Article

Microarthropod composition in Mt. Hilong-Hilong, Tandag City, Philippines: Its implication to restoration strategies

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Abstract

The paper examines the diversity, abundance, and ecological roles of microarthropods in three habitats namely: agroecosystems, dipterocarp forests, and secondary mixed dipterocarp forests. Soil samples were taken from Mt. Hilong-hilong ecosystems, and microarthropods were extracted using a modified Berlese Tullgren funnel. The results showed 3,738 microarthropods belonging to 16 different groups, with Oribatida dominating the Acari group. Agroecosystems had low diversity but high abundance of Acari and Collembola, suggesting agricultural practices degrade soil biodiversity and ecosystem function. Dipterocarp forests had high diversity but lower abundance, reflecting the stability and complexity of undisturbed ecosystems. Secondary mixed dipterocarp forests showed moderate diversity and abundance, indicating transitional ecosystems recovering from past disturbances. This gradient reflects the varying degrees of habitat complexity, stability, and disturbance across the different land uses. The results highlight the significant impact of land-use change on soil biodiversity and offer valuable insights for designing effective restoration and conservation strategies to promote resilient and sustainable ecosystems.

Keywords microarthropod; ecological roles; agroecosystems; secondary dipterocarp forests; dipterocarp forests; restoration

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1 Introduction

Forest ecosystems are dynamic landscapes that foster rich biodiversity due to their varied topography and biogeography (Pant et al., 2023). However, these forests are increasingly vulnerable to environmental degradation caused by both natural and human activities, affecting their composition and health. Thus, investigating species richness patterns and the factors influencing them is crucial for effective conservation and management (Pant et al., 2023).

Mt. Hilong-hilong is a forested mountain range area, spanning several municipalities in the provinces of Caraga Region (Agusan del Norte, Agusan del Sur, Surigao del Norte, and Surigao del Sur), northeastern Mindanao Island, southern Philippines (Plaza and Sanguila, 2015). It is an astonishing habitat for various flora and fauna, thus, designated as the one of the Key Biodiversity Areas (KBA) in Mindanao (Gracia Jr. et al., 2021; Mallari et al., 2001). This watershed forest provides essential ecosystem services, including nutrient cycling, carbon storage, erosion control, increased biodiversity, soil formation, wildlife corridors, water storage, filtration, food, timber, and recreation (EPA, 2024).

Despite its ecological significance, Mt. Hilong-hilong faces severe anthropogenic pressures, particularly in the Awasian Watershed Forest Reserve. Activities like timber extraction, land conversion, slash-and-burn agriculture, road construction, and deforestation lead to biodiversity loss and environmental degradation (BirdLife International, 2020; Plaza and Sanguila, 2015; Brooks et al., 2002; Dar et al., 2022; IPBES, 2019; Baccini et al., 2012). These practices also cause soil degradation, profoundly impacting soil properties and functions (Veldkamp et al., 2020; Nyasha, 2021).

Soil represents one of the most important reservoirs of biodiversity (Dey and Hazra, 2021), suffers from reduced vegetation cover and organic matter, leading to decreased biological activity and nutrient cycling, and increased susceptibility to erosion (Lal, 2015; Magdoff and van Es, 2021). When soil properties and functions are disturbed it is more likely that soil fauna are affected. Among soil fauna, that are possibly affected by forest destruction are microarthropods. Microarthropods, including mites, springtails, and other minute organisms, are essential components of the forest floor. They contribute significantly to the decomposition of organic matter, nutrient cycling, and soil formation. These processes are crucial for sustaining plant growth and maintaining soil structure, which are foundational for a thriving forest ecosystem. The health of these tiny organisms directly influences the larger ecological balance, affecting everything from the smallest plants to the tallest trees.

Human activities disrupt these delicate balances, reducing microarthropod populations and soil health, thereby affecting plant diversity. However, fostering healthy microarthropod populations can significantly aid in ecosystem restoration. Enhancing organic matter, reducing tillage, promoting biodiversity, minimizing pesticide use, and creating suitable habitats can reverse soil degradation and maintain productive soils (Abbas and Parwez, 2019). Documenting microarthropod populations in Mt. Hilong-hilong can provide baseline data on soil health, offering insights into the ecological impact of human activities. Understanding and leveraging the role of microarthropods in these ecosystems is crucial for restoring degraded forests and fostering resilient, sustainable landscapes. Their role in improving soil health and supporting plant communities underscores their importance in ecological restoration efforts.

2 Study Area and Methodology

2.1 Study site

A field investigation was carried out in the eastern part of Mt. Hilong-Hilong in Brgy. Awasian, Tandag City Surigao del Sur. Geographically situated between 9.075°N and 126.154°E (Fig. 1). Topographically characterized as predominantly flat, with some areas having gentle slopes and undulating terrain. Its climatic condition is classified as Type II according to the Philippines' weather classification system. This type is characterized by rainfall that is evenly distributed throughout the year, with a very short dry season (PAG-ASA, 2011).

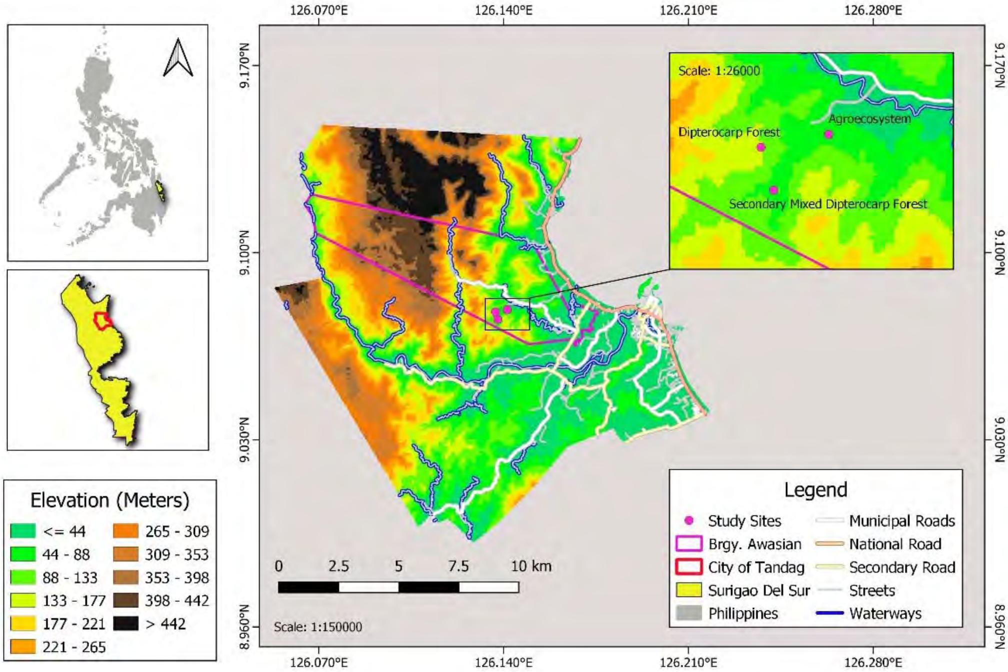


Fig. 1 Location Map of the Study Area showing the three habitats within Tandag City, Surigao del Sur, Philippines.

Along 2 km transect line, study areas are characterized by three habitats namely, agroecosystem, secondary mixed-dipterocarp and dipterocarp. Agroecosystem geographically located at 9°04'39"N 126°08'34"E, was situated at the lower elevation that extends from 50-100 meter above sea level (masl). The area has an open to slightly closed canopy cover approximately less than 20% within a slope of 5-100. Its major vegetation is composed of grasses, sedges, undetermined herbs, *Cocos nucifera*, and *Paraserianthes falcataria* as the dominant plant species. There are also fruit trees around namely: *Lansium domesticum* and *Durio zibithenus*. This area is approximately 10-20 meters away from the human settlements.

Secondary mixed dipterocarp on the other hand, is located 9°04'26"N 126°08'21"E, situated at the mid elevation about 120-160 masl. It is approximately 500-700 meters away from human settlements. With a slope of approximately 25-300 and canopy cover of 75 – 85%, this area were dominated by secondary growth dipterocarp tree species with some fruit trees, such as *Durio zibithenus*. There were several *Bambusa spp.* planted along streams. Soil litter is moderately thick within slightly moist soil.

Dipterocarp forest geographically located in 9°04'36"N 126°08'18"E, is around 160-250 masl. It has a slightly closed to closed canopy cover of about 80-95% with a slope fo 30-400. The dominant plant species in this area was *Shorea spp*. under the family Dipterocarpaceae. There were also noted ferns and shrubs in the area. This area is near the watershed control area of Tandag Water District. Soil litter was dry to moist but thicker as compared with Secondary Mixed Dipterocarp.

2.2 Data collection

2.2.1 Sampling techniques

In each habitat, a line transect of 100m was established. In each transect, 6 (50 cm x 50 cm) quadrat was laid down alternately with a distance of 20m each. Five random soil samples were obtained from each quadrat with the aid of hand-held shovel up to 5 cm depth, after removing the leaf litter on the surface. The 5 soil samples were mixed homogeneously to constitute a composite sample from which 100g of soil sample was taken for microarthropods collection. The soil samples were separately placed and labeled accordingly in a zip lock pouch and were immediately brought to the laboratory for arthropod extraction using modified Berlese funnel method.

2.2.2 Microarthropod Extraction and Identification

Microarthropods were extracted for a period of one week from the soil samples collected using a modified Berlese-Tullgreen Funnel apparatus. This apparatus is a closed funnel system, with a screen in the middle where soil sample are placed and a light source (incandescent lamp) placed about 30cm on top of the sample. The effect of light and heat of the incandescent lamp aids in gradual drying of the soil, creating inhospitable condition for soil fauna which drives soil fauna to move downward and ultimately fall into the collection tubes (Kumar and Maurya, 2023; Menta et al., 2018) containing 70% ethyl alcohol with few drops of glycerol under the funnel (Menta et al., 2018). Samples collected in the tubes through extraction were poured carefully in petri-dish for further sorting and separation of soil microarthropod groups. Needles and fine camel hairbrush (Nos. '0' and '00') were used for picking up the specimens from the petri-dish and microarthropod groups were preserved separately in Effendorf tubes containing 70% alcohol (Saha et al., 2020). A wide field stereoscopic binocular microscope (Koppace Model) with 40x magnification was used for sorting and counting of the microarthropod. Taxonomical identification to the nearest family taxa were done with the aid of identification key utilized by Kandziora-Ciupa et al., (2021) namely: Identification Key (a): https://www.zoology.ubc.ca/~srivast/mites/index.html; ver.1.0 and Identification key (b): https://keyserver.lucidcentral.org/key-server/player.jsp?keyId=56 and Insom, La Terza (2012) and other published taxonomic keys and literature available in the World Website.

2.3 Data analysis

To study community structure of soil microarthropods in three distinct habitats of Mt. Hilong-hilong, abundance, dominance, Shannon diversity (H'), evenness were calculated through the aid of Paleontological Statistics Software 4.03. One way analysis of variance (ANOVA) was calculated to determine significant difference across sites at 5% level of significance and was subjected to post-hoc tests to identify variables that are different.

3 Results and Discussion

Table 1 presents the microarthropod composition and relative abundance in three habitats of Mt. Hilong-hilong. A total of 3,738 soil inhabiting microarthropod individuals (Table 1) belonging to 16 groups under Phylum Arthropoda were extracted from 18 samples obtained in three sampling sites. In terms of distribution, agroecosystems had the highest number of microarthropods, with 1,714 individuals making up 45.85% of the total population. Dipterocarp forests had 1,063 individuals (28.44%), and secondary mixed dipterocarp forests had 961 individuals (25.70%).

Abundance and dominance depict higher mean values favoring Agroecosystem while Shannon Diversity (H'), Evenness and Simpson's Indices favoring Dipterocarp Forest. Only Shannon Diversity (H') indices significantly showed difference (F = 5.372; *p*< 0,05) across habitat. Specifically, in terms of taxonomic richness (Fig.2b), Dipterocarp Forest had higher taxa-richness recorded with 31 microarthropod groups while the Agroecosystem had only 27 and 28 for secondary mixed dipterocarp.

Table 1 Microarthropod abundance and relative abundance (%) in three habitats of Mt. Hilong-hilong, Awasian, Tandag City, Surigao del Sur.

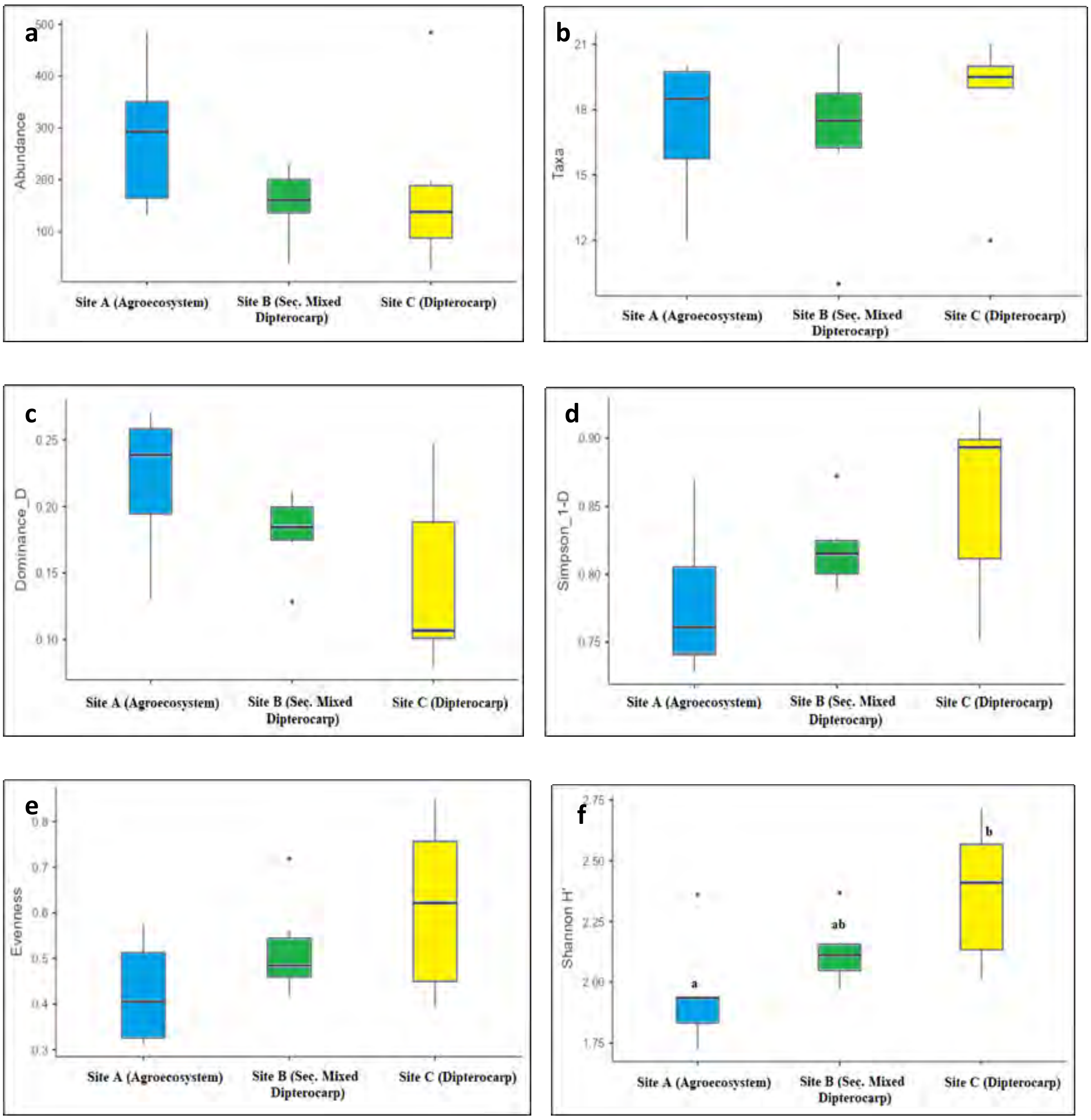
Groups	Sites						Total Abundance	Total RA*
	Agroecosystem		Secondary Mixed Dipterocarp		Dipterocarp			
	Abundance	RA*	Abundance	RA*	Abundance	RA*		
Acari	1194	69.66	537	55.88	739	69.52	2470	66.08
Arachnida	8	0.47	8	0.83	11	1.03	27	0.72
Chilopoda	2	0.12	6	0.62	4	0.38	12	0.32
Coleoptera adults	33	1.93	13	1.35	28	2.63	74	1.98
Collembola	125	7.29	135	14.05	88	8.28	348	9.31
Diplopoda	1	0.06	0	0	3	0.28	4	0.11
Diplura	12	0.70	6	0.62	6	0.56	24	0.64
Diptera	7	0.41	5	0.52	13	1.22	25	0.67
Hemiptera	11	0.64	3	0.31	33	3.10	47	1.26
Hymenoptera	238	13.89	106	11.03	97	0.38	441	11.80
Pauropoda	2	0.12	6	0.62	4	1.32	12	0.32
Psocoptera	14	0.82	5	0.52	14	0.56	33	0.88
Protura	6	0.35	10	1.04	6	0.56	22	0.59
Pseudoscorpionida	6	0.35	5	0.52	3	0.28	14	0.37
Symphyla	3	0.18	2	0.21	5	0.47	10	0.27
Thysanoptera	31	1.81	81	8.43	8	0.75	120	3.21
Larvae	21	1.23	33	3.43	1	0.09	55	1.47
Total No. of Individuals	1714	100.00	961	100	1063	100	3738	100

**relative abundance (%)*

Diversity index (H') (Fig.2f) and evenness (J') (Fig.2e) were relatively higher in Dipterocarp Forest (H'=2.37; J'=0.613) compared to those in Agroecosystem (H' = 1.95; J' = 0.424) and Secondary Mixed Dipterocarp (H' = 2.13; J' = 0.520). Moreover, dominance is higher (D=0.221) in Agroecosystem compared to other habitats. The findings highlight a distinct contrast between agroecosystems and dipterocarp forests in terms biodiversity metrics, each with implications for tailored restoration strategies.

The study on microarthropod composition and abundance across three habitats of Mt. Hilong-Hilong reveals distinct ecological dynamics in biodiversity and population densities. In agroecosystems, higher mean values of abundance and dominance suggest that a few species are highly prolific, thriving under the homogeneous and frequently disturbed conditions typical of agricultural lands. This environment promotes certain adaptable species while suppressing others, leading to lower overall biodiversity. Such findings corroborate with work of Gong et al. (2023) and Zhou et al. (2022), where microarthropod group acari were able to adapt or developed mechanisms to withstand harsh environmental conditions. This could be the possible reason why they exists abundantly in various ecosystems. Some acari also have relatively long lifespans, allowing them to persist in the soil for extended periods. This longevity contributes to their overall abundance over time.

Dipterocarp forests on the other hand, show higher values for Shannon Diversity (H’), Evenness, and Simpson’s Indices reflecting a more balanced and diverse ecosystem. The complex habitat structures and stable conditions with minimal disturbances in these forests support a wide range of species, contributing to their high biodiversity and ecosystem resilience. Secondary mixed Dipterocarp forests present an intermediate state, with ecological characteristics between those of agroecosystems and Dipterocarp forests. These forests may have experienced some level of disturbances but are in the process of recovery, showing a mix of species abundance, dominance, and diversity metrics.



Note: Different letters in the box plots indicate significant difference @ p<0.05

Fig. 2 Box plots comparing mean values of microarthropods (a) abundance, (b) richness, (c) dominance, (d) Simpsons diversity, (e) evenness and (f) Shannon diversity across habitats of Mt. Hilong-hilong, Tandag City, Philippines.

In terms of taxonomic groups, the top three most abundant groups were Acari, Hymenoptera (specifically Formicidae ants), and Collembola (Fig. 3). Acari were found in all samples and made up more than 66% of all microarthropods, followed by Hymenopterans with 11.80% and Collembolans (9.31%). Within the Acari group, three main groups of mites were identified: Mesostigmata, Prostigmata, and Oribatida. Oribatida exhibited the most significant number of families, accounting for 9 out of 14 families. These mites resemble small beetles and are called beetle mites (Widyastuti, 2005), characterized by its hard shell, prominently displaying a brown to slight brown exoskeleton. This group includes a wide variety of species with different shapes and sizes, ranging from 0.1 mm to 2 mm in length.

Second most abundant group in the area is the Hymenoptera particularly the Formicidae accounting for 11.80% of the total individuals. They are more prevalent in agroecosystems than in other locations. They were included in this study since they are found to be part of the soil as “soil dwellers” (Cerda and Dejean, 2011).

The observed Formicidae within the sites exhibit color variation, with the majority being black, while others display hues of red, brown, orange, or yellowish. In terms of size, they also vary, since they are found sometimes in colony, their size can vary depending on their role in the colony.

Collembola also called springtails, are small wingless soft-bodied hexapods that are usually measured between 1 and 3 mm in length. The scientific name refers to the collophore, which is a unique abdominal appendages that characterizes all Collembola (Dukes et al., 2022). It possessed spring-operated jumping mechanism, comprising an abdominal furca and tenaculum. collembola is more abundant in secondary mixed forests (n=135), followed by agroecosystems (n=115) and dipterocarp (n=88). Three collembolan groups dominate Mt. Hilong-hilong, these are, Symphypleona, Entomobryomorpha and Poduromorpha. The first two sub orders were found in three habitats while the latter (Poduromorpha) are found only in Dipterocarp Forest. The group Pseudoscorpiones Chilopoda, Diplopoda, Pauropoda, and Symphyla, though among the least observed, are commonly present in microarthropod communities. They appear in soil samples, albeit in minimal quantities.

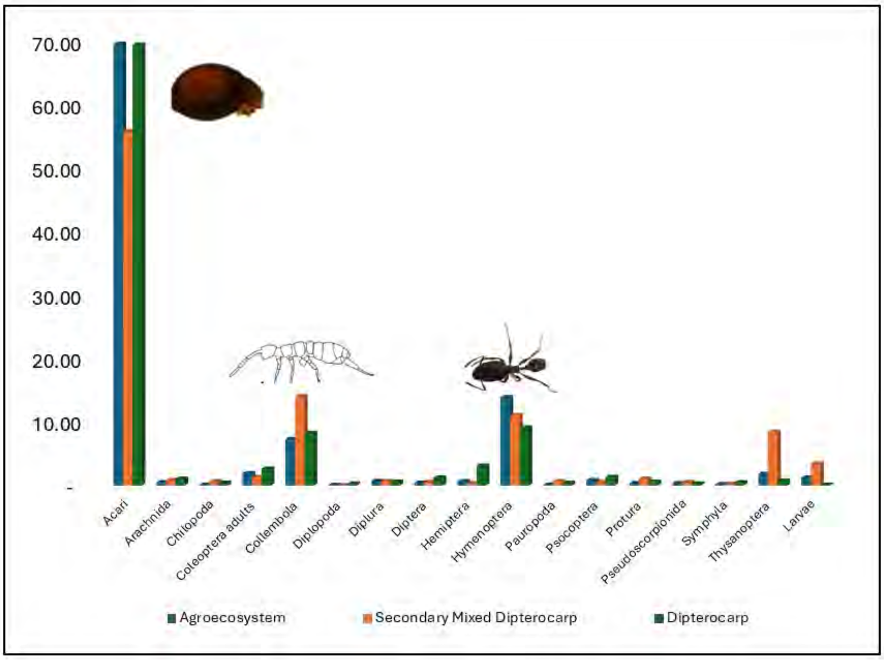


Fig. 3 Taxa Richness and relative abundance (%) of microarthropods in three habitats of Mt. Hilong-hilong, Awasian, Tandag City, Surigao del Sur.

Taxonomic assemblages also vary significantly across habitats. Acari, Collembola, and Hymenoptera showed notable variations across habitats. Acari being the most abundant group aligns with worldwide patterns indicating that Acari group as highly abundant among soil fauna and in various ecosystems. (Seastedt, 1984; Widyastuti, 2005; Sopsop and Lit, 2015; Saha et al., 2020; Guo and Siepel, 2020; Lienhard and Krisper, 2021; Mantoni et al., 2021). The notable variations of these microarthropod (Acari, Collembola, and Hymenoptera) across habitat reveal important patterns related to their diversity, abundance, and dominance, and ecological roles of these microarthropods. These patterns have significant implications for restoration ecology and soil health management.

In agroecosystems, Acari show low diversity but high dominance, indicating an imbalance in the soil ecosystem due to anthropogenic disturbances. Restoration efforts should focus on diversifying soil habitats and reducing disturbances through practices like no-till farming and incorporating organic matter.

In dipterocarp forests, higher Acari diversity but lower overall abundance suggests a stable, complex environment with a variety of microhabitats supporting specialized species. Conservation of these forests is crucial for maintaining ecological integrity and the diverse Acari communities that contribute to soil health. Secondary mixed dipterocarp forests show moderate Acari diversity and abundance, reflecting a transitional ecosystem with improving soil conditions and habitat heterogeneity. Restoration strategies should enhance habitat complexity and protect natural regrowth. The study's findings suggest Acari, Collembola and Hymenopterans can serve as bioindicators of soil health, with high diversity and balanced abundance indicating good soil quality, while low diversity and high dominance suggest disturbed conditions.

Comparably, the present study reveals a clear gradient difference in microarthropod diversity and biodiversity metrics which reflects varying degrees of habitat complexity, stability, and disturbance across different land uses. These findings highlight the significant impact of land-use change on soil biodiversity and emphasize the need for conservation and sustainable management practices to restore and maintain soil health. This further suggests different tailored ecological restoration approaches for each habitat. Ecological restoration assist the recovery of an ecosystem that has been damaged or destroyed (SER, 2004). At the landscape level, the goal of forest restoration is to regain ecological functionality (Lamb, 2014; Chazdon, et al., 2015). As supported by Holl et al. (2017), prior to selecting a restoration approach, natural resilience of a given site should be assessed. The high variations in the rate of recovery across sites need to be carefully considered with several options to decide which is being suited to the site. The basis are the baseline assessment that considers both biotic and abiotic conditions, since not all sites recover quickly without active planting, examining microfauna and improvement of abiotic conditions. A successful forest and landscape restoration reverses environmental degradation, strengthen the resilience of landscape, secures forest-based livelihoods, and optimizes ecosystem goods and services to meet the changing needs of society (IUCN and WRI, 2014).

For agroecosystems, the focus should be on increasing habitat heterogeneity and reducing disturbances to promote biodiversity. Strategies could include crop diversification, agroforestry, conservation tillage, and the use of cover crops and organic amendments. These practices can create a more favorable environment for a broader variety of species, enhancing ecosystem resilience and sustainability. For Dipterocarp forests, restoration efforts should prioritize preserving and enhancing their complex habitat structures. This can be achieved by protecting existing forest areas from logging and other disturbances, promoting natural regeneration, and reforesting degraded areas with native plant species. Maintaining a variety of microhabitats and minimizing disturbances will support the high biodiversity and ecological functions typical of these forests. Secondary mixed Dipterocarp forests require strategies that facilitate their transition towards the biodiversity levels of primary Dipterocarp forests. Restoration in these areas can focus on enhancing structural complexity, controlling invasive species, and promoting the growth of native vegetation. By supporting the natural successional processes, these forests can gradually recover their ecological integrity and resilience.

4 Conclusions

Overall, the study highlights a gradient in Collembola diversity and abundance across different habitats, with primary dipterocarp forests showing high diversity and low abundance, secondary forests showing moderate diversity and high abundance, and agroecosystems showing low diversity but high abundance. These patterns emphasize the need for tailored restoration strategies to enhance soil health and biodiversity. In agroecosystems, integrating sustainable practices can promote habitat complexity and support diverse microarthropod communities. In secondary forests, protecting and enhancing natural regrowth will aid in ecological recovery. Conservation of dipterocarp forests is essential to maintain their biodiversity and ecological functions. By understanding and promoting diverse and balanced microarthropod communities, we can improve soil health, enhance ecosystem services, and contribute to the sustainability and resilience of both agricultural and forested landscapes.

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