

Abundance and Distribution of Millipedes (Diplopoda) in Wera Nature Recreation Park

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Abstract

Millipedes (Diplopoda) play an important role in forest ecosystems, particularly in the decomposition of organic matter and the recycling of nutrients, thereby contributing to soil fertility and ecosystem stability. This study aimed to determine the abundance and distribution patterns of millipedes (Diplopoda) in Wera Nature Recreation Park, Balumpewa Village, West Dolo District, Sigi Regency, Central Sulawesi. The research was designed as a quantitative descriptive study. Sampling was carried out using an exploratory survey method combined with hand collection techniques at three observation stations. These stations were selected using purposive sampling based on differences in environmental characteristics and habitat conditions. Data collection was conducted in three repetitions at two-week intervals to obtain representative data on millipede communities. In addition to species collection, measurements of physical environmental parameters were also performed, including light intensity, soil pH, air temperature, and humidity, as these factors are known to influence the presence and distribution of soil macrofauna. The results showed that six millipede species were recorded, belonging to three orders and three families. The average environmental conditions at the study site included a light intensity of 722.2 lux, soil pH of 6.8, temperature of 28.2°C, and humidity of 76.7%. These conditions indicate a habitat that is relatively less optimal for millipede populations. The species abundance index was classified as low, suggesting limited population sizes within the study area. However, the Relative Abundance Index (RAI) revealed variation among species, with two species categorized as having high relative abundance, one species moderate, and three species low. Analysis using Morisita's Index and the Standardized Morisita Index (Ip) demonstrated that all recorded species exhibited a clumped distribution pattern. This distribution suggests that millipedes tend to concentrate in specific microhabitats that provide suitable moisture, shelter, and food resources. Overall, the findings indicate that unstable environmental conditions may restrict millipede distribution, causing them to utilize only particular microhabitats that meet their ecological requirements.

Keywords: Diplopoda; Abundance; Distribution; Sulawesi; Wera.

INTRODUCTION

Sulawesi is the 11th largest island in the Wallacea biogeographical region, covering an area of approximately $\pm 175,000$ km². The island has a unique and remarkable landscape characterized by a combination of marine, coastal, forest, and mountainous ecosystems (Pitopang & Ramawangsa, 2020). Geographically, Central Sulawesi is located at the heart of Sulawesi Island and is recognized as one of the world's centers of biodiversity and a global "biodiversity hotspot" (Mannan et al., 2024). This high level of biodiversity is reflected in the extensive forest cover of Central Sulawesi, which comprises approximately 64% of its total area and serves as habitat for a wide variety of endemic flora and fauna (Ratag et al., 2023). Nevertheless, many plant and animal species remain poorly explored, particularly in terms of their ecological aspects. One such group is soil macrofauna, including

millipedes (Diplopoda), which play an important role in forest ecosystems (Iniesta et al., 2020).

Millipedes (Diplopoda) are a highly diverse group of soil-dwelling arthropods, with an estimated global diversity of up to 80,000 species, although only about 12,000 species have been scientifically described to date (Bogyó et al., 2022). Among soil arthropods, millipedes are key contributors to the decomposition of organic matter and nutrient cycling in forest ecosystems (Tóth & Hornung, 2019). In addition, their presence can serve as a bioindicator of environmental quality due to their sensitivity to ecosystem changes (Abdar, 2022). Morphologically, millipedes have elongated, cylindrical bodies with two pairs of legs on most body segments. Despite being commonly referred to as "millipedes," the number of legs does not reach a thousand; even the largest species possess fewer than one hundred pairs of legs. During locomotion, their legs move in a wave-like motion (Windbiel & Rojas, 2019). Millipedes generally

inhabit moist environments such as forests, grasslands, caves, and high mountainous areas in tropical and subtropical regions (Wang et al., 2018).

One area in Central Sulawesi with high ecological potential as a millipede habitat is Wera Nature Recreation Park. Like many natural vegetation areas in Indonesia, Wera Nature Recreation Park is traversed by a river known as the Wera River and is characterized by well-preserved tropical rainforest. Classified as a protected forest area with ecotourism potential, including scenic waterfalls and natural landscapes, the park features hilly and sloping topography rich in biodiversity (Evanjeli et al., 2019). According to Article 1 of Law Number 32 of 2024, a Nature Recreation Park is defined as a conservation area utilized for research, science, education, cultivation support, and environmental services, particularly for nature-based tourism (Sandika, 2021). Wera was first designated as a Nature Recreation Park by the Ministry of Agriculture in 1980, covering an area of 250 ha. This area was later revised in 2014 by the Ministry of Forestry to 349.39 ha. Currently, Wera Nature Recreation Park is managed by the Central Sulawesi Natural Resources Conservation Agency (Kasmiati, 2021).

Preliminary observations indicate the presence of millipedes (Diplopoda) in the area; however, no scientific studies have systematically documented their abundance and distribution patterns. This condition highlights the need for ecological research to obtain data on abundance, distribution, and environmental characteristics of millipedes, which can provide a comprehensive understanding of their presence in the area. Therefore, this study aims to determine the

abundance and distribution patterns of millipedes (Diplopoda) in Wera Nature Recreation Park, Balumpewa Village, West Dolo District, Sigi Regency, Central Sulawesi Province.

MATERIALS AND METHODS

Study area

The study was conducted in Wera Nature Recreation Park, located in Balumpewa Village, West Dolo District, Sigi Regency, Central Sulawesi Province (Figure 1). Wera Nature Recreation Park is a conservation area currently managed by the Central Sulawesi Natural Resources Conservation Agency (BKSDA), while administratively it falls within Balumpewa Village, West Dolo District, Sigi Regency, Central Sulawesi Province. The park covers an area of 349.39 hectares and is situated approximately 19 km south of Palu City. The site can be accessed by both two-wheeled and four-wheeled vehicles, with a travel time of approximately 45 minutes. To reach the waterfall area, visitors must continue their journey for about 2 km from the main parking area. The selection of research stations was based on purposive sampling by considering environmental characteristics (Asrulla et al., 2023). Based on this approach, the research area was determined to cover 10% of the total area of the park and was divided into three research stations. Station 1 was located along the tracking path leading to the waterfall, Station 2 along the pine forest tracking path, and Station 3 in the pine forest area adjacent to cocoa plantations (Ulvah & Nirmalasari, 2021).

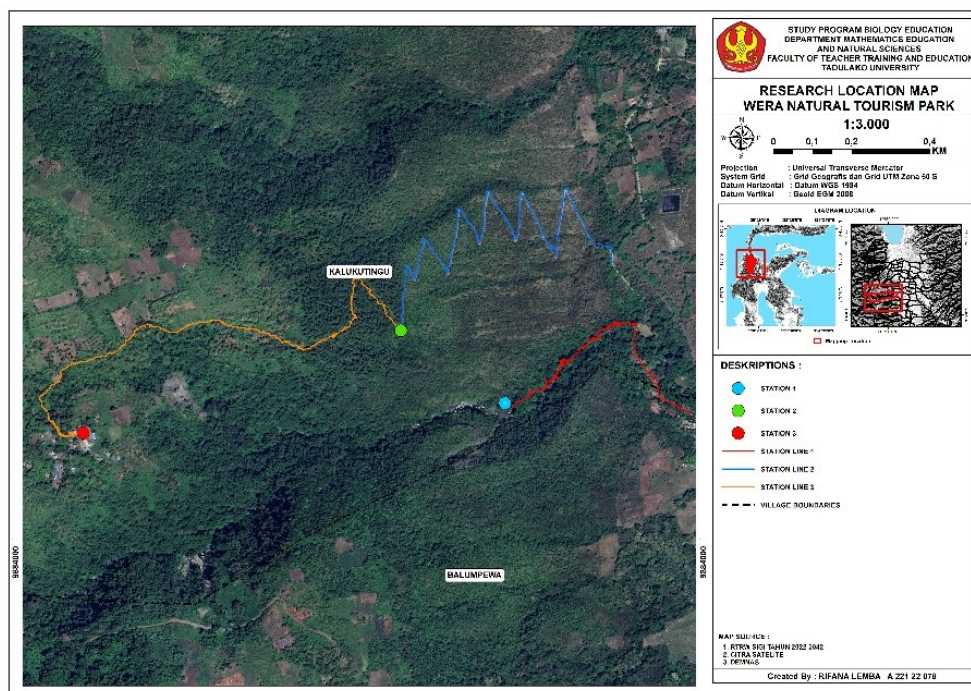


Figure 1. Map of the research location in Wera Nature Recreation Park, Balumpewa Village, West Dolo District, Sigi Regency, Central Sulawesi.

Procedures

Preparation Stage

The preparation stage began with field observations and preliminary surveys to assess the presence of millipedes (Diplopoda) in Wera Nature Recreation Park, Balumpewa Village, West Dolo District, Sigi Regency, Central Sulawesi Province. These preliminary observations aimed to obtain an overview of habitat conditions, environmental characteristics, and the potential occurrence of millipedes (Diplopoda) at the study site. In addition, this stage involved the initial determination of research locations and stations based on terrain conditions and environmental characteristics. During this stage, all required administrative preparations were completed, including obtaining a research permit from the Faculty of Teacher Training and Education (FKIP), Universitas Tadulako, addressed to the Central Sulawesi Natural Resources Conservation Agency (BKSDA) as the managing authority of the conservation area. This permitting process was conducted to ensure that all observation and sampling activities complied with regulations governing conservation areas.

Sampling Stage

Sampling of millipedes (Diplopoda) was carried out using exploratory survey and hand collection techniques. The exploratory survey involved systematically traversing each predetermined research station, including tracking paths and forested areas, to observe and locate millipede individuals. All individuals encountered were counted and recorded at each station to obtain abundance data. Hand collection was conducted by directly collecting specimens using bare hands, ensuring that the samples remained intact and that their morphological characteristics were preserved. This method was chosen because it is effective for collecting millipedes, which generally exhibit low mobility and are commonly found on the soil surface, within leaf litter, or beneath decaying wood, and it is suitable for achieving the objectives of the study (Ulvah & Nirmalasari, 2021).

Measurement of Physical Environmental Conditions

Measurements of physical environmental conditions were conducted to assess abiotic factors influencing the presence and distribution of millipedes (Diplopoda) at the study site. Measurements were carried out in three sampling periods with two-week intervals. This interval was selected by considering the relatively low mobility of millipedes, allowing environmental changes to be observed more accurately over time. The environmental parameters measured included light intensity, soil pH, temperature, and humidity. These parameters were selected because they strongly influence millipede activity, survival, and distribution. Extreme changes in physical environmental conditions, such as high temperatures or low humidity, may cause physiological stress and even mortality in millipede species (Bowen & Hembree, 2015).

Sample Identification Stage

Identification of millipede (Diplopoda) samples was conducted directly at the study site to minimize specimen damage and reduce the risk of misidentification. The identification process involved observing key morphological characteristics, including body shape, coloration, size, and the number of body segments. To enhance identification accuracy, the iNaturalist application and the Global Biodiversity Information Facility (GBIF) database were used as reference tools. The use of these platforms allowed the researchers to compare the morphological features of the collected specimens with globally verified species records, thereby ensuring that the identification results were scientifically reliable.

Data analysis

Abundance

$$R = \frac{(S - 1)}{\ln N}$$

Description:

- R = Species abundance index
 S = Total number of species in a habitat
 N = Total number of individuals in a habitat

Criteria:

- R < 2.5 = Indicates low species abundance
 2.5 ≤ R ≤ 4.0 = Indicates moderate species abundance
 R > 4.0 = Indicates high species abundance

Relative Abundance Index (RAI)

$$RAI = \frac{n_i}{n} \times 100\%$$

Description:

- n_i = Number of individuals of a given species
 n = Total number of individuals recorded

Criteria:

- < 15% = Low
 15–20% = Moderate
 20% = High

Distribution Patterns

$$I_d = n \frac{(\sum X_i^2 - \sum X_i)}{(\sum X_i)^2 - \sum X_i}$$

Description:

- I_d = Morisita's Index
 N = Number of sampling stations
 $\sum X_i$ = Total number of individuals of a species across all sampling plots
 $\sum X_i^2$ = Sum of squares of the total number of individuals of a species across all sampling plots

Criteria:

Because distribution patterns are difficult to interpret solely using Morisita's Index, the analysis was continued using the Standardized Morisita Index, which refines the interpretation by applying an absolute scale ranging from -1 to +1.

Uniformity Index (Mu)

$$Mu = \frac{(X_{0.975}^2 - n + \sum x_i)}{(\sum x_i - 1)}$$

Clumping Index (Mc)

$$Mc = \frac{(X_{0.025}^2 - n + \sum x_i)}{(\sum x_i - 1)}$$

Description:

Mu = Uniformity index

Mc = Clumping index

$X_{0.975}^2$ = Chi-square value with degrees of freedom ($n - 1$) at a 97.5% confidence level

$X_{0.025}^2$ = Chi-square value with degrees of freedom ($n - 1$) at a 2.5% confidence level

n = Total number of research stations

$\sum x_i$ = Total number of individuals of a species across all stations

Standardized Morisita Index (Ip)

The value of the Standardized Morisita Index (Ip) was determined using one of the following equations:

If $I_d \geq Mc \geq 1.0$

$$Ip = 0.5 + 0.5 \left(\frac{I_d - Mc}{n - Mc} \right)$$

If $Mc > I_d \geq 1.0$

$$Ip = 0.5 \left(\frac{I_d - 1}{Mc - 1} \right)$$

If $1.0 > I_d > Mu$

$$Ip = 0.5 \left(\frac{I_d - 1}{Mu - 1} \right)$$

If $1.0 > Mu > I_d$

$$Ip = 0.5 + 0.5 \left(\frac{I_d - Mu}{Mu} \right)$$

Interpretation of the Standardized Morisita Index:

$Ip < 0$ = Uniform distribution pattern

$Ip = 0$ = Random distribution pattern

$Ip > 0$ = Clumped distribution pattern

RESULTS AND DISCUSSION

Physical Environmental Condition Observations

The study conducted in Wera Nature Recreation Park, Balumpewa Village, West Dolo District, Sigi Regency, Central Sulawesi Province, was carried out by exploring three research stations that had been determined using purposive sampling based on environmental characteristics. Measurements of physical environmental conditions were performed at each station to obtain supporting data related to millipede (Diplopoda) habitat preferences. The environmental parameters measured included light intensity, soil pH, temperature, and humidity (Table 1).

Table 1. Physical environmental condition measurements in Wera Nature Recreation Park.

No	Parameter	Station 1	Station 2	Station 3	Average
1.	Light Intensity (Lux)	533,3	950	683,3	722,2
2.	Soil pH	6,8	6,8	6,8	6,8
3.	Temperature (°C)	26,7	31,3	26,7	28,2
4.	Humidity (%)	81,7	65,7	82,7	76,7

Millipede (Diplopoda) Species

The study conducted in Wera Nature Recreation Park, Balumpewa Village, West Dolo District, Sigi Regency, Central Sulawesi Province, involved exploration of three predetermined research stations. Observations of

millipede (Diplopoda) species were carried out in three sampling repetitions with two-week intervals to obtain representative data on species composition and occurrence (Table 2 and Figure 2).

Table 2. Millipede (Diplopoda) species in Wera Nature Recreation Park.

No	Order	Family	Species	Station		
				1	2	3
1.	Spirobolida	Rhinocricidae	<i>Anadenobolus monilicornis</i>	✓	✓	✓
2.			<i>Epibolus pulchripes</i>	✓	✓	✓
3.			<i>Trigoniulus corallinus</i>	✓	✓	✓
4.	Julida	Julidae	<i>Pachyiulus varius</i>	✓	✓	✓
5.			<i>Pachyiulus cattarensis</i>		✓	
6.	Sphaerotheriida	Zephroniidae	<i>Zephronia profuga</i>	✓		

**Figure 2.** Millipede (Diplopoda) species. A1. *Anadenobolus monilicornis*, A2. *Epibolus pulchripes*, A3. *Trigoniulus corallinus*, A4. *Pachyiulus varius*, A5. *Pachyiulus cattarensis*, A6. *Zephronia profuga*.

Species Abundance and Relative Abundance Index (RAI) of Millipedes (Diplopoda)

The study conducted in Wera Nature Recreation Park, Balumpewa Village, West Dolo District, Sigi Regency, Central Sulawesi Province, involved exploration of three predetermined research stations. The millipede

(Diplopoda) data obtained from field observations were further analyzed to determine the species abundance index and the Relative Abundance Index (RAI). These analyses were performed to describe the structure of the millipede community and to identify dominant species within the study area (Table 3).

Table 3. Species abundance index and Relative Abundance Index (RAI) analysis of Millipedes (Diplopoda) in Wera Nature Recreation Park.

No	Species	ni	IKR %	Category
1.	<i>Anadenobolus monilicornis</i>	2.567	51.39139139	KR (High)
2.	<i>Epibolus pulchripes</i>	1.409	28.20820821	KR (High)
3.	<i>Trigoniulus corallinus</i>	233	4.664664665	KR (High)
4.	<i>Pachyiulus varius</i>	769	15.3953954	KR (High)
5.	<i>Pachyiulus cattarensis</i>	12	0.24024024	KR (High)
6.	<i>Zephronia profuga</i>	5	0.1001001	KR (High)
	N	4.995		
	S	6		
	Ln N	8.516192691		
	R	0.587116823		

$R < 2.5 = \text{High species abundance}$

Distribution of Millipedes (Diplopoda)

The study conducted in Wera Nature Recreation Park, Balumpewa Village, West Dolo District, Sigi Regency, Central Sulawesi Province, involved exploration of three predetermined research stations. The millipede

(Diplopoda) data obtained from field observations were subsequently analyzed using distribution indices to determine the distribution patterns of each species across the study area (Table 4).

Table 4. Distribution of Millipedes (Diplopoda) in Wera Nature Recreation Park.

No	Species	(X _i)	(X _i ²)	Id	Mu	mc	Ip	Category
1	<i>Anadenobolus monilicornis</i>	2,567	6,589,489	3	0,9992404521	1,0020958691	1	Clumped
2	<i>Epibolus pulchripes</i>	1,409	1,985,281	3	0,998615767	1,0038196023	1	Clumped
3	<i>Trigoniulus corallinus</i>	233	54,289	3	0,9915991379	1,0231810345	1	Clumped
4	<i>Pachyiulus varius</i>	769	591,361	3	0,9974622396	1,0070026042	1	Clumped
5	<i>Pachyiulus cattarensis</i>	12	144	3	0,8228181818	1,4889090909	1	Clumped
6	<i>Zephronia profuga</i>	5	25	3	0,51275	2,3445	1	Clumped
	n					3		

$Ip > 0 = \text{Clumped distribution pattern}$

Discussion

Environmental changes resulting from pollution and habitat degradation are commonly assessed using physical and chemical indicators. However, many environmental scientists have proposed alternative approaches through biological monitoring (biomonitoring), which utilizes biological components, such as animals and plants, as indicators of environmental conditions (Purwaningrum, 2025). One soil-dwelling arthropod group that has been proposed as a suitable bioindicator for evaluating soil quality is millipedes (Husamah & Rahardjanto, 2019). Ecologically, millipedes (Diplopoda) function as saprophagous organisms that play an important role in biogeochemical cycles by decomposing organic matter into nutrients that can be reutilized by plants (Windbiel & Rojas, 2019).

Consistent with the findings of this study, two millipede species were recorded only during the first sampling period, whereas numerous carcasses of millipedes were found during the second and third sampling periods. This phenomenon is thought to be related to the behavioral and ecological characteristics of these species, which tend to emerge to the soil surface during periods dominated by westerly winds and prefer to remain concealed beneath leaf litter (So et al., 2022). Millipedes (Diplopoda) are also highly sensitive to environmental changes, particularly increases in temperature, alterations in humidity, soil pH, and light intensity, which can lead to physiological stress and mortality (Darmi et al., 2023). This observation is supported by Ramanathan et al. (2021), who reported that millipedes are widely distributed across nearly all biogeographical zones of the world, except in regions with extreme environmental conditions, such as areas with extremely low temperatures and hyper-arid deserts characterized by very low humidity levels. Therefore, millipedes (Diplopoda) can serve as indicators of environmental conditions and contribute to improving soil structure, organic matter content, and nutrient availability (Abdar, 2022).

The analysis showed that the species abundance index was categorized as low, while the Relative Abundance Index (RAI) was relatively high, indicating that Wera Nature Recreation Park represents a less fertile area that does not strongly support high millipede abundance. An area is considered to have good fertility when the species abundance index is high and the relative abundance index is low, reflecting balanced competition among species within a community. In contrast, areas with low species abundance and high relative abundance indices are generally characterized by dominance of a few species and less favorable environmental conditions (Sandika, 2021). The relatively low suitability of Wera Nature Recreation Park for millipede abundance may be attributed to limited vegetation cover, as millipedes typically prefer habitats with dense vegetation that

provide sufficient food resources and shelter (Tertilt & Decker, 2012).

Based on the analysis, the standardized Morisita index (I_p) values for all six millipede species were greater than zero, indicating a clumped distribution pattern. Such distribution patterns are common in natural ecosystems and are strongly influenced by heterogeneity in abiotic environmental conditions across the study area. Although millipedes (Diplopoda) are capable of inhabiting a wide range of terrestrial environments, including forests, grasslands, deserts, and caves, several environmental factors play a critical role in shaping their distribution patterns, particularly temperature, humidity, rainfall, and light exposure (Gilgado et al., 2022). This is further supported by Tóth and Hornung (2019), who emphasized that moisture availability is a key environmental filter for millipedes, especially in disturbed soil habitats. Because the exoskeleton of millipedes is permeable to water, the risk of desiccation limits their occurrence to habitats with relatively high humidity and adequate shelters, such as decaying wood and leaf litter (Akkari et al., 2015).

CONCLUSIONS

In conclusion, a total of six millipede (Diplopoda) species were recorded at the study site. Overall, species abundance was low, while the Relative Abundance Index (RAI) indicated two dominant species in the high category, one species in the moderate category, and three species in the low category. All recorded species exhibited a clumped distribution pattern, indicating that millipedes tend to occupy specific microhabitats that provide suitable food resources and shelter. This pattern reflects suboptimal environmental conditions that limit habitat suitability and restrict millipede occurrence to favorable microhabitat patches.

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Competing Interests: The authors declare that there are no competing interests.

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