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Diversity of Collembola on Various Post-Rehabilitation Land Covers

Risandika Astanovia Dewi[1], Ananto Triyogo[2*], Eny Faridah[2]

[1]Graduate Program of Forestry Science, Faculty of Forestry, Universitas Gadjah Mada, Jl.Agro No.1, Bulaksumur Yogyakarta, Indonesia 55281
[2]Faculty of Forestry, Universitas Gadjah Mada, Jl. Agro No.1, Bulaksumur Yogyakarta, Indonesia 55281

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Abstract

The success of rehabilitation has altered environmental conditions from critical land to new habitats for living organisms. One of the representative and sensitive mesofauna to environmental changes is Collembola. Various vegetation cover almost all of the rehabilitation area, which has impacts on microclimate and soil quality as important factors to Collembola existence. This study investigated the diversity and abundance of Collembola and its relation to environmental factors on various land covers, including teak, grass, and mixed stand land cover. Data were collected in an observation plot of 20 m × 20 m using purposive samples, including environmental measurements, Collembola collection, and soil samples for physical and chemical analysis. The results showed that different land covers affected the abundance and diversity of Collembola, even though the statistical analyses of TLC, GLC, and MLC were not significantly different. However, TLC has a higher litter thickness and organic material than the other land cover types. A few families of Collembola, such as Cyphoderidae, Brachystomellidae, Katiannidae, Isotomidae, Oncopoduridae, and Isotogastruridae, show their correlation to climatic and edaphic factors in a certain land cover.

Keywords: Collembola, soil properties, critical land, vegetation cover

**Correspondence author, email: ananto.triyogo@ugm.ac.id; triyogo99@yahoo.com*

Introduction

Environmental changes due to improvement or degradation at various scales have impacts on ecosystem stability (Mentis, 2020). Ecosystems will naturally move towards an establishment to achieve a steady state (Crossman et al., 2016) which requires time depending on its condition (Yirdaw et al., 2017). Rehabilitation on critical land will restore ecosystem functions such as production, protection, and conservation, which will contribute to promote habitat for living organisms (UNEP, 2021). The stability of an ecosystem can be shown through the presence of organism diversity (Prokopová et al., 2019). The diversity of flora and fauna in a new formation indicates that the landscape conditions have been restored (Triyogo et al., 2020). Moreover, land rehabilitation will lead to enhanced soil quality (Supriyo et al., 2013), thus providing a suitable habitat for living organisms to perform their ecological functions (Kusumandari et al., 2021).

The Wanagama I Education and Research Forest (ERF) was established from bare and critical land and consists of numerous compartments that are expected to represent the progress of land development after rehabilitation (Triyogo et al., 2020). The successful rehabilitation of the Wanagama I ERF resulted in vegetation growth and species diversity, especially beneficial interactions between ecological, social, and economic factors (Kusumandari et al., 2021). Different treatments were applied to each compartment during the early stage of rehabilitation. Thus, each compartment has a distinct appearance, particularly in the vegetation structure as land cover (Supriyo et al., 2013). Furthermore, different types of vegetation will provide specific habitats and affect the presence of soil fauna, which can be used as an indicator (Shrestha & Budha, 2022). In this study, three different vegetation land covers were chosen to represent the different rehabilitation treatments. Teak land cover represents rehabilitation progress by monoculture stand, while mixed stand land cover refers to rehabilitation land using various vegetation. Meanwhile, the grass land cover is a rehabilitation with grass and cover crops, but no stand.

Previous studies on fauna presence as a bioindicator of ecosystem health have been conducted, such as the presence of ant communities in two different habitats (Triyogo et al., 2020) and the presence of natural enemies on different land uses (Triyogo et al., 2022). Another study on the effect of different characteristics of forest ecosystems using soil arthropods as bioindicators showed that Collembola is one of the dominant taxa that has impressive abundance and can be used to represent habitat conditions (Damayanti et al., 2023).

Collembola (springtails) are important soil mesofauna (Breure, 2004) that can be found in abundance and are sensitive to environmental changes (Machado et al., 2019; Marcin et al., 2022; Bellini et al., 2023). Moreover, the presence of Collembola communities in the soil can be used as soil environmental quality bioindicators related to habitat changes through vegetation composition due to rehabilitation (Gonçalves et al., 2020; Marcin et al., 2022; Arboláez et al., 2023). However, no assessment has ever been made regarding the impact of soil quality on the presence of Collembola after rehabilitation in Wanagama I. This study presents the results of Collembola communities and their relationship to climatic and edaphic factors in three different land covers. Thus, the main objectives were to a) determine Collembola abundance and diversity in three different land cover types and b) improve our understanding of the relationship between Collembola presence and soil quality.

Methods

Study area Research was conducted in Wanagama I ERF, Gunungkidul District, Yogyakarta Special Region Province, Indonesia. Wanagama I is located in a karst landscape (limestone rocks), which is also part of the Gunung Sewu zone. Observation plots were distinguished into three different land cover types by vegetation coverage: teak land cover (TLC), grass land cover (GLC), and mixed stand land cover (MLC) (Table 1, Figure 1). Sampling was carried out from February to July 2022 to collect Collembola and environmental measurements (Table 2). The environmental measurement data consisted of climatic factors (litter thickness, litter water content, relative light intensity, soil temperature, and soil humidity) and edaphic factors (physical and chemical properties), and were taken from 09.00 a.m. to 14.00 p.m. with three replications in each plot. Light intensity was measured by lux meter Lutron LX-101A, and soil temperature and humidity were measured by a thermohygrometer HTC-2 Digital Thermohygrometer. The field observations were conducted during the rainy season, however, there was an absence of rain when the data on Collembola and environmental conditions were collected.

Collembola collection and identification procedure Data were collected in observation plots of 20 m × 20 m, with three replications for each land cover. A total 9 observation plots were purposively placed considering environmental

Table 1 Description of studied sites in three different land covers

Parameters	Teak	Grasses	Mixed stands
Vegetation life form	Tree (dominant), weeds, and shrubs	Grasses (dominant), and weeds	Pioneer tree species (dominant), weeds, and shrubs
Plant composition	Teak (*Tectona grandis*), raining mountain grass (*Oplismenus compositus*), siam weed (*Chromolaena odorata*)	Elephant grass (*Pennisetum purpureum*), cogon grass (*Imperata cylindrica*), green summer grass (*Brachiaria subquadripara*), siam weed (*Chromolaena odorata*)	Gliricidia (*Gliricidia sepium*), macassar oil tree (*Schleichera oleosa*), formis (*Acacia auriculiformis*), brown-pine (*Podocarpus neriifolius*), sappanwood (*Caesalpinia sappan*), porcupine flower (*Barleria prionitis*)
Tree canopy layer	1	0	2

Table 2 Climatic and edaphic factors measurement between three different land covers

Parameters	Teak land cover	Grasses land cover	Mixed stands land cover
Climatic			
Litter thickness (cm)	4.93	1.73	1.17
Litter water content (%)	15	19	31
Light intensity relative (%)	59.07	82.24	35.84
Soil temperatue (°C)	33.656	31.278	30.43
Soil humidity (%)	40.22	49.89	52.56
Physical soil properties			
Bulk density (g cm^{-3})	1.06	0.953	0.84
Particle density (g cm^{-3})	2.08	1.953	1.9
Porosity	49.14	51.283	55.937
Soil texture	Clay	Clay	Clay
Chemical soil properties			
Organic matter	6.943	5.603	6.160
C-organic (%)	4.027	3.273	3.573
N-total (%)	0.157	0.137	0.217
C/N ratio	26.410	24.187	16.723
Soil pH	6.737	7.003	7.060
P available (ppm)	3.003	3.567	4.027

conditions and vegetation cover. Pitfall traps, litter samples, and soil samples were used to collect the Collembola. Nine pitfall traps were installed using the grid method (Triyogo et al., 2017, 2022) at each observation plot for 24 hours (da Silva et al., 2022). Thus, 81 pitfall traps were installed in three different land covers.

Litter and soil samples from the monolith method were collected from five replications (one center and four corners) at each observation plot (Muturi et al., 2009; Shrestha & Budha, 2022). Litter from the aboveground was collected using a square plot of 25 cm × 25 cm, and the depth attempted to match its thickness. Moreover, it was composited to obtain 150 g of litter from each observation plot. Monolith methods were used to collect soil samples (25 cm × 25 cm × 5 cm) and composited for 1 kg as the sample of each observation plot (Muturi et al., 2009; Lammel et al., 2015; Roy et al., 2021).

Collembola were extracted from litter and soil samples using Berlese Funnel and exposed to a 25 W lamp for a period of 6 days. After separation from the other fauna, which also fell from the funnel, Collembola specimens were observed and counted using a stereo zoom microscope DSZ44. Binocular biological microscope Olympus CX31 was used to identify and classify Collembola into order, family, and morphospecies following the book reference (Suharjono, et al., 2012) and online database (collembola.org and collemboles.fr).

Physical and chemical soil properties analysis Edaphic factors were determined by parameters of physical and chemical properties. Each observation plot was represented by one undisturbed soil (one center) sample and 1 kg of disturbed soil sample from five composite replications (one center and four corners) to a fixed depth of 20 cm from the soil surface, excluding litter (Harta et al., 2021). Undisturbed soil samples were analyzed to obtain physical properties, including bulk density, particle density, porosity, and soil texture. Compositing disturbed soil samples aimed to obtain a representative mixed sample for the determination of chemical properties, including pH, C-organic, N-total, C/N ratio, available phosphorus (P-Olsen), and organic matter.

Data analysis Total abundance and mean abundance of Collembola were calculated and pooled based on land cover. The difference between land cover types in Collembola abundance was calculated as the mean number of Collembola individu per trap (combination of pitfall, litter sample, and monolith) with error standards. The significance of differences in Collembola abundance in each land cover type was tested with a one-way ANOVA at the 5% significance level. The diversity of Collembola was determined using the Shannon index (H'), dominance index (C), and Sorensen similarity index (S). Canonical correspondence analysis (CCA) was applied to explore potential relationships between Collembola families and environmental factors (climatic and edaphic) using the "*vegan*" package from R Studio 2023.06.0+421.

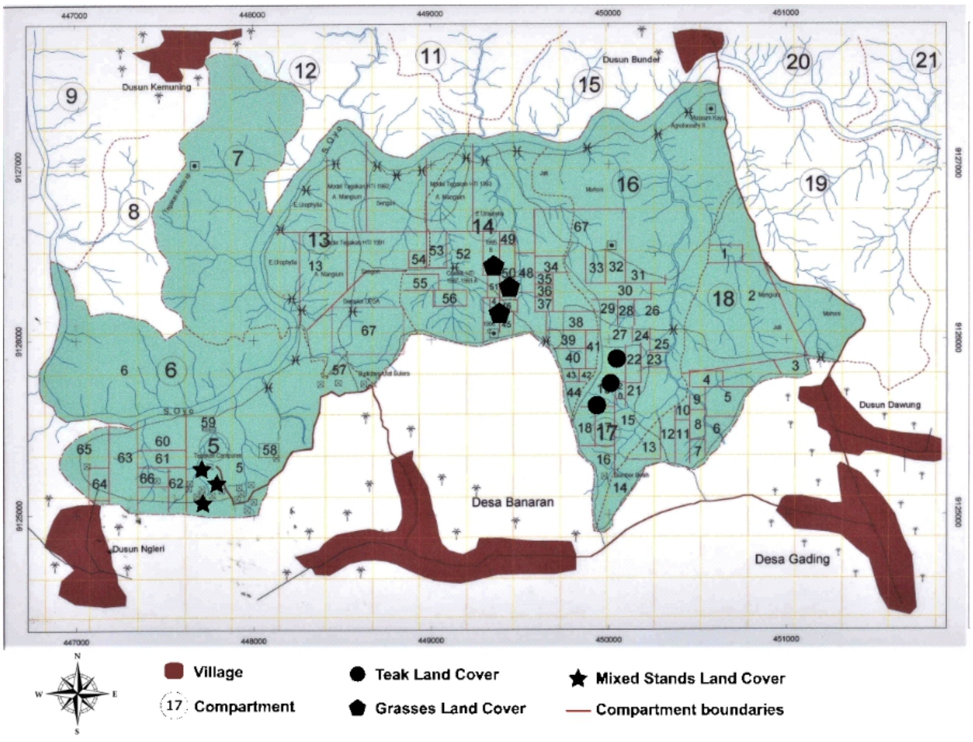

Figure 1 Map of the study area in Wanagama I ERF, Gunungkidul District. Black shapes represent the location of replicants site, teak land cover by circle (compartment 17), grass land cover by pentagon (compartment 14), and mixed stands land cover by star (compartment 5). (Source: Document of Wanagama Forest).

Results and Discussion

Collembola abundance and diversity A total of 477 individuals, representing 3 orders, 14 families, and 22 morphospecies of Collembola were found in three different land covers. The relative abundance of Collembola was higher in TLC (6.00 ± 1.97 individuals trap^{-1}), MLC (4.42 ± 0.72 individuals trap^{-1}), and GLC (4.03 ± 0.69 individuals trap^{-1}), respectively. However, there were no significant differences, F = 0.667, p-value = 0.54, in the relative abundance of Collembola between the three land cover types (Figure 2a). These findings showed that Collembola as an organic matter decomposer requires habitat with sufficient food supply (da Silva et al., 2022; Harta et al., 2021), such as TLC, which provides an abundance of litter (4.93 cm) among the other land covers (Table 2).

Three orders of Collembola were discovered in three different land cover types, namely Entomobryomorpha, Poduromorpha, and Symphypleona. Among these orders, Entomobryomorpha seemed to predominate in nearly all land covers (Figure 2b), with the highest proportion in TLC (81.82%), MLC (78.77%), and GLC (39.10%), respectively. Entomobryomorpha is known as cosmopolitan Collembola, which allows it to be found in several types of habitats (de Lima et al., 2022).

Based on relative abundance, Entomobryomorpha was abundant in TLC (4.91 ± 1.87 individuals trap^{-1}), while Symphypleona (0.85 ± 0.08 individuals trap^{-1}) was abundant in GLC (Figure 2c). Preferences of Symphypleona in dry and opened or sun-exposed habitats, such as in GLC, are supported by its morphological body (Daghighi & Hajizadeh, 2019). On the other hand, Poduromorpha had significant differences in relative abundance between GLC (1.61 ± 0.44 individuals trap^{-1}) and MLC (0.30 ± 0.16 individuals trap^{-1}), F = 5.61, p-value = 0.04. Poduromorpha preferred humid habitats with enough food resources (Fernandes et al., 2009; Shayanmehr et al., 2023), and it was provided by GLC and TLC. Meanwhile, MLC had the highest litter water content and humidity, but the litter thickness was the lowest.

MLC was dominated by evergreen trees and scarce undergrowth. Evergreen trees are known to have leaves that remain green throughout the year and often produce less litterfall (Liu et al., 2016; Getaneh et al., 2022), such as *Podocarpus neriifolius* (Xie et al., 2020), *Schleichera oleosa* (Palanuvej & Vipunngeun, 2008; Anjum et al., 2021),

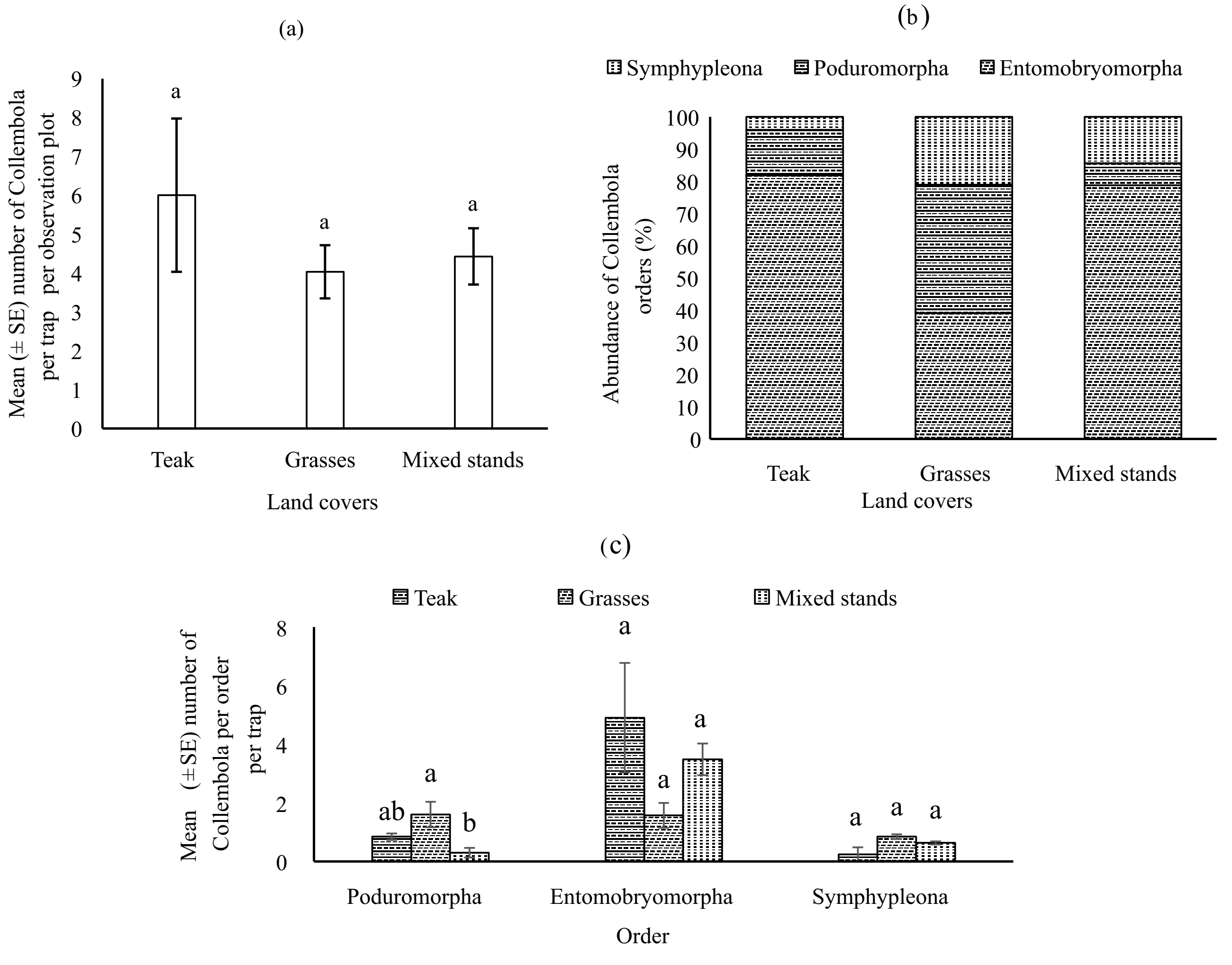

Figure 2 Collembola precense by (a) mean number per trap; (b) composition per order; (c) mean number per order per trap in three different land covers (teak, grasses, and mixed stands). Different letter indicates significant differences (p-value < 0.05)

Gliricidia sepium (Solangi et al., 2010), and *Melaleuca leucadendron* (Bar, 2021) which were found in the MLC observation plot. Thus, its condition might have an impact on the lowest presence of Poduromorpha in MLC.

In total, 5 families from Entomobryomorpha were identified and showed no significant differences between the three different land cover types (Figure 3a). Entomobryidae has the highest relative abundance in MLC (1.94 ± 0.27 individuals trap^{-1}) and TLC (1.76 ± 0.77 individuals trap^{-1}) among the other families. Entomobryidae has a wide distribution range, not only in this study (karst region) but also in other habitats with varied conditions. Previous studies showed that Entomobryidae was predominant in all observation plots consisting of four different types of land cover (Widrializa, et al., 2015); in three different environmental areas (de Lima et al., 2022); and in four different land uses (Arboláez et al., 2023).

The abundance of Paronellidae in three different land covers showed the same trend as Entomobryidae, which dominated in TLC (1.09 ± 0.51 individuals trap^{-1}) and MLC (1.21 ± 0.63 individuals trap^{-1}). Both Paronellidae and Entomobryidae are epigeic Collembola that prefer habitats with dense canopies and abundant litter (Widrializa, et al., 2015; de Lima, et al., 2022). Moreover, their habitat preferences were determined using TLC and MLC.

The four families of Poduromorpha were identified (Figure 3b) and only Hypogastruridae had a higher abundance. Hypogastruridae shows significant difference between GLC (1.24 ± 0.49 individuals trap^{-1}) and MLC (0.03 ± 0.03 individuals trap^{-1}), $F = 8.41$, p-value = 0.01. Hypogastruridae are epigeic Collembola that inhabit mid-humid habitats, heathlands, and bogs (Kyung-Hwa & Nam-Yee, 2006; Skarżyński et al., 2021). The habitats provided by TLC and MLC meet these preferences; thus, Hypogastruridae can be found in abundance in both land cover types.

The five families of Symphypleona were found only in certain land-cover types (Figure 3c). Only Bourletiellidae was found in three different land covers. On the other hand, Arrhopalitidae was found in GLC (0.12 ± 0.12 individuals trap^{-1}) because its prefer mid-humid open area and often found under rocks and litter in grassland area (Vargovitsh, 2022). Whereas, Katiannidae (0.21 ± 0.13 individuals trap^{-1}) and Sminthurididae (0.33 ± 0.15 individuals trap^{-1}) were abundance merely in MLC which has the higher soil humidity (52.56%) and litter water content (31%) (Table 2). Both Katiannidae and Sminthurididae prefer habitats with high humidity, such as near rivers or inhabiting mosses (Palacios-Vargas & René Vacaflores-Argandoña, 2020).

The inconsistent distribution of Symphypleona represents the social habits of Collembola, namely aggregation. Collembola aggregations result from interactions with less favorable or even suitable environmental factors (Widrializa, et al., 2015). Aggregative behavior of Collembola is influenced by pheromones (Sánchez-García et al., 2018), and is carried out to mitigate drought and temperature stress or any undesirable conditions (Potapov et al., 2020).

The result of Collembola diversity through Shannon-Wiener diversity indices (H') and dominance indices (C) shows different categories and low dominance between the three different land covers (Table 3). The higher H' in GLC (2.31) showed that Collembola are capable of thriving in dry habitats with sparse to almost no canopy cover (Alatalo et al., 2015). Collembola communities might be positively affected by fibrous root systems, which are correlated with belowground biomass and associated with microorganisms as Collembola food resources (Salamon et al., 2004).

Furthermore, TLC had the highest abundance of Collembola, but the diversity (2.06) was lower than that of GLC. We presume that, this is due to unfavorable environmental factors in TLC, which has a higher soil temperature as well as the lowest soil humidity and litter water content. The abundance of litter thickness in TLC seemed to support only Collembola abundance but not diversity.

The MLC has more stable climatic and edaphic conditions for Collembola than TLC and GLC, but in terms of diversity, it is actually the lowest. The low H' value might be related to the limited availability of litter in MLC, which results in low presence of individuals in each family. However, in general, this will lead to low diversity of Collembola in MLC.

The Sorensen similarity indices (IS) calculation shows that all of the three different land covers have high similarity on Collembola communities (Table 4). The presence of similar Collembola communities in different habitats might be the result of the ability to adapt to environmental changes. However, the highest similarity of Collembola communities was found in TLC and GLC (87%), which may be due to similarity of common human activities, mostly the cut-and-carry system on grasses or undergrowth around in the observation plot. Rather than in other land covers, human intervention in GLC is more frequent for at least every three months when people cut the grass.

Relationships between climatic and edaphic factors to Collembola presence The results of canonical correspondence analysis (CCA) between climatic and edaphic factors with the presence of Collembola families showed no relation to a certain family in a particular land cover (Figure 4). Litter thickness is related to the presence of Cyphoderidae in the TLC. This might be due to habitat preferences of Cyphoderidae, which can be found in the nests of social insect colonies (mites or ants) with litter abundance (Bellini et al., 2023).

Brachystomellidae were linked to light intensity and soil temperature factors. These relationships can be found in TLC, which is shown by the initial land covers near the arrow line (Figure 4). Brachystomellidae inhabits litterfall and has been adapted to open areas such as beaches (Abrantes et al., 2010) or grasslands (Greenslade et al., 2013). It seems that Brachystomellidae can tolerate habitats with high soil temperatures and low soil humidity, as provided by TLC.

The relationship between Katiannidae and soil humidity shown in the CCA biplot is in line with previous findings. Katiannidae have living preferences in habitats that provide humus and humid soil (Palacios-Vargas & René Vacaflores-Argandoña, 2020). The habitat provided by MLC was assumed suitable for Katiannidae due to its climatic and edaphic conditions, which have higher soil humidity, litter water content, and lower C/N ratio (Table 2).

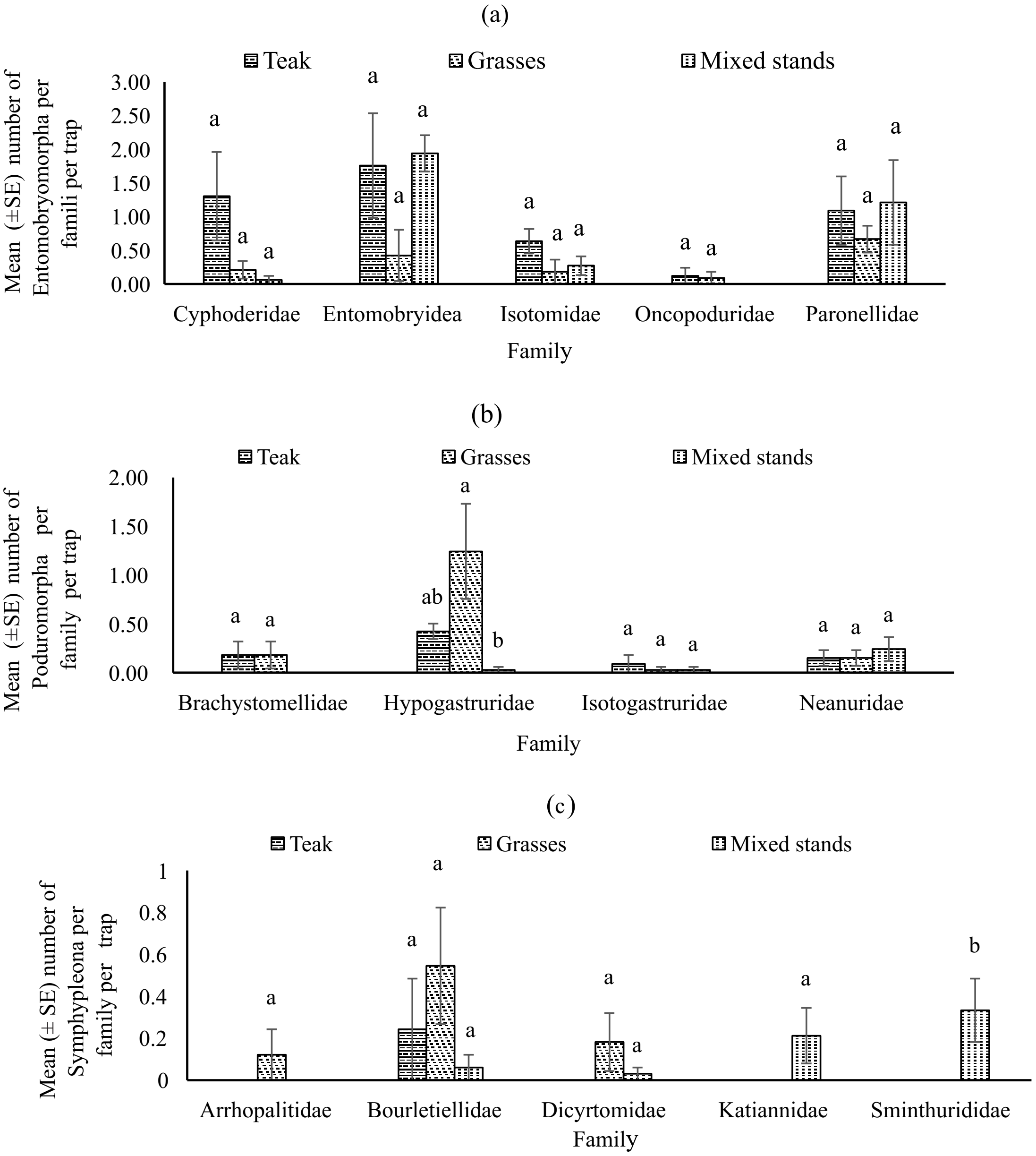

Figure 3 Mean number of Collembola per order (a) Entomobryomorpha (b) Poduromorpha (c) Symphypleona per family per trap in three different land covers (teak, grasses, and mixed stands). Different letters indicate significant differences (p-value < 0.05).

Table 3 Shannon-Wiener diversity indices (H') and dominance indices (C) of Collembola in three different land covers

Land covers	H'	Category	C	Category
Teak	2.06	Low	0.17	Low dominance
Grasses	2.31	Moderate	0.15	Low dominance
Mixture	1.79	Low	0.27	Low dominance

The existence of Collembola in habitats interacts with the forest floor and soil conditions, both directly or indirectly. (Arboláez et al., 2023; Chagnon & Pare, 2000). The variances in soil chemical and physical properties in the three different land covers may have been impacted during the beginning stages of the Wanagama I succession process (Supriyo et al., 2013). The relationship between Collembola and soil chemical and physical properties is shown in the CCA ordination biplot graphic (Figure 5).

In total, three families out of 14, namely Cyphoderidae, Brachystomellidae, and dan Isotomidae, showed relation to bulk density, soil particle density, organic matter, and C-organic, which existed in the TL Campuran (Figure 5). Most Cyphoderidae inhabit termite mounds belowground. Termite

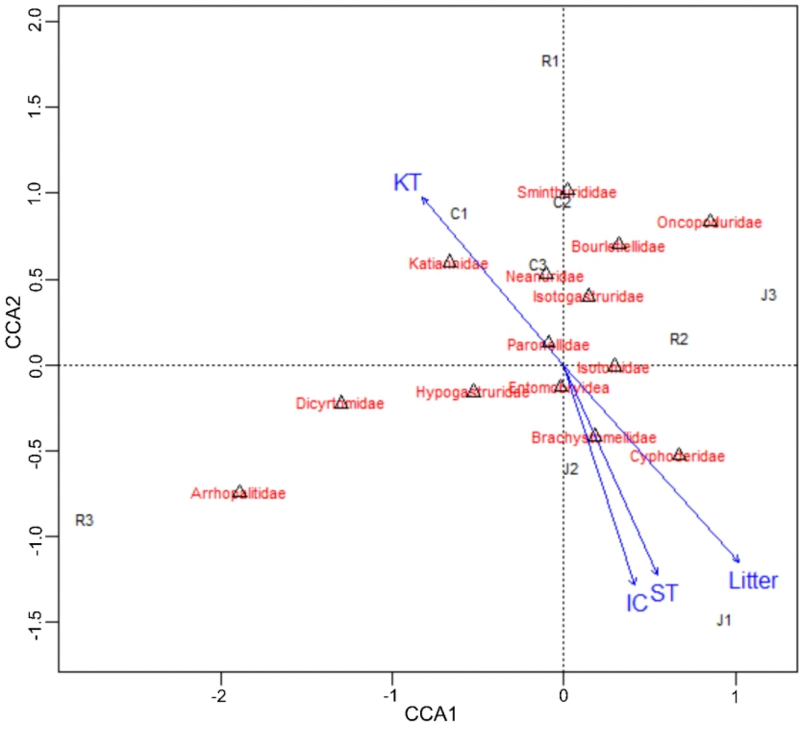

Figure 4 Ordination biplot of Canonical Correspondence Analysis (CCA) with famili abundance of Collembola and climatic factors (KT = soil humidity; ST = soil temperature; IC = light intensity relative; Litter = litter thickness) on three different land covers (J1, J2, J3 = teak land covers; R1, R2, R3 = grasses land covers; C1, C2, C3 = mixture land covers)

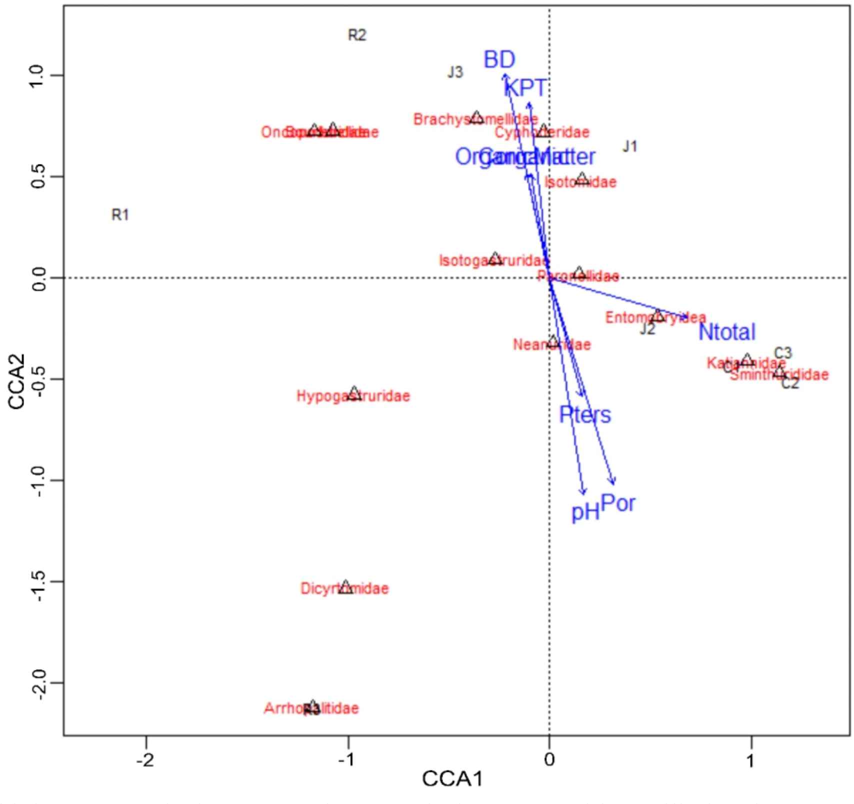

Figure 5 Ordination biplot of canonical correspondence analysis (CCA) with famili abundance of Collembola and edaphic factors (BD = bulk density; KPT = soil particle density; Por = soil porosity; OrganicMatter = soil organic matter; C-org = C-organic) on three different land covers (J1, J2, J3 = teak land covers; R1, R2, R3 = grasses land covers; C1, C2, C3 = mixture land covers)

mounds are known to have higher bulk density than the surrounding soil (Sileshi et al., 2010). Bulk density (1.06 g cm^{-1}) and soil particle density (2.08 g cm^{-1}) in TLC have the highest value among the other land covers (Table 2). This might be the result of soil parent material characteristics (Shan et al., 2019) and monoculture plantation, which have less contribution to improved soil aggregates.

In contrast, GLC has no trees and is dominated by grasses and undergrowth, but its bulk density is lower than that of TLC. The fibrous root system on grasses and undergrowth may contribute to soil improvement for the low bulk density (Renaud et al., 2004). The ability of grass roots to bind the soil helps decrease bulk density, which may be caused by soil compaction; thus, soil aggregates in GLC are more stable (Zhu et al., 2023).

A similar trend was found in soil porosity, pH, and P-available, which are related to Neanuridae (Figure 5). Neanuridae can inhabit humid soils with stable soil porosity (Sano et al., 2019). Soil porosity refers to soil pores that can hold water and air; thus, Collembola have space to grow. Furthermore, Collembola, as an organic matter decomposer, produces fecal pellets that contribute to soil aggregation (Siddiky et al., 2012). A biplot of CCA with edaphic factors (Figure 5) showed that none of those three land covers were in line with the arrow of this relation. However, MLC has higher soil porosity and P-availability, which indicates that this habitat is suitable for Neanuridae.

Soil improvement leads to better aeration, which affects the soil pH (Sahu et al., 2022). The pH values in all three different land covers are normal (Table 2) and still provide suitable habitat for Collembola, which have a pH tolerance range of 2–9 (de Boer et al., 2010). The presence of Collembola might be affected by P-availability (Harta et al., 2021). However, available has related to pH, soil aeration, and the nitrogen cycle (Hossain et al., 2013).

N-Total content showed relations to Entomobryidae, Sminthurididae, and Katiannidae in MLC (Figure 5). The high value of N-Total and low value of C-organic in the MLC are most likely influenced by vegetation composition, which is dominated by leguminous species (Xu et al., 2020) that decompose easily. The relationship between these families and N-Total indicates that Collembola plays a role in maintaining the C/N ratio in soil, where carbon decreases and nitrogen content massively rises. N-Total and C-organic content in soil are related to energy sources for microbial living, which is one of the Collembola sood resources (Widrializa, et al., 2015). Abundant availability of C-organic contributes to enhanced Collembola survival along with the growth of microbial activity (Kaneda & Kaneko, 2004).

The presence of Isotomidae, Chypoderidae, and Brachystomellidae, which tend to be found in TLC, is related to the abundance of soil organic matter and C-organic. Observation plots in TLC had higher litter thickness and C-organic content, which allowed Collembola to decompose the litter. Thus, the abundance of litter is related to the increase in C-organic content as a result of decomposition. This CCA result is in line with previous findings (da Silva et al., 2022) and also proves that each family of Collembola has a role in the soil.

A few families were found to gather at the center of the CCA graphic or were distributed far from the arrow line (Figure 4 and 5). This might indicate that the existence of these families was not highly affected by climatic or edaphic factors. This is likely due to the ability of families to adapt to different conditions in each land cover type. Overall, the CCA results showed that the presence of Collembola is determined by the microclimate habitat. The development of habitats after rehabilitation in Wanagama I, with stable climatic and edaphic factors, provides an optimal habitat for Collembola (Arboláez et al., 2023).

Conclusion

The obtained results allow for a better understanding of how different land covers create their microclimate conditions and affect the abundance and diversity of Collembola. The abundance of Collembola is not only related to the presence of litterfall as a food source but also to climatic factors. Although the statistical analysis of Collembola abundance in TLC, GLC, and MLC was not significantly different, TLC had higher litter thickness and organic matter than the other land cover types. Certain families of Collembola were related to several climatic and edaphic factors, and it is inclined in certain land covers. Our research provides information that besides preserving diversity, it is also important to increase the abundance of Collembola by enriching planting with species that are suitable for each land cover type.

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