https://doi.org/10.17221/38/2025-JFS

Soil macroarthropod dynamics in response to environmental disturbances in a forest remnant ecosystem: A case study at Cibodas Botanical Garden

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Citation: Rinti A., Marsandi F., Nasution T., Zuhri M., Efendi M., Prayogi H., Danarto S.A., Fajri H., Sihombing V.S., Indrawan D.A. (2026): Soil macroarthropod dynamics in response to environmental disturbances in a forest remnant ecosystem: A case study at Cibodas Botanical Garden. J. For. Sci., 72: 1–13.

Abstract: Disturbing the remaining forest ecosystem in the Cibodas Botanical Garden (CBG) has affected the dynamics of the soil macroarthropod communities. This study was conducted in three remaining forest locations in the CBG with different levels of disturbance. Soil macroarthropod samples were collected using the pitfall trap method with 30 traps and analysed using the Shannon-Wiener diversity index, Pielou's evenness, Simpson's dominance, and Margalef's species richness to assess the dynamics of the soil macroarthropod community. This study analysed how these communities respond to different levels of disturbance in the garden, namely Jalan Akar (JA; low), Wornojiwo (WJ; moderate), and Ciismun (CI; high), which were influenced by tourism activities and local environmental conditions. The results showed that individuals from the Hymenoptera group accounted for 60.05% of the total number of soil macroarthropods found. Site WJ, which experienced moderate disturbance, had the highest number of individuals and species richness of soil macroarthropods. In contrast, site CI, which experienced high levels of disturbance, had a lower number of individuals and lower species richness, diversity and evenness indices. Site JA, which experienced low levels of disturbance, exhibited higher diversity and evenness indices. These results demonstrate that disturbance affects the presence of soil macroarthropods at their respective levels of disturbance. However, analysing the spatial distribution of soil macroarthropods in each studied taxon using the Morisita index revealed that they were dominantly clustered and exhibited varied distribution patterns. The study concludes that maintaining minimal disturbance is essential to preserve soil biodiversity and ecological balance in managed forest ecosystems such as the Cibodas Botanical Garden.

Keywords: abundance; diversity; ecosystem; forest; soil macroarthropods

Supported by the Organization for Life Science and Environment (RP-ORHL 2023).

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https://doi.org/10.17221/38/2025-JFS

Forest remnants in botanical gardens play an important role in supporting soil macroarthropod biodiversity, which is a key component in maintaining the balance of the soil surface ecosystem (Neves 2024; Coleman et al. 2024). However, the existence of these areas is increasingly threatened by various human activities and increasing natural disturbances (Jacobson et al. 2019; Okolo et al. 2020; Yang et al. 2025). In the remnant forest areas of botanical gardens, anthropogenic activities and natural disturbances often degrade the habitats of soil macroarthropods, and these impacts are exacerbated by climate change, thereby reducing biodiversity (Morris 2010; Scanes 2018). Destructive anthropogenic activities, such as land destruction, littering, pedestrian pressure (Kung'u et al. 2023; Daudi et al. 2025), and natural disturbances, such as heavy rain, strong wind, thunderstorms, and soil surface erosion, lead to fallen trees, soil degradation and pollution that threaten biodiversity (Delong et al. 2012; Coyle et al. 2017). These conditions can cause direct mortality of organisms or slowly destroy habitats that previously supported the survival of soil macroarthropods (Wilson et al. 2016; Didham et al. 2020; Bowd et al. 2021). A key challenge in managing these areas is to maintain ecosystem quality in the face of increasing anthropogenic pressures and natural disturbances to the environment (Zhou et al. 2024).

Soil macroarthropods are a group of macro-sized soil arthropods that perform activities above the soil surface during certain periods (Villanueva-López et al. 2019; Wang et al. 2024). Soil macroarthropods play an important role in maintaining the balance and sustainability of soil ecosystems (Forstall-Sosa et al. 2021; Marsandi et al. 2023). In addition, soil macroarthropods act as ecosystem engineers by significantly modifying soil structure and processes (Bottinelli et al. 2015; Castro et al. 2025). Soil macroarthropod groups respond differently to disturbance-induced changes in soil surface conditions (Siira-Pietikainen et al. 2003; Tulande-M. et al. 2018; Vazquez et al. 2020; Vanolli et al. 2023). The presence of soil macroarthropods is sensitive to environmental conditions, making them an indicator of ecological changes due to ecosystem disturbance (Marsandi et al. 2024; Wang et al. 2024). However, soil macroarthropods are one of the least studied components of tropical ecosystems (Gongalsky 2021; Mathieu et al. 2022).

The remnant forest area with biodiversity-based management and use in the Cibodas Botanical Garden is an important factor affecting ecosystem stability, and disturbances to these areas will also affect the presence of aboveground macroarthropods (Zuhri, Mutaqien 2013; Galloway et al. 2021; Tóth et al. 2021). Habitat complexity, characterised by vegetation cover, diverse understorey vegetation, and minimal soil disturbance, is strongly associated with the abundance and diversity of soil macroarthropod communities (Peng et al. 2020; Eckert et al. 2022). An in-depth understanding of how components of land disturbance levels affect the distribution and resilience of soil macroarthropods is essential (Bengtsson 2002; Todman et al. 2016; Wang et al. 2024). These insights can support biodiversity-based management strategies to maintain the stability of soil surface ecosystems, enhance environmental resilience, and strengthen conservation efforts (Villanueva-López et al. 2019; Marsandi et al. 2023).

This study aims to assess the response of soil macroarthropods to levels of disturbance, both natural and anthropogenic. The study classified disturbance levels into three categories: low (no fallen trees, erosion, inorganic waste, or human traces), moderate (presence of fallen trees, some erosion, and reduced tree density), and high (tourist activity, waste accumulation, and local resource collection). At these three different disturbance levels, the species richness, individual composition, diversity, and distribution patterns in the remnant forest area will be analysed to help identify the best management strategies to conserve soil macroarthropod diversity and support the sustainability of the remnant forest ecosystem in the Cibodas Botanical Garden area.

MATERIAL AND METHODS

Study site. The Cibodas Botanical Garden (CBG) is located on the slopes of Mount Gede in the Cipanas area of the Cianjur Regency in West Java (6°44'10'S , 106°59'25'E). The area has an average elevation of between 1 300 and 1 425 m a.s.l. and the average air temperature is 20.6 °C with a relative humidity of 81%. The average annual rainfall is around 2 950 mm. These conditions support the sustainability of ecosystems and biodiversity. The remaining natural forest areas in the CBG contain around 137 tree species with a density of 306 individuals per hectare (Mutaqien, Zuhri 2011).

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This study was conducted at three locations within the remaining forest area of the Cibodas Botanical Garden (Figure 1). The locations were selected based on the level of anthropogenic and natural disturbance that occurred. The three locations that showed the level of disturbances are presented in Table 1.

In addition to serving as a conservation and research centre for tropical mountain plant biodiversity, the CBG is a popular nature tourism destination, receiving a high number of visitors each week. The main sources of ecological pressures affecting the integrity of the Cibodas Botanical Garden ecosystem are recreational activities by visitors, natural ecological pressures, and anthropogenic practices around the area.

Research methodology. Soil macroarthropod samples were taken using the pitfall trap method in October 2023, assuming the dynamic nature of soil macroarthropods. The pitfall trap installation points were placed at each research location (JA, WJ and CI) by taking into account areas often travelled by soil macroarthropods, which require relatively moist soil conditions with litter on the ground surface. The pitfall traps were filled with a mixture of ethylene glycol and 15% detergent to reduce surface tension (Souza et al. 2012; Sheikh et al. 2018; Przybyszewski et al. 2020), and the traps

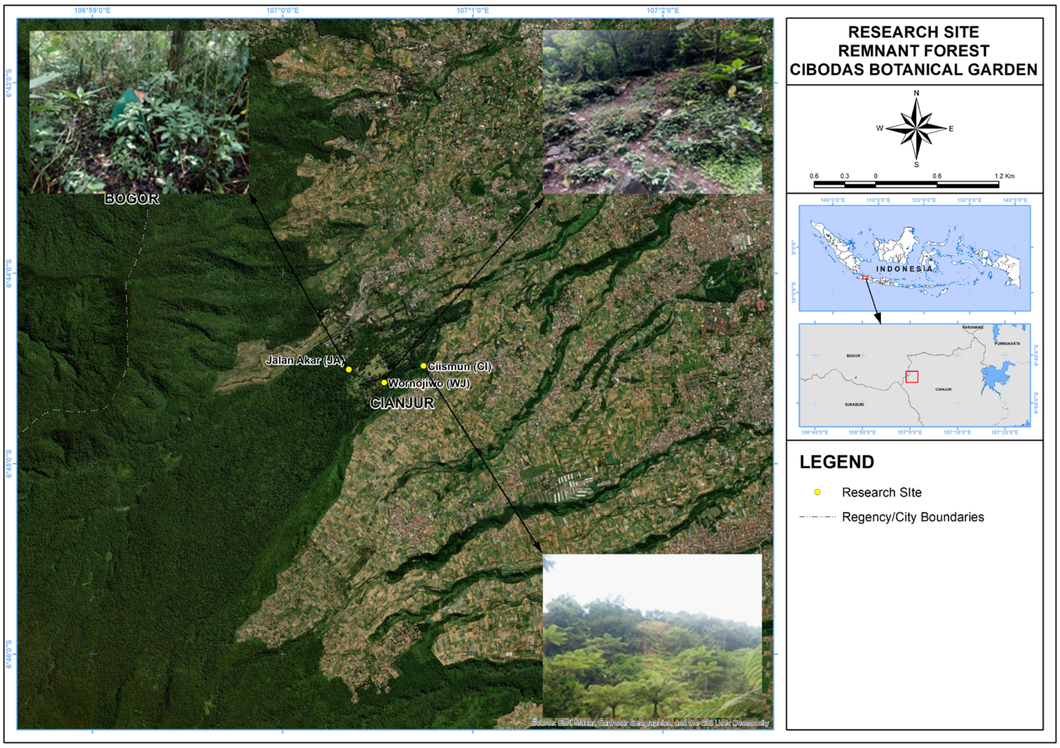

Figure 1. Research site in remnant forest, Cibodas Botanical Garden (CBG)

JA – Jalan Akar (6°44'30.34'N, 107°00'20.85'E; 1 417 m a.s.l.); WJ – Wornojiwo (6°44'34.45'N, 107°00'32.06'E; 1 407 m a.s.l.); CI – Ciismun (06°44'29.17'N, 107°00'44.45'E; 1 311 m a.s.l.)

Table 1. Characteristics of each research location

Location	Level of disturbance	Characteristics
Jalan Akar (JA)	low	No fallen trees, no soil erosion, no inorganic waste, no footpaths, and no traces of tree felling.
Wornojiwo (WJ)	moderate	Presence of fallen trees, eroded soil, and lower tree density.
Ciismun (CI)	high	Tourist path leading to a waterfall, presence of inorganic waste, and local activities such as trading and collecting young bamboo shoots.

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were left in place for two days. Ten pitfall traps were set at a distance of 10 m from each other at the study sites (JA, WJ, and CI), for a total of 30 traps (3 study sites × 10 traps). The captured soil macroarthropods were preserved in 70% ethanol and transported to the laboratory for sorting and identification. Identification was performed using the most commonly used taxonomic keys (Edgecombe 2010; Triplehorn, Jhonson 2005; Dippenaar-Schoeman, Foord 2020; Murguía-Romero et al. 2021). Additionally, BugGuide.net and BoldSystem.org were used to confirm corresponding images.

Data analysis. The analysis of the research data was carried out by calculating the Shannon-Wiener diversity index, the Pielou evenness index, the Simpson dominance index, and the Margalef species richness index (Strong 2016; de Souza Bueno, Fambrini 2020; Morris et al. 2014). These indices were applied to analyse the dynamics of changes in the species composition of soil macroarthropod communities. The following Equations (1–4) were used to calculate each index:

Shannon-Wiener index:

$$H = -\sum Pi \ln Pi \tag{1}$$

where:
Pi – number of individuals of the i-th species $\left(\frac{n_i}{N_i}\right)$;
H – diversity index;
n_i – number of individuals in one species;
N – total number of individuals of the species found.

Pielou index:

$$e = \frac{H'}{H_{max}} \tag{2}$$

where:
e – evenness index;
H' – diversity index;
H_{max} – maximum diversity index (ln S);
S – number of species found.

Simpson index:

$$D = \sum \left(\frac{n_i}{N}\right)^2 \tag{3}$$

where:
D – dominance index.

The Margalef species richness index is used to calculate the species richness value. It is calculated according to Equation (4).

$$Dmg = \frac{S-1}{\ln N} \tag{4}$$

where:
Dmg – Margalef species richness index.

Next, the distribution pattern of soil macroarthropods was calculated and determined using the Morisita index, see Equation (5).

$$Id = N\frac{\sum X^2 - \sum X}{\left(\sum X\right)^2 - \sum X} \tag{5}$$

where:
Id – Morisita index;
X – number of individuals per plot;
N – number of sampling plots.

To determine the distribution pattern of soil macroarthropods, it is necessary to calculate the values of Mu and Mc using the following Equations (6) and (7).

$$Mu = N\frac{X^2_{0.975} - n + \sum X_i}{\sum X_i - 1} \tag{6}$$

$$Mc = N\frac{X^2_{0.025} - n + \sum X_i}{\sum X_i - 1} \tag{7}$$

where:
Mu – Morisita index for uniform distribution pattern;
$X^2_{0.975}$ – Chi-square value with free degree (n – 1) and confidence interval 97.5%;
Mc – Morisita index for clustered distribution patterns;
$X^2_{0.025}$ – Chi-square table value with free degree (n – 1) and confidence interval 2.5%.

Then, the standardised calculation of the degree of Morisita (Ip) was performed using the following Equations (8–11).

$$Ip = 0.5 + 0.5\left(\frac{Id - Mc}{N - Mc}\right), \text{if } Id \geq Mc > 1 \tag{8}$$

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$$Ip = 0.5\left(\frac{Id - 1}{Mc - 1}\right), \text{if } Mc > Id \geq 1 \quad (9)$$

$$Ip = 0.5\left(\frac{Id - 1}{Mu - 1}\right), \text{if } 1 > Id > Mu \quad (10)$$

$$Ip = -0.5 + 0.5\left(\frac{Id - Mu}{Mu}\right), \text{if } Id > Mu > Id \quad (11)$$

Equations (8–11) refer to the following statements, among others:

(*i*) The first condition, if the value of $Id > 1$ and $Id \geq Mc$, then use Equation (8);

(*ii*) The second condition, if the value of $Id > 1$ and $Id < Mc$, then use Equation (9);

(*iii*) The third condition, if the value of $Id < 1$ and $Id > Mu$, then use Equation (10);

(*iv*) The fourth condition, if the value of $Id < 1$ and $Id < Mu$, then use Equation (11).

The final step is to determine the distribution pattern of soil macroarthropods based on the *Ip* value:

– If $Ip < 0$, then the distribution pattern is uniform.

– If $Ip = 0$, then the distribution pattern is random.

– If $Ip > 0$, then the distribution pattern is clustered.

RESULTS AND DISCUSSION

Total number of individuals and taxa of soil macroarthropods. A total of 438 individuals of soil macroarthropods were collected from forest remnants in the Cibodas Botanical Garden (CBG). The macroarthropod groups found represented 4 classes, 14 orders, and consisted of 40 morphospecies. Hymenoptera accounted for approximately 60% of the total specimens, indicating their dominance in the soil macroarthropod community, followed by Diptera (14.61%), Araneae (5.25%), and both Orthoptera and Coleoptera (5.02%). Several other orders had percentages below 5%, as shown in Figure 2.

This data indicates that the macroarthropod community in this area is dominated by Hymenoptera. This can be interpreted as a result of their ability to adapt to the ecological conditions of the remnant forest. Although they are less prevalent, other groups also demonstrate species diversity that contributes to the balance of the soil surface ecosystem. These results provide a comprehensive picture of the composition of the macroarthropod community in the remnant forest area of the Cibodas Botanical Garden. This information can be used as a basis for conservation and biodiversity management efforts in this environment.

The abundance and diversity of soil macroarthropods identified in the remnant forest area of the Cibodas Botanical Garden (CBG) reflect a typical community structure in a relatively well-preserved tropical montane forest ecosystem (Mutaqien, Zuhri 2011; Marsandi et al. 2023; Wang et al. 2024). A broad taxonomic representation is shown by the large number of individuals of soil macroarthropods collected, with the Hymenoptera group having the highest percentage of individuals (Marsandi et al. 2024). This indicates that the Hymenoptera group plays an important ecological role in ecosystem processes in the soil surface layer, particularly as predators, parasitoids and decomposers (Huber 2009; Jorge et al. 2024). This pattern of dominance is consistent with previous findings in ecosystems with low levels of forest disturbance that Hymenoptera are often important indicators of the stability and quality of soil ecosystem health (Thom, Seidl 2016; Triyogo et al. 2020). The dominance of Hymenoptera taxa in the macroarthropod community in the remnant forest area of the Cibodas Botanical Garden indicates a favourable ecological selection pattern for this group in the face of fragmented environmental conditions and anthropogenic pressures (Blaimer et al. 2023). The physiological advantages and adaptive behaviours of Hymenoptera, including resource use efficiency and colonisation ability, allow them to maintain and even expand their territories in disturbed habitats (Quiñones, Pen 2017).

In addition, the proportional abundance of other orders such as Diptera, Araneae, Orthoptera and Coleoptera indicates the functional diversity of macroarthropod communities that support decomposition, predation and nutrient recycling processes (David 2014; Sagi, Hawlena 2021; Coulis et al. 2016). Conversely, the low proportion of macroarthropods from the other orders (< 5%) may indicate specific microhabitat limitations or environmental pressures affecting the abundance of these taxa. Although these taxonomic groups were recorded in lower proportions, their presence is still important as they reflect the sustainability of complex ecological functions such as decomposition, predation and mutualistic interactions (Wang et al. 2024). These results highlight the importance of maintaining habitat heteroge-

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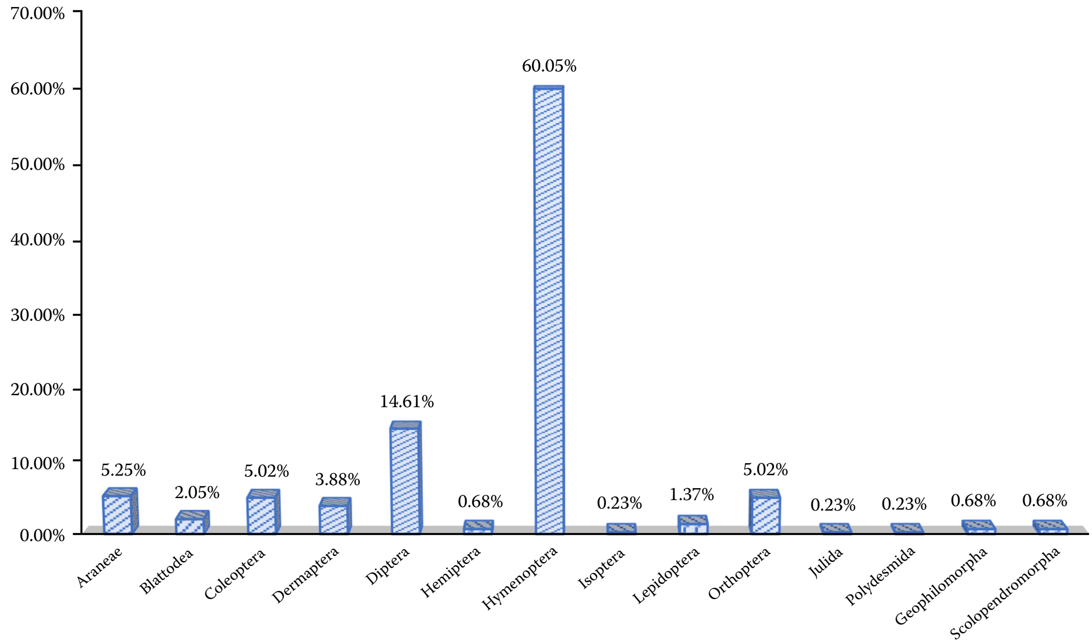

Figure 2. The percentage of individuals of macroarthropods

neity to support functional diversity of macroarthropods, which in turn maintains the stability and resilience of soil ecosystems.

Disturbance in the Cibodas Botanical Garden affects the abundance of soil macroarthropods. Each level of disturbance shows a different total number of soil macroarthropods. Figure 3 illustrates the variation in total abundance among groups of soil macroarthropod taxa at various disturbance levels within the remaining forest area of the garden.

The highest abundance of soil macroarthropods was found in areas with moderate disturbance (WJ), with 197 individuals divided into 13 taxa groups. In contrast, areas with high levels of disturbance (CI) had the lowest abundance of soil macroarthropods, with only 95 individuals divided into 10 groups of taxa. Meanwhile, areas with low disturbance (JA) had an abundance of 146 soil macroarthropods belonging to nine groups of taxa. These results show that high levels of disturbance are associated with decreased abundance and diversity of soil macroarthropod taxa. Conversely, the area with moderate disturbance (WJ) had a higher number of individuals and a greater diversity of soil macroarthropod taxa than the other areas. Interestingly, the low disturbance area (JA) had a lower abundance of individuals and fewer soil macroarthropod taxa than the medium disturbance area (WJ). Disturbing the CBG remnant forest ecosystem does not always negatively impact the number of soil macroarthropod individuals or taxa.

Based on this pattern, it can be assumed that the soil macroarthropod community prefers environments with moderate levels of disturbance, such as those seen in the WJ area, in terms of the number of individuals and groups of taxa. Moderate disturbance may provide a more diverse microhabitat, supporting larger numbers of individuals of various taxa. These results provide important insights into the ecological preferences of soil macroarthropods in the CBG (Cibodas Botanical Garden) area. They also suggest that certain levels of disturbance may influence soil community structure.

The phenomenon of increasing individual abundance and group size of soil macroarthropod taxa in areas of moderate disturbance (WJ) indicates a positive ecological response of the macroarthropod community to the environmental heterogeneity created by moderate disturbance intensity (Yang et al. 2015; Wang et al. 2024). In disturbance ecology, the concept of the intermediate disturbance hypothesis (IDH) explains that intermediate levels of disturbance can create more microhabitatally diverse environmental conditions, which in turn can support the coexistence of different species with different ecological needs (Collins, Glenn 1997; Weithoff et al. 2001). Results from the Cibodas Botanical Garden (CBG) support this hy-

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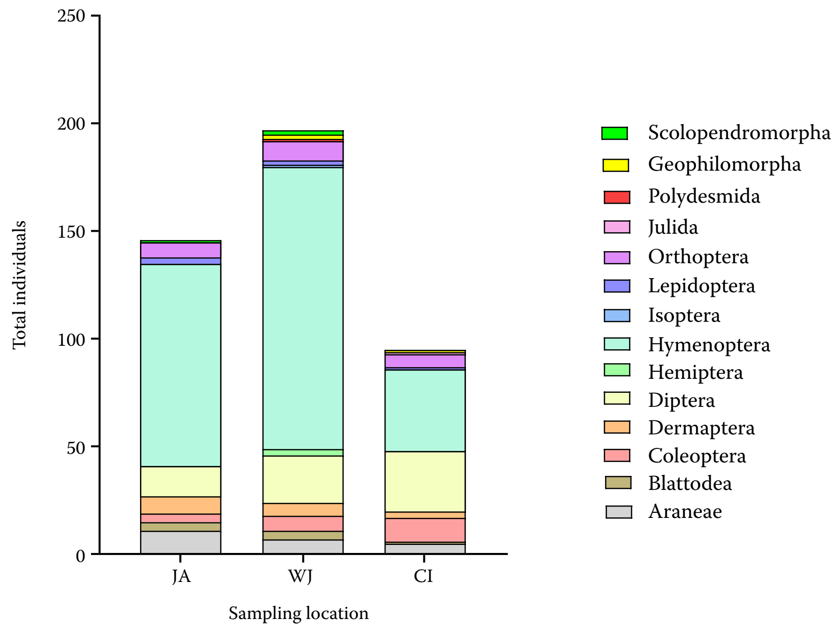

Figure 3. The total number of soil macroarthropods in the remnant forest of the Cibodas Botanical Garden is based on the level of disturbance experienced

JA – Jalan Akar; WJ – Wornojiwo; CI – Ciismun

pothesis, showing that moderate disturbance not only increases habitat complexity but also expands the ecological niche that can be filled by different groups of soil macroarthropods (Smith et al. 2014; Gough et al. 2024). In contrast, the decline in numbers of individuals and taxa in areas of high disturbance (CI) indicates that excessive environmental pressures can lead to the loss of essential habitats, reduce resource availability and increase stressful conditions for soil macroarthropods, thus hindering their community viability (Yang et al. 2025). Interestingly, the low disturbance site (JA) showed lower abundance and diversity of taxa than the moderate disturbance site, possibly reflecting limited microhabitat variation and more intense competition between taxa under more stable environmental conditions (McGunnigle et al. 2025). Overall, this pattern suggests that the community dynamics of soil macroarthropods in CBG forest remnants are strongly influenced by the intensity of ecological disturbance, which can, to some extent, increase the diversity and stability of soil ecosystems (Siira-Pietikainen et al. 2003; Villanueva-López et al. 2019).

The response of soil macroarthropods to various levels of disturbance is evident through the variations in their abundance and diversity at three research sites in the remaining forest area of Cibodas Botanical Garden. These variations are presented in Table 1. Sites with moderate levels of disturbance (WJ) showed that almost all of the taxa found in the other two sites (JA and CI) were also found in this location, except for Julida. In contrast, the CI location, which had a high level of disturbance, had four taxa that were not found: Hemiptera, Isoptera, Polydesmida, and Scolopendromorpha. In areas with low levels of disturbance (JA), five taxa were absent, including Hemiptera, Isoptera, Julida, Polydesmida, and Geophilomorpha. Overall, the data reflect that the amount of variation in soil macroarthropod taxa is highest in sites with moderate levels of disturbance. In contrast, areas with low levels of disturbance tended to have fewer taxa groups. These results highlight how soil macroarthropods respond to and adapt to different environmental changes and stresses. A moderate level of disturbance indicates that the ecosystem of the study site experiences only natural disturbances. This tends to increase the variation in the number of macroarthropod taxa on the soil surface of the CBG remnant forest floor.

The level of disturbance in the remaining forest in the Cibodas Botanical Garden area impacts the population dynamics of soil macroarthropods. This can be seen in the variation of the diversity index, dominance index, evenness index, and species

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richness index. The results (Table 2) showed that JA had a higher soil macroarthropod diversity index value of 3.049. In contrast, CI recorded an *H'* value of 2.901, and WJ recorded an *H'* value of 2.912. Areas with light disturbance have diverse and balanced soil macroarthropod communities, meaning the ecosystems in these areas tend to be more stable and resistant to disturbance. This is consistent with the macroarthropod evenness index (*e*), which shows that JA has a higher value of 0.826.

Meanwhile, on land with a higher level of damage (CI), the macroarthropod evenness index value was lower, at 0.786, indicating a less even distribution of soil macroarthropods. The highest dominance index was found in WJ, at 0.099, indicating species dominance. Meanwhile, JA had the lowest dominance index, at 0.063, due to its high evenness of soil macroarthropods. Furthermore, WJ had the highest species richness index (*Dmg*) of soil macroarthropods with a value of 6.814, which aligns with the number of variations in soil macroarthropod taxa. CI is the area with the lowest species richness, with a value of 5.086. These results suggest that habitats with moderate levels of disturbance are capable of supporting a greater number of taxa and allowing higher dominance by certain soil macroarthropods.

The level of disturbance in each soil macroarthropod habitat likely affects the distribution pattern of these organisms in each location. These patterns illustrate the ability of soil macroarthropods to survive and adapt to their habitats. Disturbed habitats will also impact the response and distribution of diverse soil macroarthropods. Table 3 shows the distribution of soil macroarthropods in study sites with different levels of disturbance.

Overall, soil macroarthropods are distributed relatively uniformly in the remaining forest area of the Cibodas Botanical Garden. However, at the taxonomic level, each group of soil macroarthropod taxa has diverse distribution patterns. Even within one taxon, there are several distribution patterns in different habitats. Most soil macroarthropod taxa have clustered distribution patterns

Table 2. Indices of diversity, evenness, dominance, and species richness of soil macroarthropods

Taxa	Relative abundance	Rank	Occurrence index (%)		
			JA	WJ	CI
Araneae	0.053	3	7.53 (11)	3.55 (7)	5.26 (5)
Blattodea	0.021	6	2.74 (4)	2.03 (4)	1.05 (1)
Coleoptera	0.050	4	2.74 (4)	3.55 (7)	11.58 (11)
Dermaptera	0.039	5	5.48 (8)	3.05 (6)	3.16 (3)
Diptera	0.146	2	9.59 (14)	11.17 (22)	29.47 (28)
Hemiptera	0.007	6	0.00	1.52 (3)	0.00
Hymenoptera	0.600	1	64.38 (94)	66.50 (131)	40.00 (38)
Isoptera	0.002	9	0.00	0.51 (1)	0.00
Lepidoptera	0.014	7	2.05 (3)	1.02 (2)	1.05 (1)
Orthoptera	0.050	4	4.79 (7)	4.57 (9)	6.32 (6)
Julida	0.002	9	0.00	0.00	1.05 (1)
Polydesmida	0.002	9	0.00	0.51 (1)	0.00
Geophilomorpha	0.007	8	0.00	1.02 (2)	1.05 (1)
Scolopendromorpha	0.007	8	0.68 (1)	1.02 (2)	0.00
Total			0.33 (146)	0.45 (197)	0.22 (95)
Overall abundance			146	197	95
Taxa (ordo) richness			9	13	10
Shannon diversity index (*H'*)			3.049	2.912	2.901
Simpson dominance index (*D*)			0.063	0.099	0.067
Pielous measure of evenness (*e*)			0.826	0.789	0.786
Margelef diversity index (*Dmg*)			6.421	6.814	5.086

JA – Jalan Akar; WJ – Wornojiwo; CI – Ciismun

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Table 3: Distribution of soil macroarthropods

Taxa	Number of taxa	Taxa distribution (*Ip*)		
		JA	WJ	CI
Araneae	23	0.089**	–0.995	0.055**
Blattodea	9	0.016**	0.004**	0.000*
Coleoptera	22	0.055**	–0.903	0.991
Dermaptera	17	0.027**	0.051**	–1.000
Diptera	64	0.055**	0.034**	0.056**
Hemiptera	3	–	–1.000	–
Hymenoptera	263	0.011**	–0.940	0.014**
Isoptera	1	–	–	–
Lepidoptera	6	–1.000	0.022**	–
Orthoptera	22	–0.985	0.014**	0.010**
Julida	1	–	–	–
Polydesmida	1	–	–	–
Geophilomorpha	3	–	–1.000	–
Scolopendromorpha	3	–	–1.000	–
Id		0.5413	0.5523	0.4031
Mu		11.381	11.022	12.130
Mc		10.255	10.189	10.394
Ip		–0.976	–0.975	–0.983

No stars – uniform; *random; **clustered; JA – Jalan Akar; WJ – Wornojiwo; CI – Ciismun; *Id* – Morisita index; *Mu* – Morisita index for uniform distribution pattern; *Mc* – Morisita index for clustered distribution patterns; *Ip* – the degree of Morisita

in undisturbed locations (JA), while only Orthoptera and Lepidoptera show uniform distribution patterns. This illustrates that Orthoptera and Lepidoptera prefer disturbed areas. Furthermore, Blattodea, Diptera, and Dermaptera still have clustered distribution patterns in areas with natural disturbance (WJ). This reflects insect life strategies and environmental heterogeneity in the forest. The Araneae and Hymenoptera groups have uniform distribution patterns in WJ; however, the distribution pattern is clustered in JA and CI. Habitat conditions (WJ) are heterogeneous due to natural disturbances that do not completely damage the ecosystem, which allows this predator group, which has territorial or social tendencies, to be evenly distributed due to more evenly distributed food sources.

The different levels of ecosystem disturbance in each habitat proved to have a significant influence on the distribution patterns of soil macroarthropod communities (dos Santos et al. 2010; Jiang et al. 2025), as shown in Table 2. The observed spatial distribution reflects the adaptive capacity of soil macroarthropods to respond to anthropogenic and natural environmental pressures (Durán, Delgado-Baquerizo 2020). Highly disturbed habitats showed a more dispersed or even fragmented distribution, indicating ecological pressure on population viability (Vikrant et al. 2022; Marsandi et al. 2023; Wang et al. 2024). Conversely, relatively stable habitats show a more homogeneous distribution pattern, indicating environmental conditions that optimally support the existence and ecological activities of soil macroarthropods (Tamme et al. 2010; Hamm, Drossel 2017). This is in line with the theory of ecological tolerance, where the diversity and distribution of organisms are strongly influenced by their tolerance limits to environmental change (Gilbert, Levine 2017; Pásztor et al. 2016). Thus, the distribution of soil macroarthropods can be used as a biological indicator that is sensitive to the level of habitat disturbance and, at the same time, reflects the resilience of the community in maintaining soil ecosystem functions (Lavelle et al. 2021).

In this study, the distribution pattern of soil macroarthropods in the remnant forest area of the Cibodas Botanical Garden showed interesting variations depending on taxonomy and habitat conditions. In general, the results show that soil

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macroarthropod taxa tend to be evenly distributed throughout the area, but there are differences in distribution patterns between taxa. Most taxa, such as Blatodea, Diptera, Dermaptera, Lepidoptera and Orthoptera, showed a tendency for clustered distribution patterns in areas with natural disturbance (WJ), reflecting their preference for habitats with higher environmental diversity. This suggests that these macroarthropods prefer sites with natural disturbances that increase microhabitat heterogeneity (Tao et al. 2019), which in turn supports resource diversity and increases opportunities for more diverse life strategies, such as clustered distribution patterns (Kurniawan et al. 2023). In contrast, predators such as Araneae and Hymenoptera show uniform distribution patterns in habitats with natural disturbance, highlighting their ability to adapt to heterogeneous environments, as well as the close relationship between distribution patterns and hunting strategies and the social or territorial tendencies of species (Koneri, Nangoy 2017; Wenninger et al. 2019; Melo et al. 2024). This highlights the importance of habitat heterogeneity in determining the distribution patterns of soil macroarthropod taxa and its implications for ecosystem balance.

The soil macroarthropod community in the remnant forest area of the Cibodas Botanical Garden not only reflects local ecological conditions but also represents a resilient dynamic influenced by the level of habitat disturbance. The dominance patterns of certain taxa, especially Hymenoptera, as well as the functional diversity of other taxa, suggest that this community structure is strongly influenced by complex interactions between microhabitat heterogeneity, anthropogenic pressures and species' adaptive capacity. These results provide empirical support for the concepts of the intermediate disturbance hypothesis and ecological tolerance theory by showing that intermediate levels of disturbance can enrich the structural complexity of habitats, which in turn promotes community coexistence and stability. Spatial variation in the distribution of taxa further reinforces the role of soil macroarthropods as biological indicators sensitive to environmental change.

CONCLUSION

Variations in ecosystem disturbance in the remnant forest area of the Cibodas Botanical Garden led to the dynamics of the existence of soil macroarthropod communities. Sites with moderate levels of disturbance in the area had the highest total abundance of individuals, taxa, and species richness index (Margelef), reinforcing the relevance of the Intermediate Disturbance Hypothesis (IDH) and ecological tolerance theory, where moderate levels of disturbance promote higher habitat heterogeneity and allow species coexistence through the expansion of ecological niches. Conversely, high levels of disturbance reduce macroarthropod diversity and abundance, signalling a threshold of ecological stress that affects community viability. Interestingly, despite having the highest diversity index (H'), sites with low levels of disturbance had more limited total individuals and taxa of soil macroarthropods than those with moderate levels of disturbance, possibly reflecting low microhabitat variation and intraguild predation. Distribution patterns (Morisita index), which varied between soil macroarthropod taxa, also confirmed the sensitivity of macroarthropod communities to environmental change. The results of this study highlight the importance of habitat heterogeneity as a key factor in supporting the abundance and diversity of soil macroarthropods for balanced soil ecosystems. In this case, the soil macroarthropod community proved to be a sensitive biological indicator for assessing the impact of ecological disturbance on the remnant forest of the Cibodas Botanical Garden, which reflects a tropical mountain ecosystem vulnerable to fragmentation and land disturbance.

Acknowledgement: We thank the Cibodas Botanical Garden management for facility support.

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Received: May 16, 2025
Accepted: December 9, 2025
Published online: January 29, 2026