding food and shelter. Moreover, the wide leaf area and thick litter also participate in maintaining moisture on the soil surface (Butenschoen et al. 2011). In contrast to site S6 which is more dominated by Terrestrial Amphipod (Amphipod: Talitridae) abundance. Terrestrial Amphipods have high-humidity habitats under litter, weathered logs, or rocks (Gonçalves et al. 2021). In the agroforestry ecosystem at site S6, it has provided a preferred habitat for terrestrial amphipods to become cosmopolitan. They are the most abundant and major detritivores in decomposing leaf litter from agroforestry plants (*Coffea* sp.) at site S6.

Community Structure and Abiotic Correlation

The results of the ecological index calculation show that site S7 has the highest diversity (*H′* = 2.56; 1-*D* = 0.90; *J′* = 0.76) compared to other sites, although the family richness is lower. This means that at this site, the food web is still balanced without any species dominating. Fulfilment of niche habitats can be categorized equally between the community structure of the taxa. On the other hand, site S3 has high taxa richness (TR = 17), but low diversity (*H′* = 1.02; 1-*D* = 0.39; *J′* = 0.16) (Figure 3).

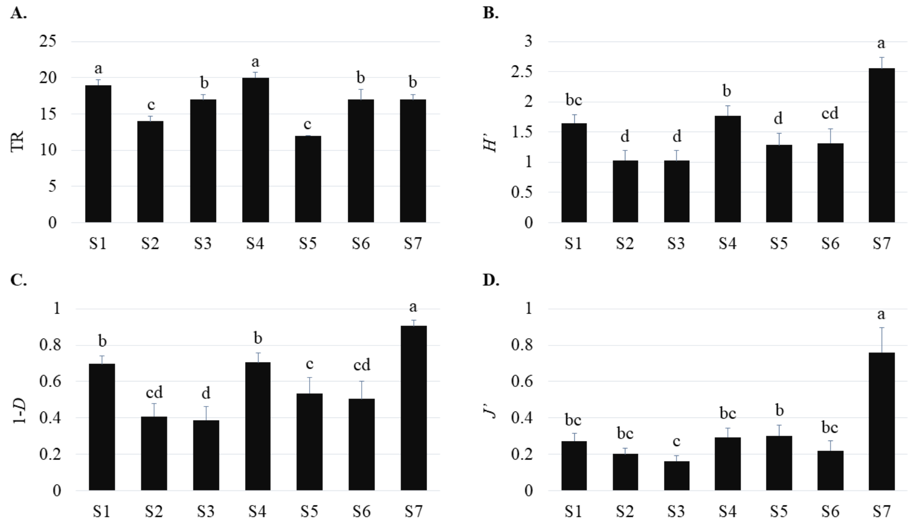

Figure 3. Differences in diversity index values at each site; A. taxa richness (TR), B. Shannon diversity index (*H'*), C. Simpson diversity index (1-*D*), and D. Pielou's evenness index (*J'*).

Habitat similarity analysis showed the formation of three different groups on the results of clustering (Figure 4) and NMDS ordination (Figure 5). S6 and S7 are grouped into the same habitat type based on the abundance and richness of soil species of arthropods and their environmental factors. Both of these sites have agroforestry land with most of

Table 3. The mean (± stdev) value of microclimate and soil physics from the measurement results at each site.

Site	Mean ± stdev				
	ST (°C)	AT (°C)	SH (%)	AH (%)	pH
S1	25.28 ± 1.30	23.75 ± 0.42	45.17 ± 20.11	55.83 ± 2.79	6.98 ± 0.04
S2	24.50 ± 0.58	23.33 ± 0.98	60.00 ± 29.61	60.50 ± 3.39	6.65 ± 0.38
S3	20.43 ± 0.54	20.83 ± 2.14	45.67 ± 26.19	85.33 ± 6.06	6.68 ± 0.21
S4	18.10 ± 0.59	21.00 ± 2.68	60.00 ± 23.66	86.83 ± 7.96	6.80 ± 0.18
S5	21.50 ± 0.40	21.67 ± 1.61	39.40 ± 5.29	86.00 ± 6.56	6.97 ± 0.06
S6	19.32 ± 0.69	18.67 ± 1.37	42.33 ± 14.04	76.33 ± 7.71	6.57 ± 0.19
S7	24.12 ± 1.21	22.17 ± 1.72	80.17 ± 25.90	59.83 ± 4.58	6.07 ± 0.61

the vegetation in the form of *Coffea* sp. However, site S7 is still classified as an ecotone because it is bordered by natural forest so it can be identified from its high diversity value without any taxa dominating (Figure 3). Ecotone provides a more varied niche that promotes a complicated community structure (Zhu et al. 2011). The uniqueness of this S7 site is its location which is classified as lowland but the vegetation structure is mostly highland plants. This is also supported by the geological structure in the form of a cliff close to the river which forms a waterfall. That way, it is undeniable that S7 has a high diversity value with varied vegetation composition. This heterogeneous vegetation can cause changes in ecological functions toward supporting ecosystem stability (Stein et al. 2014).

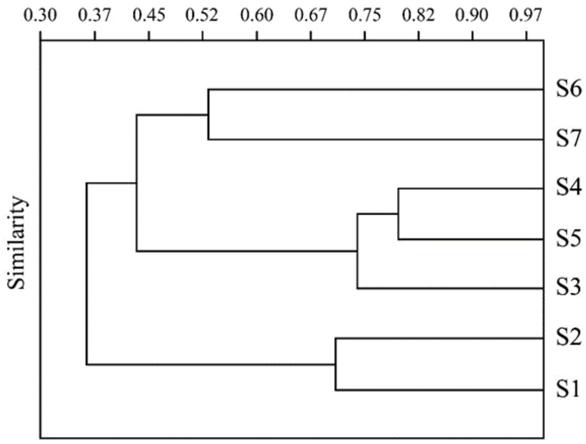

Figure 4. Hierarchical clustering analysis of soil arthropods composition with Bray-Curtis similarity between sites.

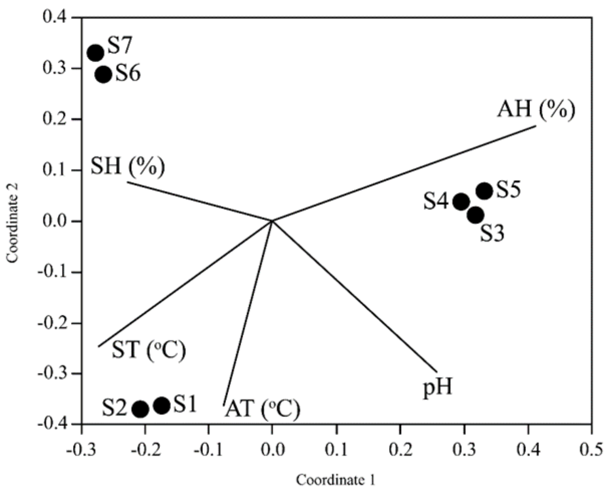

Figure 5. NMDS analysis between sampling sites with abiotic factors and soil arthropods abundance and family richness; SH= soil humidity, AH= air humidity, ST= soil temperature, AT= Air temperature; Stress = 0.092.

In the second grouping which consists of sites S3, S4, and S5, all of them are located in the highlands with most of them being upland forests with several land conversions. The change to a cereal and vegetable garden has changed the landscape structure. Management practices that are still conventional in cultivating land can reduce biodiversity, especially soil animals (Ghiglieno et al. 2020). On the other hand, the three sampling sites have a fairly high percentage of air humidity (S3= 85.33 ± 6.06%; S4= 86.83 ± 7.96%; S5: 86.00 ± 6.56%) (Figure 4; Table 3). So according to habitat suitability, the dominant taxa are springtails (Collembola: Isotomidae), resulting in a close habitat similarity.

Sites S1 and S2 are grouped in the same cluster based on the soil arthropod community structure. Likewise, the soil temperature (S1= 25.28 ± 1.30ºC; S2= 24.50 ± 0.58ºC) and air temperature (S1= 23.75 ± 0.42ºC; S2= 23.33 ± 0.98ºC) are higher than other sites (Figure 5; Table 3). This increase in temperature is possible because landscapes S1 and S2 include urban areas that do not have a wide canopy cover. Smaller and less heterogeneous canopy cover causes a significant increase in temperature in urban areas (Jung et al. 2021). In addition, the influence of residue from vehicle engines near the sampling site also initiates the increase in heat.

All arthropod soils show varying relationships between taxa and environmental variables. There is an inverse relationship between temperature and humidity levels but at different pH variables (Figure 5). The influence of air humidity slightly affects the intensity of pH in the soil. High humidity in a location can initiate wetting of the forest floor. In this way, the nutrients resulting from the decomposition and humification of the detritivore arthropod soil along with the microbes can also be absorbed through the soil porosity. Soil porosity is carried out by soil-digging arthropods, for example, termites (Termitidae) to facilitate aeration and root penetration and prevent surface crust and erosion of the topsoil (Culliney 2013). The absorbed minerals can cause changes in the biochemical content. The biochemical content of the elements carbon (C) and nitrogen (N) in the soil is an important factor in changing the soil pH level (Joly et al. 2018).

Talitridae, Neobisiidae, Cecidomyiidae, Chironomidae, Carabidae, Armadillidae, Curculionidae, and all collembola (Tomoceridae, Isotomidae, and Neanuridae) prefer to avoid habitats with high temperatures. This is related to their habitat preferences by choosing high-humidity habitats. However, terrestrial isopods (Philoscidae), spiders (Lycosidae & Lyniphiidae), termites (Termitidae), cockroaches (Blattellidae), and earwigs (Anisolabididae) can still tolerate high ambient temperatures. Some soil arthropods that have a role as predators such as spiders and earwigs are not affected by changes in environmental variables. Based on research showing temperature and humidity do not affect the life history of spi-

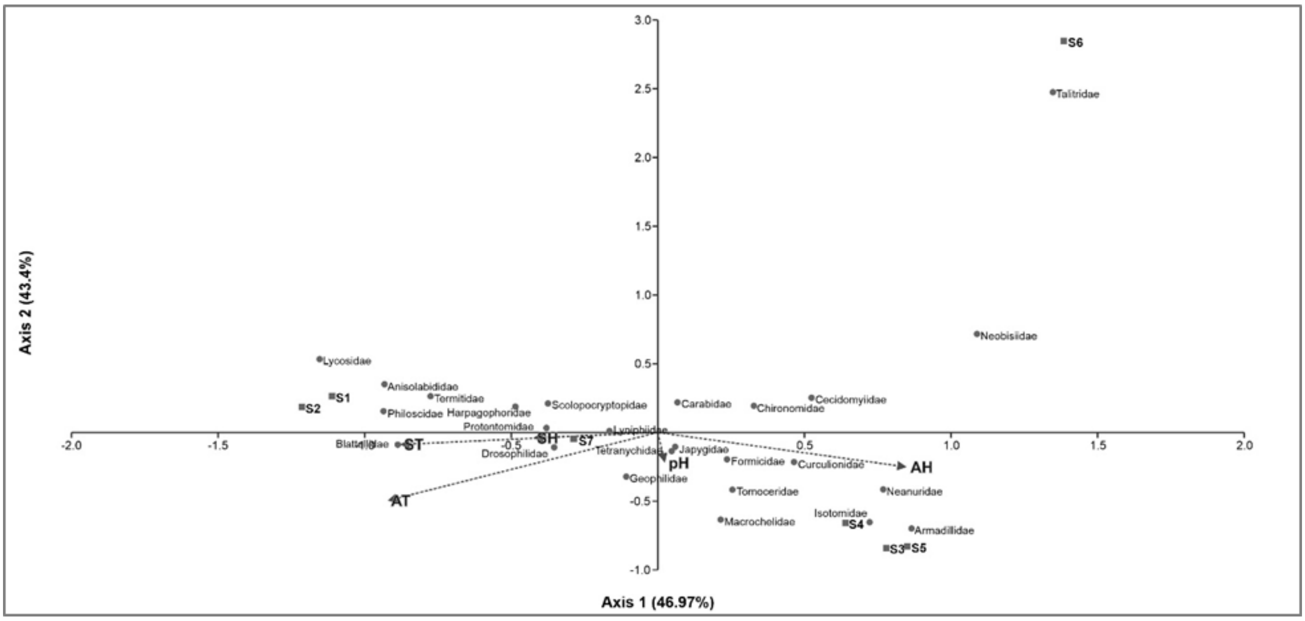

Figure 6. Ordination diagram from Canonical Correspondence Analysis (CCA) showing the relationship between soil arthropods group with abiotic factors.

ders (Steves et al. 2021). They can be dispersed and have a wide hunting range. They can hunt directly to control their prey population in a food web system.

Diversity of soil arthropods shows a variety of ecological roles in positioning themselves in food webs in terrestrial ecosystems. Natural ecosystems without any disturbance from humans lead to stability in abundance, and the richness of taxa, composition, and functional traits are more maintained. The size of the role needed in filling the availability of niches is also a determining factor in the formation of an ecosystem balance.

This research on diversification and community composition may serve as the foundation for a greater understanding of the significance of soil arthropods, particularly in Indonesia. Different subgroups of soil arthropods may be useful in soil restoration. For instance, isopods can boost nitrogen elements, which help to speed up plant growth, by acting as detritus shredders in the decaying soil organic matter (Mc Carry & Schmitz 2021). By using mixed forest floor ecosystems as a model, this potential may be exploited as an experimental object to improve soil fertility in plantation areas.

CONCLUSIONS

The diversity of site S7 is the highest compared to other sites, although the taxa richness is less than S1 and S4. Several taxa dominate them, Philoscidae (Isopoda) in urban green space areas (S1 & S2), Isotomidae (Collembola) in upland forest areas (S3, S4, & S5), and Tallitridae (Amphipoda) in agroforestry (S6 & S7). Several species that dominate this variation of habitat may have the potential to become specific decomposers in improving soil fertility. Measurement of mineral content and classification of litter can also be carried out to compare the results of the decomposition of abundant taxa against the ratio of soil biochemistry.

AUTHOR CONTRIBUTION

The research was designed by A.M.S., M.F.A., and M.F., who also collected and evaluated the data. The initial manuscript was written by B.Y., while S. and A.N. looked over, edited, and proofread the final draft. N.K. supervised the entire procedure.

ACKNOWLEDGMENTS

We gratefully acknowledge to The Directorate of Research and Community Service, Directorate General of Strengthening Research and Development Ministry of Research, Technology and Higher Education of the Republic of Indonesia (Grant number 3110.15/UN10.F09/PN/2022) provided financial support to NK for this work.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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